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Low carbon living book (edited by Horace Herring)

Case studies in low carbon living

Robin Roy

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Over two-thirds of greenhouse gas emissions in industrialized countries arise directly or indirectly from households. In Britain, homes use nearly a third of delivered energy and produce 27 per cent of total CO₂ emissions (CLG 2006). If personal transport is included the figure rises to about 40 per cent of total CO₂ emissions. If consumption of food, goods and services (including imports) is added, UK households are responsible for 76 per cent of national carbon dioxide equivalent emissions. The remaining emissions are due to government expenditure (11 per cent) and capital investment (13 per cent) (Druckman and Jackson 2009).

There have been a number of studies of personal and household carbon footprints. The Carbon Trust (2006) analysed the carbon dioxide emissions of an average UK inhabitant (totalling 11.3 tonnes CO₂ per year). The analysis included the personal footprint arising from UK imports and exports, and attributed the emissions from UK government activities and capital investment to individuals, but did not count the equivalent carbon footprint of non-CO₂ greenhouse gases. Using the Carbon Trust data, Roy (2009) provided the following breakdown of a UK inhabitant's carbon footprint (Figure 1).

Figure 1. Breakdown of all the direct and indirect carbon dioxide emissions arising from the energy use and consumption of an average UK citizen (Roy, 2009, p. 119, based on data in Carbon Trust, 2006, pp. 19, 24)

Druckman and Jackson (2010) did a similar consumption-based analysis of the carbon footprint of an average UK household (totalling 26 tonnes CO₂e per year) which produced a similar breakdown, although this study included the CO₂ equivalent effects of other greenhouse gases and excluded government activities and capital investment.

These UK studies and those carried out in other countries (e.g. a US analysis by Brower and Leon (1999)) have found that the main elements of an average carbon footprint in industrialised societies are:

- Transport (especially personal car travel and holiday air travel) – about 24 per cent of the total footprint;
- Domestic space and water heating – about 20 per cent of the total;
- Provision and use of services (insurance, finance, medical, recreation, hotels, education, telephone, etc.) – about 18 per cent;
- Food and drink (including agriculture, processing and distribution, catering, food imports and exports) – about 12 per cent;

- Purchases of consumer goods (clothes, shoes, domestic appliances, furnishings, books, newspapers, etc., etc.) – about 12 per cent;
- Domestic electricity use (for powering lights, appliances, etc.) – about 8 per cent;

Housing construction and maintenance – about 6 per cent.

This chapter provides six case studies of attempts by pioneering households, small communities and housing providers to enable a low carbon life in Britain.

The case studies include:

- Two examples of householders improving the environmental performance of their existing home and attempting to live a low carbon lifestyle;
- Two examples of new low carbon homes, one designed by a small housing developer and the other by two leading green architects;
- Two examples of pioneering low to zero carbon community housing projects.

The chapter concludes by examining the similarities and differences between the low carbon households and communities that are illustrated by the six case studies.

Eco-renovations of existing homes

Low carbon living in an 1980s Oxford house

This case study shows what a professional couple, Matthew and Angela (not their real names), have done to eco-renoate their three-bedroom 1982 mid-terraced house in Oxford, England, as part of moving to a low carbon lifestyle. Below are some extracts based on their own account of what they did, plus some additional information added by the author.

Our philosophy

‘Our aim is to show how a modern family can make serious reductions in their environmental impact, whilst still having a standard of living most of us would recognise. We aim to be practical, rather than offer solutions that few people are likely to adopt.’

Energy

We started by commissioning an energy audit of our house. This showed our house was built to low, energy efficiency standards. Our plan of action included:

- 1 Replacing the boiler with a modern condensing boiler and installing new heating controls and radiator valves.
- 2 Because of its cost, the case for installing solar water heating is usually marginal, but as we were having the central heating upgraded we decided to go for it.
- 3 Insulation is key in any eco-renovation. We noticed the biggest change when we had the cavity walls filled with mineral fibre. We put 100mm sheep’s wool insulation in the loft on top of the 70 mm of fibreglass, and insulated the walls and ceiling of the internal garage.
- 4 Our house had single-glazed windows plus secondary glazing. We decided to install the best double-glazed windows we could, and then refit the existing secondary glazing – triple glazing for a fraction of the price.
- 5 Building a conservatory which helps to heat the house in spring and autumn and acts as a heat buffer in winter. The conservatory was our largest single investment, costing over £20,000. It’s also a great space for relaxing and growing plants.

6 Building an insulated front porch to stop cold air entering the house in winter.

7 We cook, heat and provide hot water from gas, which produces lower emissions than using electricity.

Gas and electricity consumption is about 50 per cent lower than when we first moved in. One of the lessons Matthew and Angela have learned is that planning eco-renovations is often easier than finding skilled contractors to do the work.

Water

We made an effort to save water which also reduces energy use. Nationally, slightly more than a third of all domestic water is flushed down the toilet. We chose a Swedish design, which uses 2 and 4 litres, rather than up to 9 litres, a flush.

Transport

We replaced our two cars with a Toyota Prius hybrid car. It cost little more than an average saloon, about £17 500 minus a £1000 government grant available at the time, yet uses less than half the fuel of the previous cars. It has two engines, one petrol, the other electric, whose battery is charged when the petrol engine is running and by recovering energy when going downhill or braking. We get around 55 to 63 miles per gallon (5 to 4.5 litres per 100 km). Although the CO₂ emissions of the Prius are no lower than those of some super-mini diesel cars, it is a spacious family car – ‘it didn’t mean driving a “noddy” car, or trading in comfort or safety’. We also use our old bikes, which ‘allow us to get around without always jumping into the car’. We decided to live close to the city centre and to public transport. There’s no point having an eco-house and having to travel long distances to and from work. Until recently both of us could walk to work. But now Angela works 11 km away and mainly commutes by bus, except when she needs the car to travel between two sites. Matthew is changing jobs and may have to commute using their car, so Angela is exploring whether to get an electrically assisted bicycle for the days she needs personal transport.

Matthew and Angela know that air travel is a heavy polluter. But Matthew’s brother lives in Canada, as do several of Angela’s relatives, so they ‘try to get over to that excellent country

from time to time.’ Matthew acknowledges that their air travel to Canada once every one to two years more than outweighs the CO₂ savings they’ve made from eco-renovating the house.

Food

Matthew and Angela try to reduce their food impacts by various means. These include shopping in the local covered market for fresh, unpackaged food; using a delivery service of locally grown vegetables; growing some fruit and vegetables on their allotment; buying local, ethically produced meat and eating it sparingly; and reducing their consumption of imported and out-of-season fruit and vegetables.

Goods and services.

Living in a small house uses living space, and energy, efficiently. Matthew and Angela like to keep the house uncluttered, which means not buying more goods than they really need or want and recycling unwanted items. As Matthew says, ‘reduce first, reuse second, and recycle third’.

Community and society

Matthew and Angela try to reduce their carbon footprint as much as they can, but recognise that there are limits to what individuals can do. They therefore help others to follow their example by providing information to friends or colleagues and by contributing to eco-renovation open days and websites. At the community level, Matthew volunteers at a local wind farm co-operative; this should supply the electricity demand of the co-op’s 2500 members. Matthew and Angela also recognise that there are environmental issues that can only be tackled at government levels, such as planning, energy and transport policies. (Personal communication and interviews March 2008, in Roy, 2009, pp. 147-150.)

Figure 2 Oxford eco-renovated house (a) House Front and insulated porch (b) Rear conservatory and roof-top solar water heating panels (c) Toyota Prius hybrid petrol-electric car (Photos: Robin Roy)

The Yellow House

This case study shows what George Marshall, an environmental campaigner, has done to radically reduce his family's carbon footprint by eco-renovating a 1930s Oxford terraced, former council house and 'living lightly'. George Marshall bought the house in 1997 and renovated it between 1999 and 2001/2. The Yellow House – so-called because of its yellow externally insulated front wall (Figure 4a) – gives an idea of the substantial energy savings that people living even in UK houses that are difficult to improve could make. Marshall managed his eco-renovations on a fairly limited budget using a combination of DIY and professional help.

George and his wife followed a four-stage design process:

- First they discussed 'how we wanted the house to feel and what we needed it to do'.
- They then considered the constraints and opportunities provided by existing structures and materials, the site and orientation to the sun.
- The third stage was to audit the existing energy performance of the house and identify the main areas of heat loss.

- Finally, they designed environmental improvements to meet their needs and met the building regulations.

Energy

George's aim was to reduce the household's consumption of electricity, gas and water by two-thirds compared with the previous four years. In the first year he met the goal with water consumption, and halved energy use (Figure 3).

Figure 3 Annual gas and electricity use in the Yellow House have halved since eco-renovation. Electricity use is one-third of the regional average (Roy, 2009, p. 152 based on Marshall, 2007)

To achieve the energy savings George specified about double the levels of insulation of walls, loft, floor and hot water tank than required by the building regulations. (Homes built or substantially altered since 2006 are reaching or exceeding these standards as a result of tighter UK building regulations.) He had most existing windows replaced with argon-filled, low-emissivity double glazing and skylights, providing the light-filled spaces they wanted.

The central heating system was replaced by a gas condensing boiler with over-sized radiators and use of controls and room temperatures to achieve optimum efficiencies. A wood stove provides occasional supplementary heat and a solar thermal system supplies most hot water, which the family attempts to use efficiently, e.g. showering after the sun has heated the water. George replaced the old rear extension with a new one incorporating skylights plus a sun space, built partly from salvaged materials, to gather passive solar energy (Figure 4b).

To reduce use of electricity the refrigerator, washing machine and dishwasher are energy efficient models, while the cooker is gas. Washing machine and dishwasher are filled by partly solar heated water. George even experimented with adding external insulation to their second-hand chest freezer (ensuring that its external condenser coils were not obstructed). Natural lighting from windows and skylights, plus glass bricks in internal walls, is used as much as possible; and any artificial lights are low-energy ones.

Having stopped unwanted draughts, George designed a system to provide natural ventilation using pre-warmed air from the sun space flowing through rooms via adjustable vents and exiting from skylight vents at the top of the house. Warm air gathering at the top of the house is sometimes drawn back down using a fan.

Materials

George is very keen on using salvaged and recycled materials to reduce waste and embodied energy and the need for environmentally damaging materials. For example, much construction timber was salvaged and the kitchen was constructed from second-hand solid wood furniture installed under a new timber worktop (Figure 4c). The result may not be to everyone's taste, but the recycled kitchen certainly saves money and reduces impacts.

Water

George also wanted to reduce the house's consumption of water by two-thirds. This was mainly achieved by his DIY grey water system that collects waste bath and shower water in a tank above the toilet cistern and so is used to flush the downstairs toilet (Figure 4d). He also installed a low flush device on the upstairs toilet and a large water butt to collect rainwater for the garden.

Transport

George Marshall says little on transport, except 'we refuse to have a car and travel by bicycle and public transport ... Managing without a car is a struggle in a world that assumes that all parents have cars.' However, since the birth of their second child, the Marshalls reluctantly bought a car, partly to be able to take their child, who suffers from asthma, to hospital at short

notice. But the car is only used once or twice per month for local trips and for the occasional longer trip.

Food and waste

The family attempts to buy as much local food as possible from an organic box scheme and local farms and grows some fruit and vegetables on an allotment. They have also tried energy saving cooking methods such as using a modern 'hay box'. Almost all their organic waste is composted.

Community and society

George as part of his environmental work has produced a Yellow House website and CD (Marshall, 2002) which provides information on how to reduce environmental impacts in the above and other areas, including using recycled and salvaged materials and choosing low impact household appliances, flooring and furnishing.

In 2009 the Marshalls moved from the Yellow House to eco-renovate a listed building in Wales.

(Based on Roy, 2009, pp. 151-154; Further information from <http://theyellowhouse.org.uk>)

Figure 4 (a) Front of the Yellow House with its externally insulated concrete block walls, evacuated tube solar water heating panel and roof lights (b) The rear sunspace (c) The kitchen constructed from reclaimed furniture (d) The bathwater toilet flushing system (Photos: Robin Roy)

New low and zero carbon homes

Millennium Green

Millennium Green was one of the first developments of green homes aimed at the mainstream market. It comprises 24 environmentally efficient houses and a business centre for residents built in 1999-2000 by a small developer, Gusto Homes, at Collingham, near Newark, Nottinghamshire.

The firm's managing director had seen examples of ecological housing and felt there was a gap in market for such homes among the ordinary house-buyer.

Materials and energy

The houses are conventional looking but incorporate many environmental features. Construction materials, such as sustainable timber, locally sourced bricks and clay drainage pipes, were chosen to minimise environmental impacts. Insulation levels greatly exceeded the UK Building Regulations then in force: including 150mm insulation in walls and floors, 300mm of recycled newspaper in the roof space, and argon-filled, double glazed timber windows. Energy demand was further reduced by south-facing main glazing, mechanical ventilation with heat recovery and solar water heating systems. But despite their low heat demand the houses all have gas condensing boilers and radiators because local estate agents said that customers would not buy a house without central heating; and this view was supported by at least some of the early buyers. Also, some buyers preferred incandescent decorative lights rather than the compact fluorescent lamps provided.

Water

Water saving is one of the main features of the development. The homes have a rainwater harvesting system comprising an underground water tank large enough to supply over two weeks supply of water for toilet flushing, washing machines and gardening (Figure 5b). The tank is topped up from the mains when necessary and the system alerts the householder when this is occurring. Monitoring of two households showed that harvested rainwater supplied half of their water demand.

Transport

To help reduce the need for commuting, high speed internet connections were provided in the houses and an on-site business centre offers office space to enable residents to work from home. To encourage community and wildlife a shared open space and protected area have been provided.

Gusto Homes found that the Millennium Green homes cost about 10 per cent extra due to their environmental features, but this did not deter buyers, many of whom were attracted by the green features.

Figure 5 (a) One of the larger houses at Millennium Green, showing main glazing, conservatory and solar water heating panel on the south side. Insulation is much greater than required in the 1999-2000 UK Building Regulations. For commercial reasons, despite its low heat requirements, the house has gas central heating.

(b) Water for toilet flushing and washing machine is collected from the roof and stored in a large underground tank in the garden.

This four-bedroom house was priced in 1999 at £170 000; two-bedroom properties on the development started at £60 000. (Photo: Robin Roy.)

Based on Roy (2005); additional information from Sustainable Development Commission (2005)

The Autonomous House

One of the inspirations for Millennium Green was a much more radical attempt at creating a home for low carbon living. This was the Autonomous House designed by pioneering green architects Robert and Brenda Vale and built in 1993 in Southwell, Nottinghamshire. The Vales originally built the Autonomous House for themselves, but by 1999 they had moved and the house was rented to an environmentally conscious couple.

Materials and Energy

Local and recycled materials were used extensively for construction of the house which was designed to last hundreds of years. The house is almost entirely heated from passive solar energy plus incidental gains from the occupants, appliances and lights. With super-insulation, small triple-glazed main house windows and a very thermally heavy concrete construction to store heat gains there is no need for a main heating system and the new occupants only used the small wood stove for supplementary heating four times by mid Winter. Photovoltaic (PV) panels (Figure 6b) supply about half the household's electricity, mainly for water heating, lighting and cooking – no dishwasher or freezer was provided – and there is no solar water heating. Monitored energy consumption is about 13 per cent of a conventional house built to the 1995 Building Regulations (BRECSU, 1998).

Water

The house is also independent of mains water and sewerage. Rainwater from the roof is filtered through sand in the lower conservatory area and stored in tanks in the cellar. Water for drinking and cooking is further treated by a ceramic/carbon filter and drawn from a separate tap. The cellar also accommodates the tank of the composting toilet.

Low carbon living

The total project cost of the house was fairly high at £145 000, including £15 000 for the PV array but excluding land. Also living in it requires some commitment, such as opening and closing doors and windows to maximize solar gain, accepting occasional low winter room temperatures, checking the water filters and tanks and being very careful with water use to

avoid it running out. Small windows mean relatively poor natural lighting in the main house. Probably the biggest difference from a conventional house is the need to regularly rake and empty the composting toilet.

The Autonomous House shows that it is possible to design housing that achieves the required 80-90 per cent reductions in resource use and emissions, but such homes are rare and most developers and house buyers would not want to attempt such levels of sustainability.

Figure 6 (a) Cross-section of the Autonomous House showing the superinsulation in walls (250 mm mineral fibre) and roof (500 mm recycled newspaper). (Brenda and Robert Vale, architects.)

(b) The south-east facing upper conservatory for passive solar gain and the small windows of the main house to minimise heat loss. (c) A 2.2 kW grid-connected photovoltaic array supplies about half of the electricity demand.

(Photos: Robin Roy)

(Based on Roy, R. (2005), further information Vale and Vale (2000))

New low carbon communities

The Hockerton Housing project

One way of achieving sustainability for a greater number of people is to go beyond individual low carbon households to communities that are environmentally, socially, and economically sustainable. A pioneering example of this approach is the Hockerton Housing Project (HHP) that was inspired by the Vales' Autonomous House but takes the concept to the small community level, thus sharing some of the cost and effort of building and living sustainably. HHP's five family homes were constructed by the builder of the Autonomous House with help from its future residents at Hockerton village near Southwell, Nottinghamshire and completed in 1998. Each household invested about £90 000 in the project.

Materials and Energy

HHP's homes look distinctive because of the earth covering over the rear and the conservatories along the south-facing front, which trap solar heat from where it is let into the house, and. The interiors are light and modern and stay warm all year with no artificial heating because of the passive solar design, temperature regulating earth sheltering and thermally heavy concrete construction, plus triple glazing, super-insulation and heat recovery mechanical ventilation. Apart from the concrete and insulation, construction materials such as bricks and timber were chosen for reduced environmental impact.

Originally hot water was supplied by a heat pump that extracted heat from the conservatory air. Following the failure of most of the heat pumps, hot water is provided by an electric heater in a large highly insulated water tank. Initial total energy use for each unit was monitored at 25 per cent of an average UK home (BRE 2000). By 2002, after overcoming opposition from local residents, electricity for lighting, appliances and hot water was supplied from a 5 kW wind turbine and a 7.6 kW photovoltaic array on the roof, both linked to the National Grid. This allowed each household's energy demand to be reduced to 10 per cent of the UK average and the project to meet the 'autonomous' standard for housing with almost no

net CO2 emissions. In 2004 a second 5 kW turbine was installed to power a new Sustainable Resource Centre.

Water

A reed bed system provides on-site sewage treatment. The bed is an area of the lake planted with bulrush and common reed. Sewage is trickled through the bed where the roots of the plants allow contact between the waste water and oxygen in the air. This creates conditions conducive for the bacteria that feed on the organic matter in the sewage and reduce its polluting potential. The resulting effluent is clean enough to discharge into the lake without causing harm. Rain from the conservatory roofs is stored in tanks, filtered and treated with ultra-violet light and pumped to the homes for drinking. Non-drinking water is collected from the surrounding land.

Food and Transport

HHP residents produce over half of their food on-site, including vegetables, fruit, honey, eggs and some meat. Each household is permitted one conventional car, which they try to share, while cycles and an electric car provide local personal transport.

Community and society

HHP residents earn their living on-site e.g. providing sustainable living courses and tours while others have conventional jobs. Each household is expected to provide 300 hours per year to work for community activities such as maintenance and growing food. In other words, the project aims to be socially and economically as well as environmentally sustainable. Despite some initial scepticism and opposition to its first wind turbine, over time the project has changed attitudes in the local area. In 2006 a group of Hockerton villagers, helped by HHP members, got together to raise finance to buy a community owned wind turbine. A second-hand 225kW turbine was eventually installed on local farmland and in its first year of operation in 2010 generated enough electricity to nearly meet the village's total annual use.

Figure 7 The Hockerton Housing project. (a/b) Five terraced units built in 1996–98 combine a superinsulated ‘earth sheltered’ solar energy design that provides all space heating with on-site water collection and sewage treatment and small-scale organic food production. (c) Each household can have one fossil-fuelled car, but cycles and a shared electric car are used where possible. (d) Subsequently two wind turbines and photovoltaic cells were installed to provide the much of the project’s electricity, including the Sustainable Resource Centre. (Photos: Robin Roy and Horace Herring)

(Based on Roy (2005); further information from <http://www.hockertonhousingproject.org.uk/>)

Beddington Zero Energy Development (BedZED)

An example of a sustainable community at a bigger scale than the HHP is the BedZED (Beddington Zero Energy Development) in South London. BedZED began in the mid-1990s when the director of BioRegional, an entrepreneurial sustainability charity, met green architect Bill Dunster, which led them to try to develop Dunster’s idea of a zero carbon urban community. The project was initiated by BioRegional and Bill Dunster Architects (now

ZEDFactory), developed by the Peabody Trust, a large housing association that provided much of the funding, plus several partners, and completed in 2002.

BedZED houses about 200 people in 82 houses, flats and maisonettes, each with its own small ground level or roof garden, comprising about 40 per cent housing for sale, 40 per cent key worker rental and shared ownership and about 20 per cent social housing for rent.

The brightly day-lit, contemporary interiors, conservatories and gardens of the BedZED homes (Figure 8) and workspaces have proved very attractive with all quickly sold or rented.

The rooms are rather small, but people seem prepared to pay about 15 per cent extra for BedZED's design, cost saving and green features – one bed flats sold in 2002 at about £100,000 and four bed town houses for £240,000 with prices changing in line with the housing market.

Materials and Energy

As many as possible of the construction materials were locally sourced or reclaimed. The superinsulated terraces with south-facing solar conservatories and thermally heavy construction have minimal space heating requirements, hence no conventional central heating systems are required, only a towel rail/radiator in the bathroom. One of BedZED's most distinctive features are the brightly coloured roof-mounted room ventilators that turn into the wind, draw in fresh air and expel stale air via a heat exchanger (Figure 8). Some electricity is provided by PV cells on the south-facing walls and roofs.

Monitored BedZED households use less than 20 per cent of the heat and just over 50 per cent of the electricity of an average local resident (Hodge and Haltrecht, 2009). This is despite the poor performance and decommissioning of BedZED's combined heat and power (CHP) plant, which was intended to be fuelled by gas produced from tree surgery waste and to provide the community with electricity, piped hot water and space heating. Instead hot water and the small amount of room heating required is supplied from a central gas boiler and most electricity comes from the national Grid.

Water

Waste water and sewage, processed through filters and a floating reed-bed in a greenhouse, is used for toilet flushing and garden use. The use of rainwater collected from the roofs has been successful, but the reed bed system was too energy intensive and costly to operate and was replaced by an experimental membrane bio-reactor. Household mains water demand has nevertheless been cut to less than half the local average (Hodge and Haltrecht, 2009).

Transport

A green transport plan was part of the project from the start. Residents' average car mileage has been cut to under half of the local average by locating the development near bus, rail and tram routes, by restricting and charging for parking spaces, providing onsite workspaces and covered bicycle parking, and having a car-sharing club. However, it has been found that BedZED occupants fly more than average, so that their transport footprint is higher than an average UK resident (Hodge and Haltrecht, 2009).

Community and society

Although the main aim of BedZED is very low CO₂ emissions, it also aims to be economically sustainable via the work spaces and socially sustainable by providing social housing units, a nursery (since closed), allotments, village square, community centre and sports field.

Because of its many innovative features, the cost of the BEDZED project greatly exceeded the budget and the CHP and waste-water systems did not work properly. So, although widely admired, these problems somewhat damaged the reputation of sustainable housing among some housing professionals. Also, some local people feel that the novel design does suit the surrounding area.

Projects like BedZED show what can be achieved, while its higher costs and technical bugs are not surprising given the degree of innovation it involved. Since BedZED was completed its ZEDFactory architects have designed a timber frame kit house called RuralZED with heat-retaining concrete walls and ceilings that can be specified to meet the various levels of the UK's Code for Sustainable Homes up to the zero-carbon standard (Dunster et al. 2008). The

first six zero carbon ‘One Earth Homes’ based on RuralZED were completed in 2009 for a housing association as part of a development of 1360 new low carbon homes at Upton, Northamptonshire.

Figure 8. BedZED, South London (a, b, c) Views of the south-facing terraces with their roof ventilators, wall-mounted PV cells, full height solar conservatories, and ground level front or ‘sky’ gardens reached from a first floor bridge.

(Photos: Robin Roy)

(From Roy (2005); further information from Bioregional.com/what-we-do/our-work/bedzed)

Comparison between low carbon living pioneers

All the case studies in this chapter are of individuals, communities and housing providers in Britain who are pioneering low carbon homes and lifestyles mostly beyond the mainstream of households in industrial societies. What features do they have in common and how do they differ from each other?

Table 1 compares the case studies on the main elements of low carbon living.

Table 1 The low carbon living cases compared

	ECO-RENOVATIONS (householders)		NEW LOW AND ZERO CARBON HOMES (householders, communities, housing providers)			
	1980s Oxford house	The Yellow house	Millenium Green	Autonomous House	Hockerton Housing Project	BedZED
Location	Urban	Suburban	Suburban	Urban	Rural	Urban
Developer	Householder (+ contractors)	Householder (+ builder)	Small housing developer	Green architects (+ contractors)	Community group (+ green architects, builder)	Housing association (+ green architects, consultants, contractors)
ENERGY						
Home	High	High	High	Super	Super	High

insulation						
Windows	Triple (double + secondary)	Double (low e, argon)	Double (low e, argon)	Triple (low e argon)	Double (low e, argon)	Double (low e, argon)
Passive solar	Yes (conservatory)	Yes (sun space+ skylights)	Yes (orientation, windows, conservatory)	Yes (orientation, windows, conservatory)	Yes (orientation, windows, conservatory)	Yes (orientation, windows, conservatory)
Thermally heavy construction	Yes (cavity fill masonry + tiles)	Yes (ext. insulated concrete block)	Yes (cavity fill masonry+ blocks)	Very (thick concrete slab+ tiles)	Very (cavity fill concrete + tiles)	Yes (cavity fill masonry+ blocks)
Space heating system	Gas condensing + radiators	Gas condensing + oversized radiators (+ wood stove)	Gas condensing + radiators	None (occasional wood stove)	None	Central gas boiler (one radiator per home)
Hot water	Solar + gas	Solar + gas	Solar + gas	Solar PV + mains electric	Solar PV (+ mains top-up)	Central gas boiler
Ventilation	Windows, (one heat recovery fan)	Natural stack + heat recovery	Mechanical heat recovery	Windows, natural stack	Mechanical heat recovery	Natural stack + heat recovery
Electricity supply	Grid	Grid	Grid	PV + grid	Wind + grid + PV	Grid + PV
Appliances + lights	All energy saving	All energy saving	Most energy saving	All energy saving	All energy saving	All energy saving
Compact living space	Yes	Somewhat	Varies for house sizes	No	Somewhat	Yes
WATER						
Water supply	Mains	Mains + grey water toilet flush	Rainwater + mains top-up	Rainwater	Rainwater	Mains + rainwater
Toilets	V. low flush	Low flush	Low flush	Composting	Low flush	Low flush
Waste water treatment	Mains	Mains	Mains	Composting toilet, soakaway	Outdoor shared reed bed	Experimental bio-reactor
Garden/ allotment	Rainwater + mains	Rainwater + mains	Rainwater + mains	Rainwater	Rainwater	Rainwater
MATERIALS & WASTE						
Low impact construction materials	Some	Some	Most	Most	Most	Most
Reclaimed/ salvaged materials	No	Extensive use	A few	Many	Some	Some
Waste recycling	Yes	Yes	Yes	Yes	Yes	Yes
Composting	Yes	Yes	Yes	Yes	Yes	Yes
FOOD						
Local food	Yes	Yes	Some	Yes	Yes	Yes
Grow own fruit/ veg	Yes	Yes	Some	Yes	Yes	Some

Produce other food	No	Catch fish	No	No	Poultry, fish eggs honey	No
Organic food	Yes	Yes	Unknown	Unknown	Yes	Some
TRANSPORT						
Max. one car per household	Yes	Yes	Some households	Yes	Yes	Mostly
Low carbon vehicles	Hybrid car, cycles	Cycles	Unknown	Unknown	Cycles, shared electric car	A few
Public transport/ shared vehicles	Yes	Yes	Some?	Unknown	Car, cycle sharing,	Yes incl. car club
Home working	Partial	Partial	Partial + on-site business centre	Unknown	Partial + on-site work centre	Partial + on-site workshops, offices
Leisure air travel	Above UK average	Unknown	Yes, unknown impacts	Unknown	Unknown	Above UK average
COMMUNITY & SOCIETY						
Shared community facilities/ activities	No	No	Wildlife and community area	No	Food growing, water treatment, maintenance	Community nursery, café, sports field
Involved in promoting sustainable living	Yes	Extensively	Unknown	Yes	Extensively	Some
Some problems	Finding skilled trades to do eco-renovations; air travel trade-offs	Inadequate public transport for 2 child family	Acceptance of low energy lights by some households	Emptying composting toilet; natural lighting of main house	Failure of heat pumps	Cost overrun; Failure of CHP and waste water systems

The table shows that the six low carbon living pioneers share a great many features, but there are some important differences.

Energy

Something clearly shared by all the pioneers is substantial home energy saving. This is achieved in all cases by heavy insulation, thermally heavy construction and passive solar heating plus low energy lights and appliances. The Autonomous House and HHP homes are almost fully passive solar heated; the remaining households burn gas to provide some or most

space heating. Hot water is supplied in various ways, almost all with a solar thermal or PV contribution. Two-thirds of the homes have heat recovery ventilation systems. Nevertheless, most of the energy technologies employed in these building are fairly well-established; when innovative or complex systems such as heat pumps and biomass CHP systems have been tried they have failed. In terms of size, only the Autonomous House and the larger Millennium homes can be considered generous for their number of occupants, while the Oxford terrace and BedZED units provide for compact living.

Water

Another common feature is water saving. Although the carbon emissions from supplying a household with mains domestic water are relatively small (NHBC, 2010), water conservation helps reduce the pressure on scarce resources. Two sites rely solely on harvested rainwater, two on mains plus rainwater, and two solely on mains water. To reduce consumption the Autonomous House has a composting toilet while the rest use low flush WCs; the Yellow House also has a grey-water recycling system. Half water their gardens exclusively with collected rainwater and half with rainwater supplemented by mains. The Autonomous House, HHP and BedZED treat all their waste water on-site. Although some of these systems may reduce carbon emissions, recent research has shown that rainwater, grey-water and on-site waste water treatment systems often increase emissions compared to mains water supply, because of the energy embodied in equipment and electricity for pumps (NHBC, 2010). This shows that what is conventionally considered 'green' may not always prove to be the optimum environmental solution.

Materials and waste

Unsurprisingly all the low carbon pioneers recycle household waste and compost their food and garden waste. Most of the homes are built from at least some local, low impact and/or recycled materials (usually hidden in the structure), while the Yellow House makes extensive use of salvaged items. Such choices seem to be partly a matter of whether householders are

prepared for a 'recycled' rather than a glossy new look to their home; which relates to consumption values of the people concerned.

Food

Food is an area with plenty of scope for reducing emissions. Again it is not surprising to find these low carbon pioneers attempting to reduce 'food miles' by shopping locally and growing at least some vegetables and fruit in a garden or allotment. However, only HHP residents attempt to produce items such as meat and eggs as they have land available plus a commitment to shared community work for food growing. However, even they can't hope to be self-sufficient in food. Organic food is at best marginal in carbon saving, but several of the households buy at least some organic for reasons of health or taste.

Unfortunately there is little information about the goods and services consumption of the low carbon pioneers even though such consumption is a major part of an individual's or household's carbon footprint. Only the Oxford house couple stated that they deliberately avoid purchasing too much, at least partly to avoid cluttering their small home, although it is likely that committed environmentalists living in the other homes would also aim for more sustainable consumption. However, on average monitored BedZED residents bought similar amounts of consumer goods as a typical UK household (Hodge and Haltrecht, 2009).

Transport

Transport is one of the most difficult areas in which to reduce consumption, but most of these pioneers are attempting to reduce their transport footprints. Nevertheless, most own a car, even if confined to one per household either from choice or at Hockerton and BedZED by regulation. Public transport, car sharing, cycles, hybrid or electric cars are also used but the choices are much more dependent on location (urban or rural) and personal circumstances than say home energy saving. For example, the Yellow House family reluctantly acquired a car in case their second child needed urgent transport to hospital. Air travel in particular poses a dilemma for those attempting low carbon living, especially since environmental pioneers

tend to be wealthier than average and so can afford more travel. Although there is little information about these pioneers' air travel, there is some evidence that flight emissions are reducing at least some of the benefits of their low energy homes. The Oxford couple fly every one to two years to visit relatives in Canada and typical BedZED occupants have been found to fly more than average, annually flying the equivalent of a return trip to New York (Hodge and Haltrecht, 2009).

Diffusion of low carbon homes and living

Since these case studies were completed there has been an increased interest in sustainable housing, stimulated by the 2007 UK government announcement that by 2016 all new homes should be 'zero-carbon'. This initially implied that over a year each new dwelling or development should produce net zero CO₂ site emissions, but in practice is likely to mean low carbon homes with investment in off-site 'allowable solutions' such as community heating schemes, to offset any remaining on-site emissions. The strategy for achieving zero-carbon is the Code for Sustainable Homes, which sets CO₂ reduction targets, and awards points for other features including water saving, low-impact building materials, and waste recycling (CLG, 2010). The Code has resulted in architects and house-builders designing prototype zero-carbon homes and housing developments. In addition, several initiatives to encourage and help householders and others to eco-renovate existing homes have emerged. These complement government incentives to promote the installation of home insulation as well as low carbon technologies such as solar PV and heat pumps that are currently mainly confined to a niche market of green householders (Roy, Caird and Abelman, 2008). Hence, the innovations pioneered by these case study low carbon homes and living experiments are being promoted and adopted much more widely.

However, living in a low or zero carbon home is no guarantee of living a low-carbon lifestyle, especially if the householders are relatively wealthy, hence the need to also tackle the impacts caused by buying more electronic equipment, lights and appliances, increased travel and the globalised consumption of food, goods and services.

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