Title:

Enabling low carbon living in new UK housing developments

Research Paper

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Abstract

Purpose This paper describes a tool (the Climate Challenge Tool) that allows house builders to calculate whole life carbon equivalent emissions and costs of various carbon and energy reduction options that can be incorporated into the design of new developments.

Design/methodology/approach The tool covers technical and soft (or lifestyle) measures for reducing carbon production and energy use. Energy used within the home, energy embodied in the building materials, and emissions generated through transport, food consumption and waste treatment are taken into account. The tool has been used to assess the potential and cost effectiveness of various carbon reduction options for a proposed new housing development in Cambridgeshire. These are compared with carbon emissions from a typical UK household.

Findings The tool demonstrated that carbon emission reductions can be achieved at much lower costs through an approach which enables sustainable lifestyles than through an approach which purely focuses on reducing heat lost through the fabric of the building and from improving the heating and lighting systems.

Practical implications The tool will enable house builders to evaluate which are the most cost effective measures that they can incorporate into the design of new developments in order to achieve the significant energy savings and reduction in carbon emissions necessary to meet UK Government targets and to avoid dangerous climate change

Originality/value Current approaches to assessing carbon and energy reduction options for new housing developments concentrate on energy efficiency options such as reducing heat lost through the fabric of the building and improving the heating and lighting systems, alongside renewable energy systems. The Climate Challenge Tool expands the range of options that might be considered by developers to include those affecting lifestyle choices of future residents.

Keywords Greenhouse gas emissions, Housing, Assessment tool, New build, Lifestyle

Paper type Research paper

Introduction

Climate change is considered by many to be one of the most important problems facing the world community. This assessment is shared by many organisations, both governmental and non-governmental, including within the UK – the Department for Environment, Food and Rural Affairs (DEFRA 2008) and the Sustainable Development Commission (SDC 2008) and, internationally, the World Economic Forum (WEF 2006). However, there is some uncertainty regarding the precise nature and scale of climatic change and the difference that various levels of greenhouse gas emission reduction will make to the degree of the problem (Stern 2006).

Various climate scientists and political institutions are supporting the "tolerable windows approach" (Hadley Centre 2004; Grass et al 2003; UNFCCC 1994; WBGU 2003). This approach means keeping emissions below a level that could lead to disastrous consequences such as a runaway greenhouse effect, where the climate continues to warm even though no further anthropogenic greenhouse gases are emitted. Current scientific consensus is that a 60 to 80% reduction over 1990 levels of world greenhouse gas emissions is required by 2050 for the developed world, to stand a good change of avoiding "dangerous" climate change, i.e. to remain within the "tolerable window".

In response to this the UK Government has set its CO_2 emission reduction target to 80% by 2050 (Milliband 2008). Intermediate targets of a 20% reduction by 2010 and 30% by 2020 have also been set. These targets are ambitious; it is currently unlikely that the 2010 target will be met, and policies currently planned for the next 10 years are considered insufficient for the 2020 target to be met (AEA Energy and Environment 2008; DTI 2007). UK policy largely focuses on technical solutions such as energy efficiency and renewable energy. For example the Energy White Paper (DTI 2007) includes an analysis of all UK sectors and the likely carbon emission reduction to be achieved in each sector by 2020. The list of measures mentioned is largely based on energy efficiency improvements, more efficient generation and generation from renewable and nuclear sources. The potential contribution from behavioural changes is not mentioned in the document, neither are policies that encourage such behavioural shifts. Unsurprisingly the carbon reductions forecasted in the White Paper for 2020 are insufficient to meet the Government's target.

Within the domestic sector, current Government policy targets carbon emissions reduction through a number of mechanisms. These include providing energy advice through a network of local energy advice centres, subsidising installation of insulation in the home, energy efficient light bulbs and condensing boilers. In new housing developments, the main mechanism for achieving a reduction in the energy used within the home is through part L of the Building Regulations. In the UK every new house is required to meet Part L regulations on energy efficiency. Part L requires builders to meet a certain standard which leads to reduced CO_2 emissions in the use of the building. The standard covers energy used in the home for heating, hot water and lighting.

The Government intends to gradually improve the carbon emissions of new homes, to achieve a 25% reduction in energy used within the home by 2010, a 44% reduction by 2013, with a final leap to 'zero carbon' homes by 2016. The Government has set a goal for all new homes to be 'zero carbon' by 2016. A zero carbon home is defined as a home that produces no net CO_2 emissions from energy used by the people living in the home (i.e. to heat and light the home). This, however, does not include energy used in the construction of the dwelling, energy embodied in the construction materials, energy embodied in the goods consumed in the home or transport energy. There are currently no specific national policies that limit, or require an assessment of, carbon emissions from these other ways in which energy consumed by households.

Desai (2004) estimated the contribution of the energy used in a home built to 2002 Building Regulation specification to the overall footprint of a UK resident using a consumer-based accounting methodology. He found that only 11% of the energy used by a typical UK resident living in a new home is used to heat and light the home. This raises the question as to whether there is anything that a house builder can do to encourage emission reduction in the other categories which amount to 89% of emissions UK consumers are responsible for.

Whilst there is significant potential for energy and carbon savings through technological measures such as building insulation, use of high performance glazing, and efficient heating systems (PIU 2002), there is also significant potential for savings through behavioural and lifestyle changes (Oxford University Environmental Change Unit 1997) both within and outside the home. Many of these can be influenced by the design of dwellings and the developments within which they sit. For example, the location of a new housing development (in particular its proximity to services and facilities, including shops and public transport) can influence travel choices and thus the amount of energy used for travel, as can soft measures such as the production of a travel plan (Titheridge 2004). Some of measures can be incorporated into new housing developments through the land use planning system i.e. through transport and environmental assessments, and by applying certain planning conditions. A number of Local Authorities have adopted the so-called Merton Rule; this requires homes in their locality to meet a certain percentage of CO_2 emission reduction from the energy used by the home (typically 10%) by renewable energy sources. Some sites require specific targets under the Code for Sustainable Homes (CSH) to be met. A major aspect of the CSH targets is that Part L regulated emissions need to be reduced by a certain percentage (depending on CSH rating to be achieved) using a combination of energy efficiency and renewable energy measures. However, these mechanisms are not used consistently (see, for example, Hine et al 2000) and not all aspects of lifestyle are covered.

Given that our dwellings last decades, if not hundreds of years, it makes sense to take a more holistic approach than currently being adopted through the building regulations; an approach which allows behavioural and lifestyle factors to be taken into account alongside technological fixes, when assessing options for reducing carbon emissions from new housing developments. In other words – could a wider “lifestyle” approach be more effective at achieving the carbon emissions reductions required to meet the UK Government’s targets? In order to make the right choices three main factors need to be fully understood:

- the carbon equivalent emissions implications over the lifetime,
- the implication of behavioural and lifestyle choices made by the residents,
- the cost implications of different measures – so that it can be decided how money is best invested for maximum outcome in terms of minimizing emissions reduction and maximizing the benefits for the residents.

This paper describes an assessment tool (The Climate Challenge Tool) that has been developed as part of research undertaken towards an Engineering Doctorate. The research aims to develop a lifestyle approach to assessing carbon reduction options for housing developments and to examine whether a taking a lifestyle approach could lead to greater levels and more cost effective emissions reduction. Within this paper the tool is described before being used to assess carbon emissions for a typical UK household living in a typical UK dwelling and in a dwelling built to the 2006 Building Regulations. The Climate Challenge Tool is then used to evaluate a variety of different carbon reduction measures for a new housing development in South East England.

Carbon emissions assessment tools

Before opting to develop our own tool, the authors carried out a review of tools currently available to practitioners for calculating energy or carbon emissions. Tools were reviewed based on a number of criteria.

1. Whether the tool calculates the life cycle CO_2e emissions and life cycle costs of different measures and options available to house builders. This information would then enable proposed options to be ranked according the amount of CO_2e saved per £ invested.
2. Whether the tool allows a wide variety of measures to be considered, including measures which promote behavioural change, such as smart metering.
3. Whether the tool would allow the user to compare the carbon footprint of dwelling (or development) being assessed with that of a typical UK household.
4. The scope of the tool, i.e. whether it includes all energy used within the home, energy embodied in the building envelope, energy used in the production of the food and other goods and services used by the household, energy used for transport and for waste disposal.
5. Whether the tool takes into account any wider considerations such as the impact of any measures on the future residents of the buildings and the acceptability of these measures to potential residents.

As can be seen from Table 1, none of the tools reviewed met all our criteria. The tools tended to only cover the energy used in the home (for space heating, water heating, lighting, and in some instances by other appliances), with some also including the energy embodied in the building envelope. Very few of the tools included costs as well as carbon emissions as an output from the tool. Almost none of the tools allowed direct comparison with a typical UK household, but this could be achieved in most tools by entering data on, for example, the features of a typical UK home, to provide a baseline comparison.

We also reviewed a number of tools and developed to model energy and carbon emissions at a district, city or regional scale. These included TEMIS, developed for assessing energy policy at a national scale but since adapted to the city level and applied, within the UK, to Newcastle upon Tyne (1992), the EEP (Energy and Environment Prediction) model (University of Wales at Cardiff 2004), DREAM-city (Dynamic Regional Energy and Emissions Assessment Model) (Titheridge et al, 1996), TRANUS (Rickaby et al, 1992) and the Quantifiable City model (May et al, 1997). The models are generally limited to the estimation of energy and emissions, although other aspects of resource consumption are sometimes included such as waste and water. Titheridge (2004) developed separate but complimentary tools to DREAM-city that calculate costs, and wider sustainability impacts or the energy and carbon reduction measures being considered. Typically within these models CO_2 emissions are considered on a sector by sector basis, with the main sectors considered being: domestic, commercial, industrial, and transport sectors. Less frequently considered are the relationships between these sectors and how those emissions translate into the carbon impact of the products and services ultimately delivered to UK households.

Table 1: The scope of the main tools currently available to house builders for assessing the carbon emissions of their developments

Tool	**1. Outputs include Cost (£)/tonne of CO_2e saved?**	**2. Technical and behavioural options included?**	**3. Compares savings to the carbon footprint of a typical UK household?**	**4. Includes household energy use, materials, food, waste and transport?**	**5. Impact upon residents assessed?**
Life Cycle Assessment (LCA)	No, life cycle carbon emissions are sometimes included but not costs	Both may be included depending on individual assessment.	No	Yes, can do, depending on boundaries.	Yes
Life cycle Costing (LCC)	Costs are calculated but not life cycle carbon	Behaviour normally not included.	No	Yes, can do depending on boundaries.	No
Ecological footprint	Costs are not included. Life cycle carbon emissions are included but are not usually listed separately	Yes.	For the ecological footprint yes, but not for the carbon footprint.	Yes, but based on national averages.	No
EcoHomes	Costs not included. CO_2 footprint only for household energy.	Technological measures are included. Behavioural measures are touched upon.	No	Food not included.	
The Code for Sustainable Homes	Costs not included. CO_2 footprint only for household energy.	Technological measures are included. Major behavioural measures are not included.	No	Food not included. Major transport issues also not included.	Health and wellbeing covered but only at an aggregate level.
Envest	Cost and life cycle carbon.	Behaviour not included. Limited design choices available.	No	Food, waste and transport not included.	No.
SAP and Energy Certificate	No, CO_2 emission for regulated	Behaviour not included.	No, but this could be possible.	Only energy use of building is	No.

	emissions from direct energy used in home only, estimate of cost implications of energy bills			included	
ESTEEM	No, energy and CO_2 only	Some elements of mode choice included, choice of travel destinations included	No, but can compare to a typical household within a region	CO_2 emissions from personal travel generated by new housing developments only	No

In addition a number of tools were reviewed which model energy and carbon emissions at a district, city or regional scale. These included TEMIS, developed for assessing energy policy at a national scale but since adapted to the city level and applied, within the UK, to Newcastle upon Tyne (1992), the EEP (Energy and Environment Prediction) model (University of Wales at Cardiff 2004), DREAM-city (Dynamic Regional Energy and Emissions Assessment Model) (Titheridge et al, 1996), TRANUS (Rickaby et al, 1992) and the Quantifiable City model (May et al, 1997). The models are generally limited to the estimation of energy and emissions, although other aspects of resource consumption are sometimes included such as waste and water. Titheridge (2004) developed separate but complimentary tools to DREAM-city that calculate costs, and wider sustainability impacts or the energy and carbon reduction measures being considered. Typically within these models CO_2 emissions are considered on a sector by sector basis, with the main sectors considered being: domestic, commercial, industrial, and transport sectors. Less frequently considered are the relationships between these sectors and how those emissions translate into the carbon impact of the products and services ultimately delivered to UK households.

Methodology

A tool (the Climate Challenge Tool) has been developed that will enable developers to compare carbon emission reduction potential for a wide range of measures that can be designed into new housing developments. The measures included in the tool cover both technical solutions such as building integrated renewable energy and soft measures that reduce carbon emissions through encouraging environmentally responsible behavioural changes.

For the tool, a consumer-based view was adopted. In other words, the aim was to include within the tool emissions generated as a result of a households' lifestyle and behavioural choices, from the energy they use within the home, to the travel they make, the food they buy and the amount and way in which they dispose of waste. Such a consumption-based view has the potential to allow business to target those consumer products and services which have highest overall carbon emissions. Business should then be able to proactively reduce carbon emissions throughout the supply chain in a way that also delivers financial benefits over time. This point of view also means that it is easier to estimate the effect of a decision upon consumer behaviour and therefore permits including both emission savings from technical solutions and from behavioural shifts. Furthermore, policy makers should be able to formulate sensible policies which both take into account the end consumer and the overall carbon emissions implication of their policies.

Within the tool measures are split into five categories. These categories have been chosen to reflect areas which are significant in emissions and can to some extend be influenced by the house builder. These categories are:

1. **Household energy**: the carbon emitted by a home through consumption of energy (electricity and fossil fuels such as gas). A house builder can influence these emissions through energy efficient design and building integrated renewable and low carbon energy sources.

2. **Building materials**: carbon is generated in the production, transport of the building materials, construction on site and disposal at the end of the life of the building. A developer can influence this through choosing locally produced material, building materials that requires little energy to manufacture (e.g. timber), and avoiding or recycling construction waste.

3. **Transport from commuting**: the carbon emitted from cars, and public transport. A house builder can influence this by choosing a site where people can live close to where they work and by provision of low carbon transport solutions (car sharing, public transport), or carbon free transport provisions (attractive cycling paths and walkways), or by creating jobs locally for example through building offices.

4. **Food**: the embodied carbon in food from, agricultural machinery, transport, packaging material, storage and supermarket energy, can be influenced by the developer by providing allotments to grow food, and market stalls where local produce is sold, promote low carbon/ethical food, or by creating local amenities which offer local and ethical produce.

5. **Waste**: providing recycling and composting facilities reduces waste send to landfill sites where it emits methane, a very strong greenhouse gas. In addition replacing virgin products with recycled products often means a lower carbon footprint in the manufacture of the product. A house builder can influence recycling rates by including good recycling provisions and by raising awareness.

The Climate Challenge Tool allows users to calculate carbon emissions savings and the cost implications of various options available to house builders. The tool is developed in Microsoft Excel and uses a database of emission measures, their potential for carbon savings and cost, to calculate the tonnes of carbon equivalent emissions avoided per £ invested. Capital costs are offset against any monetary savings. These saving were discounted over the lifetime of the measure using net present value (NPV) calculations. In addition to capital costs energy savings and maintenance costs plus replacement costs were taken into account. The NPV was calculated using a 3% discount rate. The tool then ranks the measures being compared on the basis of cost effectiveness, defined as £ per tonne of CO_2 saved. These results can also be displayed graphically.

Available secondary data was used to assess emissions. Where reliable data was not available best estimates were used. Multiple data sources were used to increase the reliability of the estimates. This data came from for example BRE good practice publication, academic literature, government statistics, empirical measured emission reduction achievements from different measures from Bioregional and ESD, Spons and quotations from suppliers. Data from the EPA's WARM Tool was used to assess life cycle emission abatement measures from waste scenarios. In addition a range of relevant stakeholders were sought to gain insight on what emission reduction is likely for different measures that may lead to behavioural changes.

To illustrate the potential of the tool the authors first compared carbon emissions for a typical UK household in an average UK home with emissions for a typical UK household in a home build to UK 2006 building regulations for each of the five categories mentioned above. Then the tool was used to examine carbon saving measures for a proposed development on the edge of Cambridge of approximately 2000 houses containing a mixture of houses and flats. Whilst the findings are specific for this site, similar outcomes are expected for other developments in the UK. Changes would result from changes in household size and composition, environmental resource parameters, local transport networks, local amenities and overall size of the development.

A qualitative assessment was conducted for each measure taking into account the capital cost of the measure and its acceptability to residents and developers. On this basis developers can make informed choices on how to deliver carbon emissions reductions. A five point scale was used to indicate which measures are may be most appropriate.

The final examination investigated how the same emission reductions as those required by the Government's 2016 zero carbon target for new homes could be achieved through measures applied across all five categories included in our tool.

Key findings

Baseline

Initially the baseline of the emissions in the above mentioned categories was calculated. Including these five categories the emission footprint of the typical UK household is displayed in Figure 1.

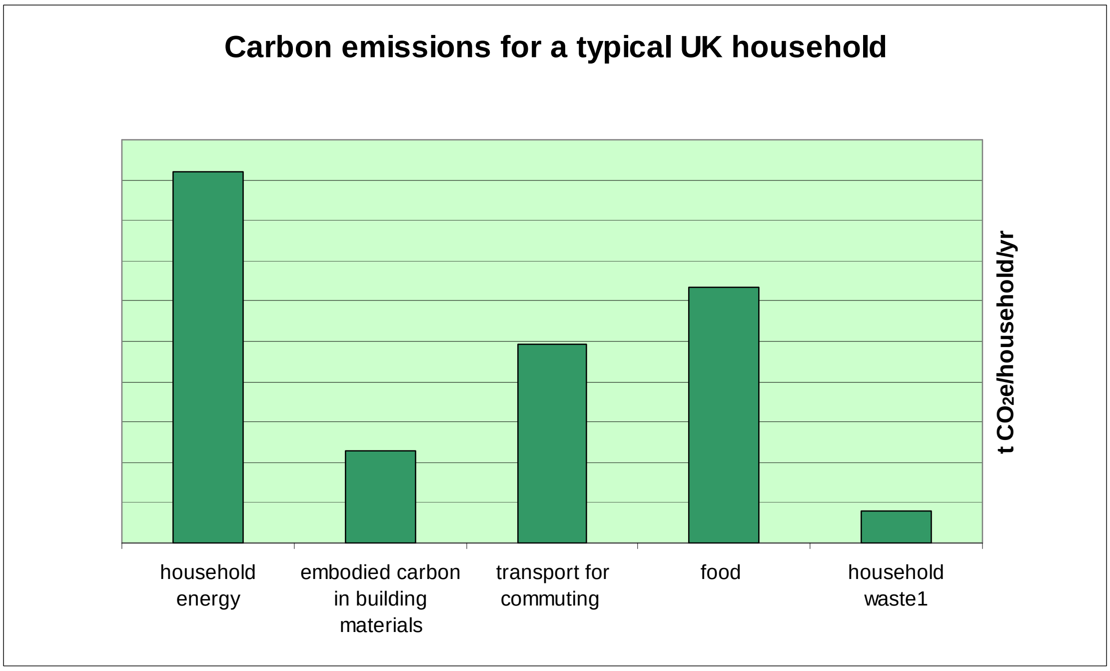

Figure 1: Carbon Emissions for a typical UK household

Under current UK legislation the only categories for which CO_2 emission is regulated and limited is the first category: household energy. As the category with the largest carbon footprint one may rightly argue that it may be sensible to focus policy on the area.

Under Part L of the building regulations every new home is required to achieve a certain energy efficiency standard under the Standard Assessment Procedure SAP. SAP forecasts a likely carbon footprint of the energy used by the home and includes most energy efficiency parameter with a few exceptions such as appliances which are not seen as integral parts of the homes themselves. In 2002 there has been a step change in the energy efficiency standard required under Part L. A home build after this date in the UK would have a household energy carbon footprint which is approximately 40% lower than that of a typical UK home, about 2.9 tonnes of CO_2e/household/yr. Then a new home the carbon footprint of transport from commuting and food is of similar importance as that of the energy used in the home itself.

Case Study Development

Household Energy

Energy efficiency

A selection of energy efficiency measures were compared for the case study development. Figure 2 orders the energy efficiency measures investigated according to their net present value over tones of CO_2e saved ratio. A number of measures on the left save carbon and have a negative NPV, this is because the value of energy savings is greater than the initial capital outlay even after discounting. Therefore make most sense in terms of both reducing emissions and saving costs. Other measures save carbon at widely varying costs. Recommendations were made both based on this cost-effectiveness criteria and based on a qualitative assessment of the measure. For example, whilst showers with a flow rate of 6 l/s or less both save money and carbon; they were not recommended as they are seen as significant comfort reduction to the residents. Note, not all these measure are included in the UK building regulation's SAP assessment. For example the water reduction measures and A rated appliances are not regulated (Figure 2).

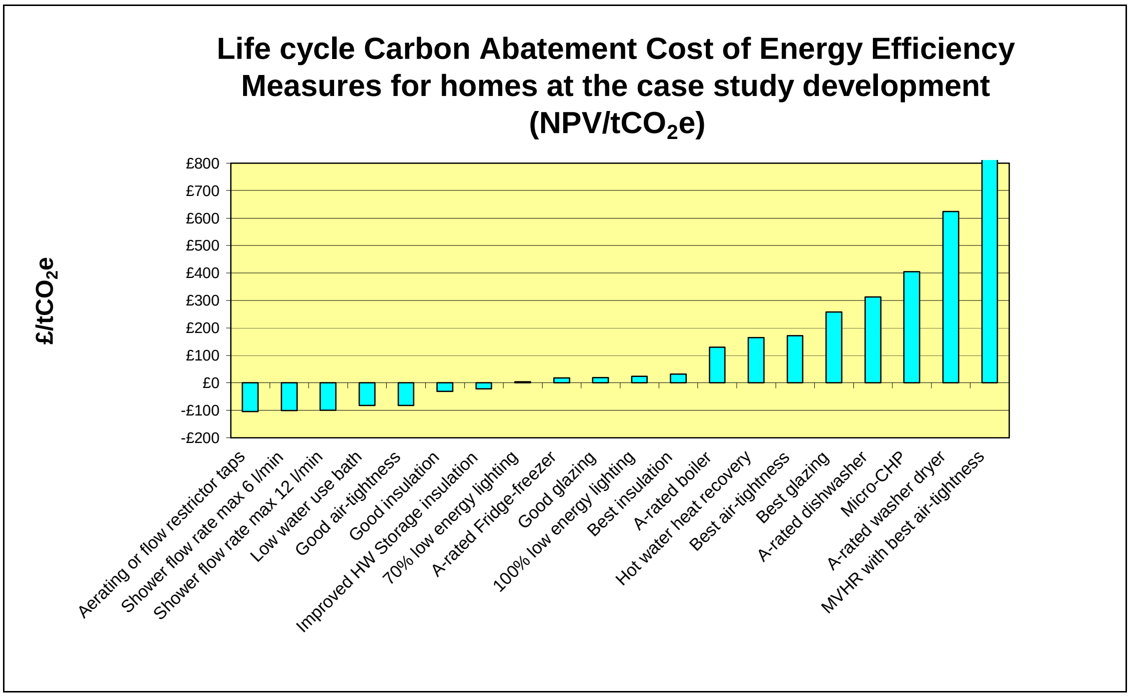

Figure 2 Life cycle carbon abatement costs of energy efficiency measures for homes within the case study development in terms of £ (at NPV) per tonneCO_2e saved

The scoring system used in the Table 2 indicates our judgment of appropriateness of each of the measures considered. This is based on a sliding scale ranging from * indicating unsuitable to ***** indicating highly appropriate.

Table 2: Recommended energy efficiency measures for the case study site

Area	**Measure**	**Descriptions**	**Capital cost estimate per dwelling**	**Recommendation**
Hot water saving measures	Aerating flow restrictor tabs	Modern mixer tap which reduces hot water consumption and makes it easier to wash hands	Plus £0 to £20 compared to equivalent mono-taps	*****
	6 l/min flow restrictors for showers	Reduce water flow rate to 6 l/min. This is a compromise in comfort, the flow is too low.	£5- £10	*
	12 l/min flow restrictors for	Reduced flow rate to 12 l/min. Flow rates at 10 l/min or above meet comfort levels.	£5- £10	*****

	showers			
	Low water use bath	Either use small bath, or for taller people use a larger size bath with lowered overflow.	Smaller baths cost less. The Ideal Standard Alto bath can be fitted with low overflow at no extra cost.	****
	Hot water heat recovery	Recovery of heat from shower water via heat exchange coil around drainage pipe. 25% of heat lost in-use and 60% of remaining heat recovered as hot water pre-heat	Approx. £350	****
Appliances	A-rated dishwashe r	Low energy appliance saving 300kWh/yr	Approx. £ 75 above typical dishwasher	***
	A-rated washer dryer	Low energy appliance saving 170kWh/yr assuming 3 uses per week.	Approx. £500 above typical washer dryer	*
	A-rated fridge freezer	Low energy appliance saving 35kWh/yr assuming 1 use per day	Approx. £250 above typical fridge freezer	****
Mechanical and electrical services	Improved boiler efficiency	SEDBUK A-rated condensing boiler (92% efficient)	Approx. £200/dwelling	****
	Improved hot water storage insulation	Increased Hot Water Storage insulation thickness (160mm factory applied)	Approx. £100/dwelling	*****
	Micro-CHP	1kWe / 6kWth Micro-CHP unit operating in response to dwelling heat demand in place of boiler	Approx. £500/dwelling	*
	MVHR with 'Best' air-tightness	Whole dwelling Mechanical Ventilation with Heat Recovery system and best air-tightness (3m3/m2/hr) supplying 0.5 ach with 66% heat exchange efficiency	Approx. £1600/dwelling	*.
	'Good' low energy lighting	70% fixed low energy light fittings	Approx. £150/dwelling	****
	'Best' low energy lighting	100% fixed low energy light fittings	Approx. £300/dwelling	****

Building Fabric	‘Good’ insulation levels	~20% improvement on Part L 2006 standard with wall U-value of 0.2W/m2K, roof U-value of 0.11W/m2K		
	“Best” insulation levels	40% improvement on Part L 2006 standard with wall U-Value of 0.2 W/m2K, roof values of 0.11 W/m2K	Highly dependant on construction detail, typically £100 to £400/dwelling.	****
	“Good” glazing	Double glazed argon filled, overall U-Value of 1.5 W/m2K	Approx. £150/dwelling	****
	“Best” glazing	Triple glazed argon filled, overall U-Value of 1.1 W/m2K	Approx. £400/dwelling	*.
	“Good” air tightness	5 m3/m2/hr at 50 Pa achieved through good detailing and workmanship.	No extra costs.	*****
	“Best” air tightness	3 m3/m2/hr at 50 Pa achieved through good detailing and workmanship, and additional draft specifications.	£200/dwelling.	****

Renewable energy

A similar analysis was conduced for renewable energy solutions. The assessment was based on a target of reducing household carbon emissions by 10% through renewable energy sources.

Figure 3 shows that for the exemplary site the only cost effective renewable energy source is a medium or large scale wind turbine. Other renewable energy sources never pay for themselves. Their costs range from approximately £200 to £700 for each tone of CO_2e saved, varying with the different renewable energy technologies. As with the energy efficiency analysis recommendations could then be made both on the £/tCO_2e ratio as well as on other practical consideration and additional benefits to residents. Key recommendations would be to employ cost effective energy efficiency measures before renewables, and for this particular site to look into the potential for developing a wind park and hot water contribution from solar energy

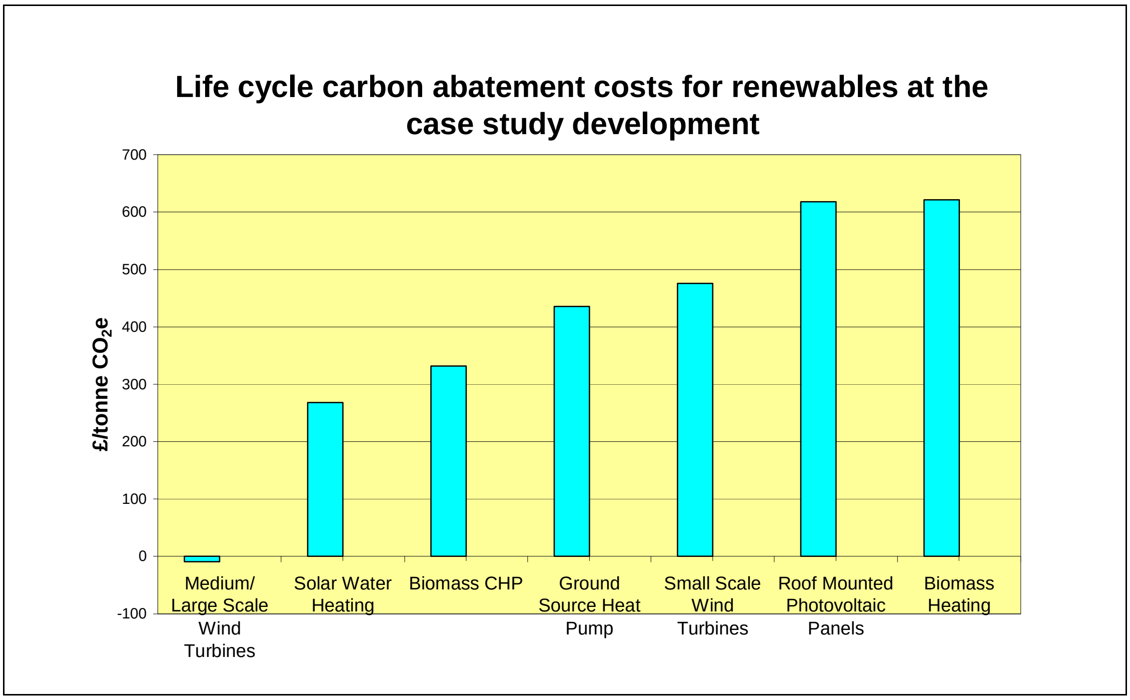

Figure 3 Life cycle carbon abatement costs for renewables options that could be installed at the case study development

Building materials

The same analysis was completed for a choice of options to reduce the carbon emissions embodied in the building materials. Figure 4 displays the CO_2e abatement costs for a number of options to reduce the carbon footprint of the building materials themselves. Cost implications vary significantly. The figure shows that it is important to understand carbon and cost implications and that significant carbon and financial savings can be made when sustainable material choices are made based on this assessment rather than on an ad hoc basis. Using construction waste seems to be the best option; using recycled cellulose insulation instead of rock wool is not cost effective. Using natural carpet is also a far more expensive choice than wooden or tiled floors, but residents may have other reasons for choosing them.

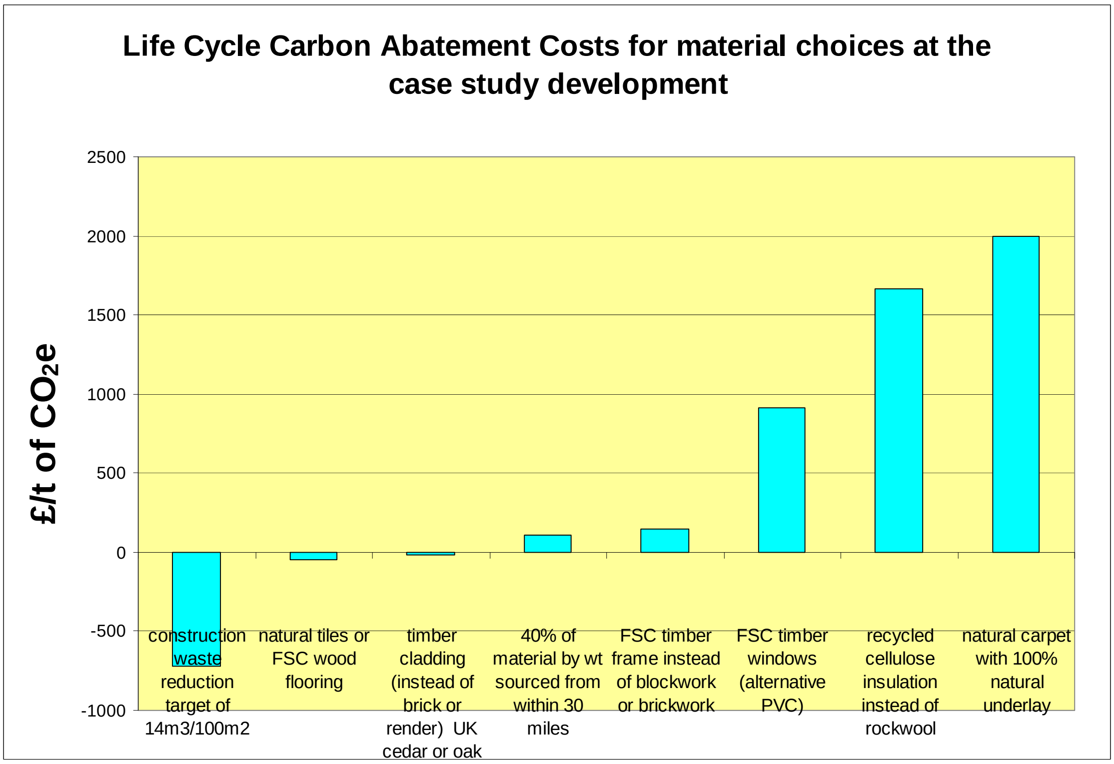

Figure 4 Life cycle carbon abatement costs for building material choices at the case study development

Transport, Food and Waste

The costs and carbon savings involved in making sustainable living easy were then investigated. These included a mixture of measures in the area of transport, consumables and waste.

An example waste scenario for our case study development is shown in Table 3. These results illustrate that CO_2e emission reduction from intelligent waste treatment can be greater than the direct emissions from waste disposal, i.e. the methane emissions from waste if sent to landfill can be more than compensated for if waste is recycled and thereby offsets the emissions that would have been caused by the use of replaced virgin material. Waste composition was based on UK typical household waste composition and quantified according to the number of household of the proposed development. Note that the waste scenario presented here was selected from a number of scenarios for the greatest CO_2e reduction achievement, and that to maximise carbon savings the best disposal method may be different for different categories of waste. The recycling, composting and incineration rates assumed reflect rates that were deemed achievable with good recycling provisions and awareness raising activity. Note reuse was not an option considered here.

Table 3 Example waste scenario

Material	**Tonnes of waste produced**	**Total CO_2 if sent to landfill (tCO_2 e)**	**Assumed recycling rate**	**Assumed compost-ing rates**	**Assumed combust-ion rate**	**Total CO_2 if sorted (tCO_2e)**	**Waste not sent to landfill (tonnes)**
Aluminum Cans	16.66	0.64	60%			-149	10
Steel Cans	37.49	1.44	60%			-40	22
Glass	197.15	7.58	60%			-30	118
Cardboard and Paper Packaging	111.07	164.86			60%	22	67
Food Scraps	340.16	485.02		40%		264	136
Garden Waste	191.60	-5.58		60%		-25	115
Mixed Paper, Resid.	242.97	298.67	60%			-343	146
Mixed Metals	6.94	0.27	60%			-30	4
Mixed Plastics	112.46	4.32	60%			-100	67
Other MSW	134.67	213.85				214	0
Total	1391.18	1171.07				-217	686
Reduction						119%	51%

Figure 5 displays a number of low cost options to reduce carbon emissions at the exemplary development. Below £100 per tonne of CO_2 are:

- the choice of the right location or mix of uses of the development such as locating homes near jobs or jobs near homes
- the improved access to sustainable local food, through creating allocated commercial space on site or nearby,
- raising awareness on sustainable living (such as home operation, access to sustainable consumables, recycling, sustainable transport options) through employing a sustainable living officer on site.

Comparing Figure 5 to Figures 2, 3 and 4, it becomes clear that there are a number of cost effective carbon reduction solutions in the area of energy efficiency and building material choice. The majority of carbon emission reduction measures however do involve additional costs. The difference in costs per unit of CO_2e saved vary significantly.

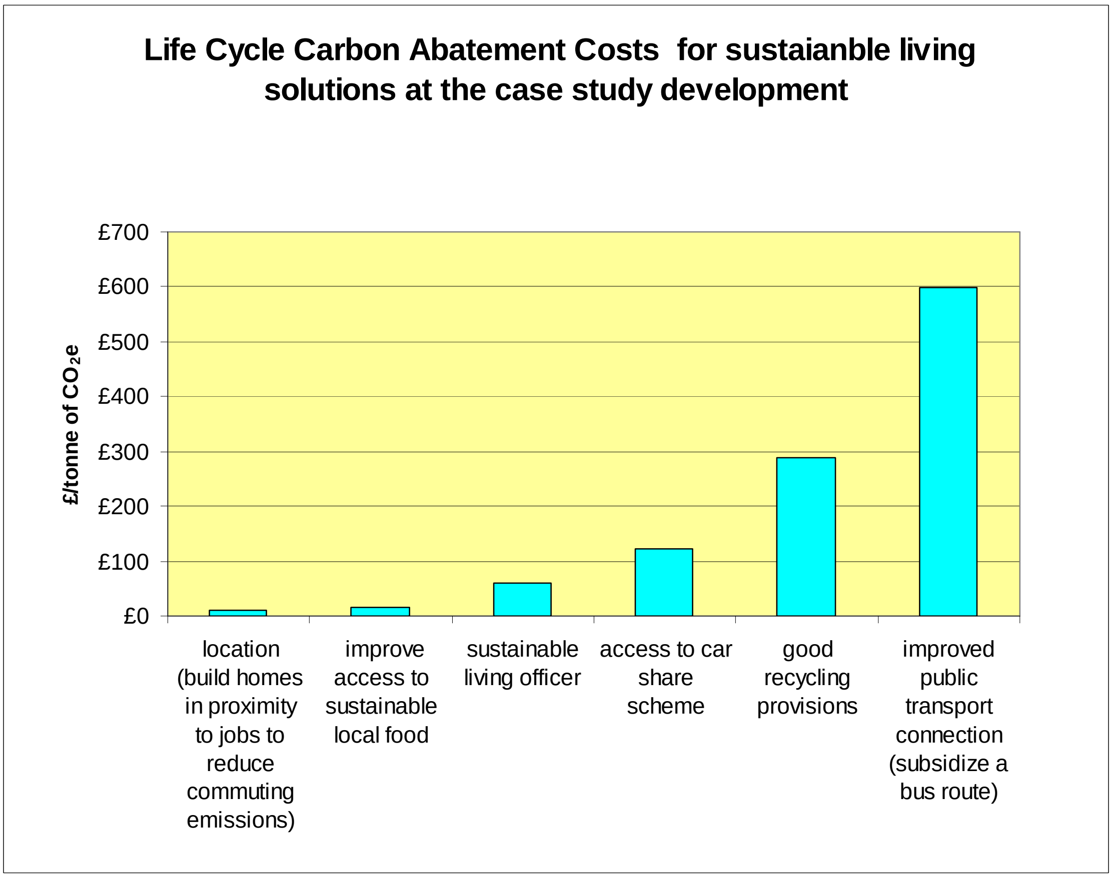

Figure 5 Life cycle abatement costs for sustainable living solutions at the case study development

In most locations the UK Government's proposed carbon emission reductions for 2010, 2013 and 2016 (25%, 44% and 100% reduction of the energy used in the homes) will require to largely use the higher end energy efficiency and renewable energy measures. A few exceptions would be sites located close to suitable sites for wind energy (i.e. near a field with medium to high wind speeds). The costs of the majority of measures employed may lie in the range of £100 and £500 per tonne of CO_2e saved. Indeed for a so called carbon neutral home (as per the Government's 2016 target) the additional capital costs compared to a home that meets building regulations may lie in the order of £20 to £36k.

The analysis shows that the extra costs of achieving a similar level of CO_2e emission reduction (2.9 tonne of CO_2 per household per yr, based on our baseline analysis) using the lifestyle approach at the exemplary NIAB site would amount to approximately £4k per home. Sensitivity analysis reveals that costs would be similar for other housing developments of similar scale and may range between £3k per home and £10k per home. Table 4 shows the chosen scenario for the exemplary development and the emissions savings which were calculated to be achieved in each category.

Table 4 Estimated CO_2e savings per household at the case study development for measures that go beyond current building regulations

Measures	**Annual CO_2e reduction (tCO_2e/household/yr**
Low cost energy efficiency measures (air tightness, low e lighting, low flow tabs and showers)	0.3
Solar hot water	0.3
20% increase in waste reduction and recycling through good provisions and awareness raising	0.5
15% carbon emission reduction of food carbon footprint through awareness raising and advice on organic veggie box schemes, once a week local farmers market	0.6
25% reduction in commuting transport emissions though choosing a location with jobs close to the homes, increased cycling, car share scheme and public transport	0.6
Low cost building material with low embodied carbon is chosen (timber frame, timber and tile flooring, timber cladding, site construction waste reduction, minimizing the use of concrete and lead)	0.3
Sustainable living officer achieves 10% uplift in recycling rates, sustainable food uptake, uptake of sustainable transport options and home energy management	0.3
Total	3.1

Figure 6 shows resulting change in household carbon footprint at the proposed development, here compared to a home that meets current building regulations. Please note that carbon footprint of the energy used in the home is significantly lower for a typical new home that a typical existing home (Figure 1).

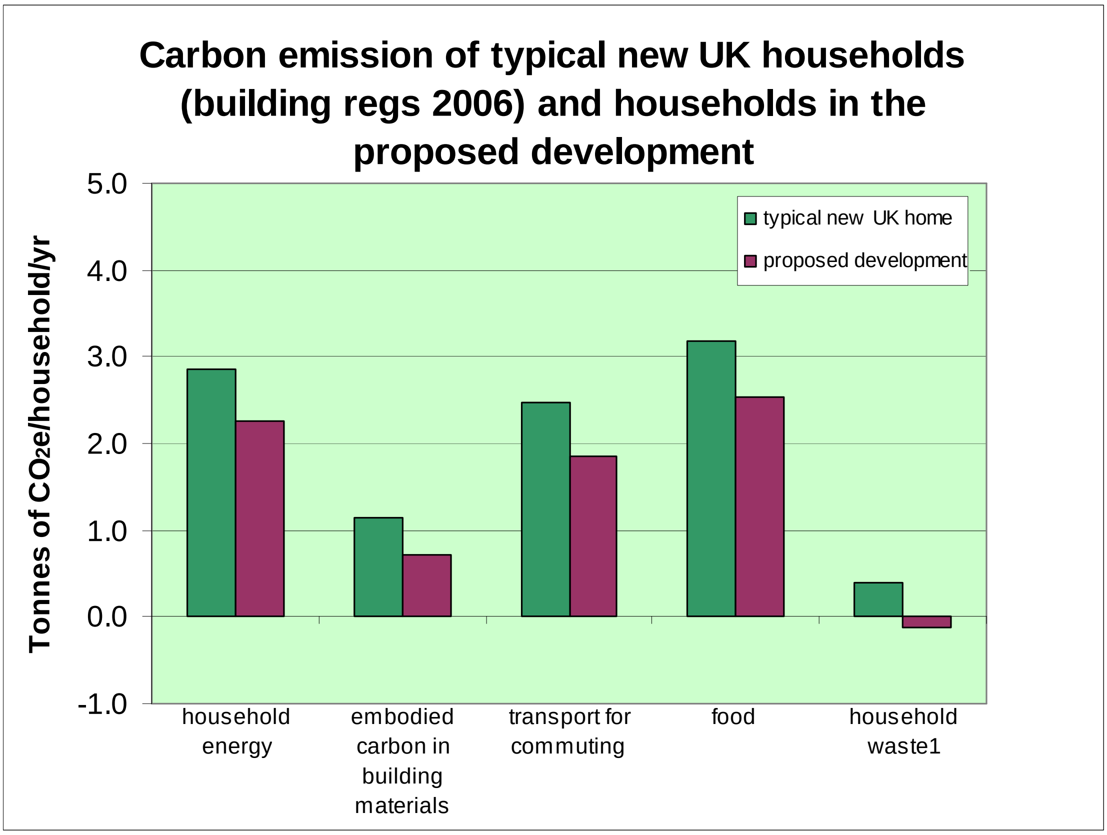

Figure 6 Carbon emissions of typical UK households in homes built to the 2006 building regulations compared with those from households in the case study development

Discussion and Conclusions

It has been shown that carbon emission reductions can be achieved at much lower costs through an approach that enables sustainable lifestyles, rather than focusing purely on reducing the emissions of the building in its use. In addition many of the low carbon lifestyle solutions have greater additional benefits to the residents than energy efficiency and renewable energy measures. Good low carbon transport provisions (walking, cycling, public transport, car-share schemes); access to jobs, amenities and low carbon consumables; convenient recycling facilities, and a sustainability officer who supports implementation and community cohesion, may be more valuable to the local residents and the wider local economy, than renewable energy and energy efficiency measures only.

To achieve its challenging climate change targets the government needs to complement their low carbon/ carbon neutral homes aspiration with policies which make low carbon living easy and attractive. In addition there is a missed opportunity to regulate or incentivise emission reduction in the building envelope itself. Transport waste and local amenity policies could have a greater

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[1] Note that for waste the baseline emissions only include emissions once the products have entered the waste stream, whereas for the proposed development the emissions saved from reduced requirements of virgin material, or from fossil fuels in the case of combustion, have been deducted from the waste treatment emissions giving a negative footprint overall.

focus on reducing CO_2e emissions. The successful emission reduction achieved through building regulations which regulate the maximum likely CO_2 emissions of a building in use, could be replicated in other categories, such as building materials, emissions from commuting, emissions from waste and consumption. This may be a more sensible and costs effective way forward than further regulating the energy used in new homes to be brought down to zero by 2016. Policies should not only target new homes by be inclusive of other policies which effect the above sectors.

The tool can be used by policy maker and developers alike in supporting the design of sustainable low carbon communities. When designing new housing developments it is important to understand the full carbon emission implication of the people living there. This assessment should not be limited to the use if the buildings only but should include a better understanding of the carbon emissions resulting from transport, consumption patterns, waste disposal and building material choices, as well as the effort that is made to raise climate change awareness on site. Only with this holistic understanding will it be possible to achieve the high level of carbon emission reductions the UK government is targeting.

Findings show that many carbon reduction measures, such as building integrated renewable energy, currently required by many local planning authorities, cost far more per tone of carbon saved than other unregulated solutions. Many of the lifestyle option have additional benefits to the residents and may even without additional policy incentives be a viable option for progressive house builders. Future work includes research into gaining a better understanding of customer preferences, wider social and environmental implications of the options. This combined with the tool's outputs on carbon and financial implications may help design more sustainable and climate friendly yet profitable developments.

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Steffie Broer

Steffie Broer has worked as a sustainable energy and buildings consultant for CAMCO since 2000, managing a variety of projects advising house builder and the public sector on sustainable energy and sustainability solutions. Since 2005, CAMCO is sponsoring Steffie to read for an Engineering Doctorate (EngD) at UCL, where Helena Titheridge is her academic supervisor. Steffie has a degree in Environmental Science and a Masters in Applied Energy and Buildings. Steffie is a registered Code for Sustainable Homes Assessor and a Chartered Engineer. In parallel to writing up her thesis Steffie is currently involved in setting up a start-up business: Bright Green Futures (www.brightgreenfutures.co.uk)which aims to apply some of the research findings from her EngD.

Helena Titheridge

Helena joined the Department of Civil, Environmental and Geomatic Engineering at University College London (UCL) as a lecturer in 2004. She started her academic career as a researcher in the Energy and Environmental Research Unit at the Open University, before joining the UCL Bartlett School of Planning in 1997. Helena has a Masters degree in Energy Management and Conservation from Middlesex University. Her doctorate which she completed in 2005 was on sustainability assessment of energy policies for the town of Milton Keynes.