MEETING THE CHALLENGE OF ZERO CARBON HOMES:

A multi-disciplinary review of the literature and assessment of key barriers and enablers

Edited by Dr Kate Theobald and Dr Sara Walker,

School of the Built Environment, Northumbria University

Contents

Introduction

We live in interesting times.

Within the built environment sector, there is an increasing pressure on professionals to consider the impact of development upon the environment. These pressures are rooted in sustainability, and particularly climate change.

But what is meant by sustainability? It is a term whose meaning is often discussed, the most common definition taken from the Bruntland report as "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). In the built environment, the sustainability issues within the environment, social and economic spheres are often expressed through design considerations of energy, water and waste.

Given the Stern Report's economic and political case for action with respect to climate change (Stern, 2006) and the IPCC's Fourth Assessment Report's confirmation of the urgency of the climate change issue and it's root causes (IPCC, 2007), the need for action to mitigate the effects of climate change is currently high on the political agenda. Excess in carbon dioxide concentrations over the natural level have been attributed to anthropogenic sources, most particularly the burning of carbon-based fossil fuels.

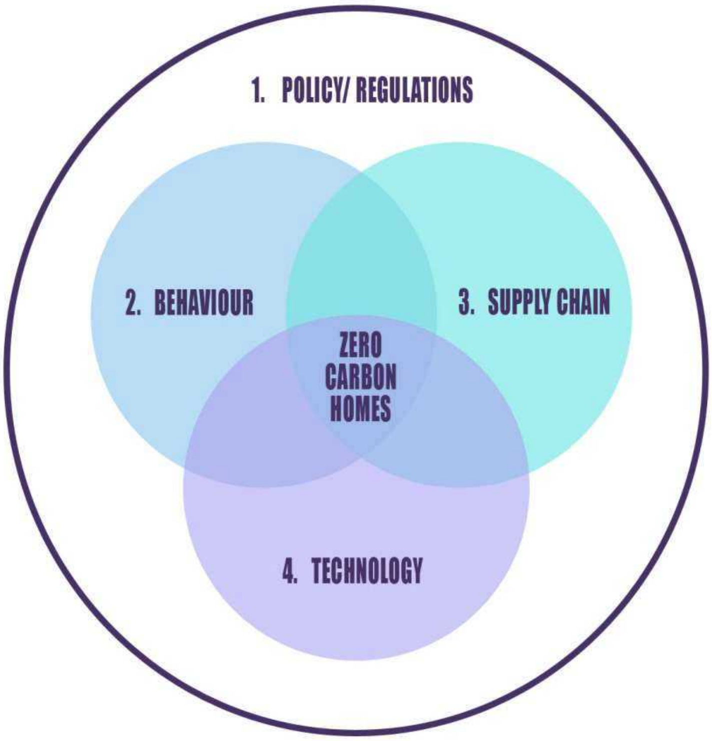
Over 40% of Europe's energy and 40% of Europe's carbon dioxide emissions arise from use of energy in buildings. Energy use in buildings is primarily for space heating, water heating, lighting and appliance use. Professionals in the built environment can therefore play a significant role in meeting targets for mitigating the effects of climate change.

The UK Government recently published the Code for Sustainable Homes (DCLG, 2006). Within this is the objective of development of zero carbon domestic new build dwellings by 2016.

It is the domestic zero carbon homes agenda which is the focus of this report.

The report is the culmination of a research project, funded by Northumbria University, and conducted from February 2008 to July 2008, involving researchers from the Sustainable Cities Research Institute (within the School of the Built Environment) and academics, also from within the School. The aim of the project was to examine, in a systematic and holistic way, the critical issues, drivers and barriers to building and adapting houses to meet zero carbon targets. The project involved a wide range of subject specialisms within the built environment and took a multi-disciplinary approach. Practitioner contribution was enabled through a workshop.

The focus of this work was to review the academic literature on the built environment sector and its capabilities to meet zero carbon housing targets. It was not possible to undertake a detailed review of energy efficiency or micro-generation technologies, the focus of the research was instead in four focussed areas: policy, behaviour, supply chain and technology.



What follows is the key findings of the review work undertaken. Chapter One presents the findings of the policy and regulation review. In Chapter Two the review of behavioural aspects of energy use in buildings is presented. Chapter Three presents the findings of the review of supply chain issues. Chapter Four presents the findings of the technology review, which focuses on phase change materials. A summary of the key barriers and enablers, and areas for future research work, concludes this report in Chapter Five.

Research is always a work in progress, and therefore comments on this document are most welcome, as are offers of collaboration towards solutions.

The School of the Built Environment at Northumbria University strives to embed its research in practical applications and solutions to the need for a low carbon economy.

The project management team would like to thank the following individuals for their contribution to the report and to the research project:

Dr Sara Walker, Director of Sustainable Buildings and Energy Systems, Northumbria University

Dr Kate Theobald, Reader, Sustainable Cities Research Institute, Northumbria University

Minnie Fraser, Senior Lecturer, Northumbria University

Dr Paul Chan, Senior Lecturer, Northumbria University

Mr Chika Udeaja, Senior Lecturer, Northumbria University

Gill Davidson, Research Associate, Sustainable Cities Research Institute, Northumbria University

Sara Lilley, Senior Research Assistant, Sustainable Cities Research Institute, Northumbria University

Margaret Horne, Director of Built Environment Visualisation Centre, Northumbria University

Correspondence regarding this report should be addressed to:

Dr Kate Theobald
Reader,
Sustainable Cities Research Institute
Email: kate.Theobald@unn.ac.uk

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Chapter One: Policy and regulatory context

Sara Lilley

Introduction

The recently published Budget 2008 (HM Treasury, 2008) sets out new policies to reduce carbon emissions across all sectors of the economy. In the Budget 2008, the Government states it aims

'to support and encourage individuals to take action themselves now/short term, and to set standards for new homes that will support zero carbon lifestyles in the future.'

A number of government policy documents have been published in recent years, covering a range of areas in relation to energy efficiency and relevant to the government, producers, suppliers and consumers. All of these policy documents aim to tackle climate change by reducing CO2 emissions. In order to do this, a number of recommendations are made; for energy and gas suppliers to encourage domestic customers to take up energy efficient measures (e.g. cavity wall insulation) and to raise standards of energy efficiency in new buildings and refurbishments, by revising the Building Regulations.

In order to achieve the target of all new homes to emit zero carbon by 2016, as set out in the Housing Green Paper 2007(DCLG 2007) a number of key planning policy documents have been published including the Planning Policy Statement (PPS) Planning and Climate Change, the Code for Sustainable Homes and the consultation document Building a Greener Future.

This review will now discuss the main Government policy documents relevant to achieving the zero carbon 2016 target.

National policy documents

This review will start with examining the national Government policy documents, which aim to tackle energy efficiency and carbon reductions.

Firstly, the Energy White Paper 2003 (DTI 2003) defined a long-term strategic vision for energy policy combining environmental, security of supply, competitiveness and social goals. It built on the Performance and Innovation Unit's Energy Review, published in February 2002, and on other reports which have looked at major areas of energy policy. Four goals for energy policy were outlined:

- to cut the UK's carbon dioxide emissions, the main contributor to global warming, by 60% by about 2050 with real progress by 2020;
- to maintain the reliability of energy supplies;
- to promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve our productivity;
- to ensure that every home is adequately and affordably heated.

The White Paper discusses electricity and gas suppliers encouraging domestic customers to invest in energy efficient measures such as cavity wall insulation, and aims to raise standards of energy efficiency in new buildings and refurbishments, by revising the Building Regulations.

The UK Energy Review published on July 2006 (DTI, 2006), outlines the Governments energy review for meeting two long term challenges in UK energy policy: to tackle climate change by reducing carbon dioxide emissions; and to deliver secure, clean energy at affordable prices. In order to encourage more individuals to become more energy efficient, the Review proposes to provide more information and clearer incentives for individuals to make better use of energy.

The Energy White Paper May 2007 (DTI, 2007) builds on a series of publications and consultations as part of a wide ranging Energy Review, including the Energy Review 2006. Again the White Paper sets out the two long term challenges: tackling climate change by reducing carbon dioxide emissions both within the UK and abroad; and ensuring secure, clean and affordable energy. The paper discusses changes to the energy planning system including improving the strategic context of planning decision (the Planning Policy Statement on Climate Change, which highlights the use of renewable and low carbon energy sources). To improve advice and information for individuals on being energy efficiency, the document announced the launch of an online CO2 calculator. To enable people to track home energy use, the White paper announced a trial of smart meters and real time displays.

The White paper discusses the introduction of Energy Performance Certificates (EPC)s for new and existing homes. Launched alongside this document was the consultation on Carbon Emission Reduction Target (CERT) for 2008-2011, formally the Energy Efficiency Commitment (EEC). Both EPCs and CERT will be discussed later in this review.

The Regional Development Agencies are expected to set regional energy priorities and implement the White Paper at the regional level, including setting regional carbon reduction targets and prioritising energy technologies for support in their area by December 2007.

The 2004 Energy Efficiency Plan (Defra, 2004) sets out how Government intended to deliver the commitments relating to energy efficiency, stated in the 2003 Energy White Paper. The UK Energy Efficiency Action Plan 2007 (Defra, 2007) aims to address two Government commitments: to meet the requirements in Article 14 of the Energy End-Use Efficiency and Energy Services Directive to produce a National Energy efficiency Action Plan for submission to the European Commission; and to review and update the Government's 2004 Energy Efficiency Action Plan reflecting policy developments arising from the 2006 Climate Change Programme, the 2006 Energy Policy review and the 2007 Energy White Paper to provide a comprehensive statement of UK energy efficiency policy. The plan sets a target to reduce emissions from the UK's residential housing stock by 31% on 1990 levels by 2020.

The Stern Review (2006) discusses the effect of climate change and global warming on the world economy. The review recommends a shift towards a low carbon economy to reverse the effects of global warming. In order to stabilise climate influencing emissions the Review outlines three elements to be implemented together; carbon pricing, supporting technology and the removal of behavioural barriers.

The Climate Change and Sustainable Energy Act 2006 (House of Commons, 2006) is an Act of Parliament which aims to boost the number of heat and electricity microgeneration installations in the United Kingdom, therefore helping to cut carbon emissions and reduce fuel poverty. Microgeneration involves the local production of electricity by homes and businesses from low-energy sources including small scale wind turbines, ground source heat pumps and solar electricity installations.

The Housing Green Paper 2007 (DCLG, 2007) outlines the government's plans for delivering Gordon Browns commitment of three million additional new homes by 2020. The Green paper outlines the government's targets for all new homes to emit 25 per cent less carbon by 2010, 44 per cent less by 2013 and zero carbon from 2016. For existing houses the paper proposes improvements in the way Energy Saving trust supports households in improving the energy performance of houses.

The Budget 2008 recommends individuals improve the energy efficiency of products in the home, which could provide one of the most cost effective ways of meeting the Governments climate change and energy goals. Recommendations include improving insulation in homes, making homes more affordable to heat and reducing waste energy, which could play a part in reducing emissions. The Budget highlights the Carbon Emissions Reduction Target (CERT), which obliges suppliers to install energy efficient measures i.e. loft and cavity wall insulation in homes (discussed further on in this review).

For home buyers, The Budget 2007 announced a time-limited Stamp Duty Tax exemption for new zero carbon homes from October 2007, and the Government announced in the Budget 2008 that it will extend the Stamp Duty Land Tax exemption to new flats. Changes will be made and Government departments will charge a fee when assessing whether a home meets the zero carbon standard. To enable the construction industry to prepare for delivering zero carbon homes before 2016, Government will set out a definition for a zero carbon home by the end of 2008, following a consultation in the summer of 2008. Government has allocated funding for the launch of a new 2016 delivery unit, in 2008, to guide, monitor and coordinate the zero carbon programme.

The 2016 Taskforce will

- Identify the barriers to implementation of the zero carbon 2016 target, and put in place measures to address them.
- Develop a commitment publication alongside the final Building a Greener Future policy statement, which will set out the respective roles of Central and Local Government and business as we move towards the zero carbon 2016 target.
- Develop a timeline for steps that need to be taken over the next ten years to support the implementation of the zero carbon 2016 target.

The Climate Change Bill 2008 (House of Commons, 2008) provides a long-term framework for the UK to achieve its goals of reducing carbon dioxide emissions, and will ensure that steps are taken towards adapting to the impacts of climate change. This Bill puts into statute the UK's targets to reduce carbon dioxide emissions through domestic and international action by at least 60 per cent by 2050 and 26-32 per cent by 2020, against a 1990 baseline.

Government has recently announced 15 proposals for Eco-towns, designed to address the housing shortage and affordability, climate change and sustainable living. There will be 10 main settlements built, and construction will be underway by 2010. A key requirement of the eco-town is to meet zero carbon standards across the development and set standards for environmental sustainability. Outcomes for the eco-towns will include the application of environmental technologies. There will be a mix of approaches including design that limits the need for energy in all buildings and localised low or zero carbon energy sources. Developments should also meet the U ambient air quality standards.

Government support programmes

The Government is launching a number of services to support homeowners and house builders in achieving the zero carbon 2016 target.

The *Green Homes Service* will be launched in 2008 by the Energy Saving Trust, on behalf of the Government. An information service for householders to seek a home energy check, providing advice on energy saving, water saving, waste reduction and recycling aswell as information relating to available grants, discounts and financial support.

The *Carbon Challenge* is being delivered by English Partnerships on behalf of the Department of Communities and Local Government with the aim to accelerate the house building industry's response to climate change.

The Challenge aims to fast-track the creation of a number of new communities designed to meet the highest level of the Code for Sustainable Homes, but will still meet English Partnerships key requirement for high standards of quality and design and will seek to maintain the cost efficiencies evident through the Design for Manufacture Competition.

The Carbon Challenge will assist house builders to develop the skills and technology needed to meet the 10-year environmental goals being set by Government for new housing development, and in particular, will act as a testing ground for the Code for Sustainable Homes and the new Planning Policy Statement on climate change.

The DTI currently run a Low Carbon Building Programme (LCBP). This aims to encourage a more holistic approach to reducing carbon dioxide emissions, by demonstrating how energy efficiency and micro generation work together to create low carbon buildings. This will run until 2009, and grants are available for medium and large scale micro generation projects for public, not for profit and commercial organisations, but also small projects for home owners and community groups.

Building regulations/planning policy and new homes

Building regulations are one of the key tools in raising the energy efficiency standards of new homes. The key planning policy documents in relation to achieving the zero carbon target for new developments by 2016 include the Planning Policy Statement (PPS) Planning and Climate Change, the Code for Sustainable Homes and the consultation document Building a Greener Future.

Communities Secretary Ruth Kelly announced a package of measures to reduce carbon emissions from new homes in December 2006. She set out a new timetable and strategy to make all new homes zero carbon by 2016. The Building a Greener Future: Towards Zero Carbon Development 2006 (DCLG, 2006) included:

- gradually tightening up building regulations up to 2016 to increase the energy efficiency of new homes and eventually make them zero carbon
- a Code for Sustainable Homes to give homeowners more information about how green their property is
- a draft Planning Policy Statement on climate change.

This was aimed at planners and house builders, proposing that by 2016, all new homes built in England should be zero carbon, meaning over a year, the net carbon emissions from all energy use in the home would be zero (from washing, cooking and electrical appliances as well as space heating, cooling ventilation, lighting and hot water). This will be achieved by improving the energy performance of homes and increasing the use of renewable and low carbon sources of energy, either installed in the home or supplied to the entire development.

The document states by 2010 all new homes will have achieved a 25% improvement in energy/carbon performance of building regulations, through further improvement in the fabric of dwellings and in the efficiency of heating and lighting. A further target of 44% improvement by 2013 based on the energy efficient standards is set out in the Code for Sustainable Homes. This would require low or zero carbon energy use, using technological innovations, at the development level e.g. Combined Heat Power or at the building level e.g. solar hot water heating.

Part L of the Building regulations (ODPM, 2006) contains minimum energy efficiency standards for new housing in England and Wales. Revised in 2002, 2005 and 2006, this has significantly improved the energy performance standards of new houses. A house built today is 40% more efficient than one built before 2002.

The Planning Policy Statement (PPS) 2007 (DCLG, 2007) sets out how local and regional planning can support a low carbon economy, including the target to make all new homes carbon neutral by 2016. It recommends that climate change considerations are built into all spatial planning concerns. This indicates how the location, siting and design of new development can contribute both to the reduction of emissions and delivery of zero carbon development, and to the shaping of sustainable communities that are resilient to climate change.

Officially launched on December 13, 2006, the Code for Sustainable Homes (DCLG, 2008) introduced in April 2007 is a voluntary Code for Sustainable Homes to influence the builders of new development. It is an environmental rating scheme for housing in England, under which new homes are given a 'star rating' to indicate their environmental impact, ranging from level 1 to level 6 (high sustainability). This aims to guide industry in the design and construction of sustainable homes, to consider energy as well as water, materials, waste and ecology. The Code specifies standards in the areas of energy efficiency, water conservation, surface water management, site waste management, household waste management, and the use of materials. There are six levels of the Code, each containing mandatory minimum standards for energy efficiency and water efficiency. Level 1 under the Code approximates to an EcoHomes "Pass" rating and Level 4 approximates to an "Excellent" rating.

The Budget 2008 (HM Treasury, 2008) has announced that to ensure opportunities to reduce carbon emissions from new housing between now and 2016 are taken up, new homes built on central government land, released through the public sector programme from April 2008, will reach a minimum Level 3 of the Code for Sustainable Homes. Furthermore from 6 April 2008 law householders will have to provide an Energy Performance Certificate (EPC) for all new and newly built homes that are completed after that date

Retrofitting existing homes

A concern for the 2016 target of zero carbon homes is making existing homes more energy efficient: 'As the average existing home requires four times the energy to heat as one built to current minimum standards, tackling the energy performance of existing homes is crucial' (Defra, 2007).

The Energy Efficiency Commitment (EEC) was one of the key policy mechanisms to deliver energy efficiency improvement measures into existing homes in Great Britain, between April 2002 and March 2008. This outlined targets for energy (gas and electricity) suppliers to achieve, for the promotion of energy efficient improvements in the household sector in Great Britain.

From April 2008 until March 2011 the Carbon Emissions Reduction Target (CERT) (Defra, No date) will build on the EEC. This is an obligation on energy suppliers to achieve targets for promoting reductions in carbon emissions in the household sector. CERT will aim to deliver overall lifetime savings of 154 $MtCO^2$, equivalent to annual net savings of 4.2$MtCO^2$, and to the emissions from 700,000 homes each year, stimulating £2.8 billion investment by energy suppliers in carbon reduction measures.

CERT focuses on vulnerable consumers and the suppliers must direct at least 40% of carbon savings to low income and elderly consumers, ensuring a large number of fuel poor households, not eligible under the current criteria, are eligible for support. Suppliers will be able to promote microgeneration measures i.e. biomass community heating and CHP; and other measures for reducing the consumption of supplied energy.

The Budget 2008 mentions the Green Homes Service which will be launched April 1st. The service will assist people to improve the energy efficiency of their homes, directing them to practical steps they can take and the full range of support available, including help via the CERT. A budget of £26 million has been allocated to this, for 2008-2009. The Budget announced the launch of the Green Homes Forum from autumn 2008, to support effective delivery and harness enthusiasm and expertise of interested parties including community groups

Since the beginning of 2008, all homes for sale require a Home Information Pack, prepared by the seller which contains an Energy Performance Certificate (EPC). From autumn 2008, homes for rental will also require an EPC for tenants.

The House of Commons Communities and Local Government Committee research report Existing Housing and Climate Change (2008) recommends Government devise a Code for Sustainable Homes for existing homes, containing a minimum performance standard, based on Standard Assessment Procedure ratings. SAP is a Government Assessment Procedure for the energy performance of individual buildings, ratings between 1 and 100, which 100 represents the best performance possible.

Fuel Poverty and Energy Efficiency

Fuel poverty programmes will now be discussed, concentrating specifically on how these aim to address and improve energy efficiency of existing homes.

The Warm Front programme (Defra, BERR, 2007) launched in June 2000, is the Governments main grant funded programme for tackling fuel poverty. It installs energy efficient measures including central heating and insulation, in vulnerable private sector households. Funding for 2008-2011 is estimated at £800 million, and could help an estimated 400,000 vulnerable households. Eaga plc have been contracted to manage the programme, but Defra retain overall responsibility, thus ensuring the programme's main aim to tackle fuel poverty in a cost effective way, is being achieved.

The other Government programme, Decent Homes main aim is: '*To bring all social housing into decent condition, with most of the improvement taking place in deprived areas, and to increase the proportion of private housing in decent condition occupied by vulnerable groups.'* (DCLG, 2006)

Since 2001 the number of non-decent homes in the social housing sector has been reduced by over 50 per cent. By 2010 DCLG expects 95 per cent of all social housing to meet a decent standard. The work undertaken by landlords on meeting the thermal comfort criterion improves the energy efficiency of the housing stock. This contributes towards wider government goals on ending fuel poverty and climate change. The thermal comfort criteria of the Decent Homes Standard requires dwellings to have both effective insulation and efficient heating.

DCLG recommends that landlords take the opportunity to go over and above the Standard when carrying out work. For instance: installing extra insulation; fitting double glazing; replacing old boilers with new condensing ones; considering using low carbon, renewable or other innovative technologies. Landlords can seek funding for works from energy suppliers via the EEC (Energy Efficiency Commitment) programme or in the private sector from the Warm Front programme. Both schemes are overseen by the Department for Environment, Food and Rural Affairs (DEFRA).

Local Government

The Home Energy Conservation Act (HECA) 2005 (Defra, 2008) requires every local authority with housing responsibilities to prepare, publish and submit to the Secretary of State an energy conservation report identifying:

- practicable and cost-effective measures to significantly improve the energy efficiency of all residential accommodation in their area; and
- report on progress made in implementing the measures.

HECA has served to focus the attention of local authorities more closely on the energy efficiency of all residential accommodation, and on developing an integrated approach to their housing and energy efficiency strategies. Improvements achieved through HECA will contribute to meeting the UK's Climate Change commitments.

Defra has undertaken a review of HECA, as implemented in England, January 2008, to assess the HECA's continued success in delivering improvements in energy efficiency for the household sector over the past ten years. The Review also considers options for the future of the HECA.

North East policy documents

This section of the review will look at the policy documents for the North East region in relation to achieving the 2016 zero carbon target for homes.

The Energy North East Partnership (ENE) has representatives from the Assembly, One North East and Government Office for the North East. ENE has appointed a regional energy officer to help the region contribute to the national energy agenda in a co-ordinated way.

The North East has one of three national pilot Energy Advice Centres, the North East Advice Centre. They provide free practical help for householders and access to grants for installing energy efficiency measures. They also provide advice and support for local authorities and housing professionals.

The North East Assembly is responsible for the production of the Regional Spatial Strategy (RSS) and Regional Housing Strategy (RHS), and is in a strong position to influence the take-up of EU targets to save 20% of energy consumption by 2020. The current Regional Housing Strategy (RHS) (North East Assembly, 2007) identifies the need to improve energy efficiency in both the new and existing housing stock, with policies in the draft RSS supporting the use of renewable energy sources. A micro renewables toolkit has been developed to assist both planners and developers to meet targets to incorporate renewable energy sources.

The Climate Change Action Plan (Sustaine, 2008) for North East England outlines what the region needs to do if it is to tackle climate change. It shows how all sectors have the opportunity to be involved in this work, to take direct action and influence how the regional plan is developed. The plan provides a framework for all climate change action in North East England. Building on existing action plans developed at a sub-regional and local level, it aims to coordinate and facilitate action at a regional level to ensure responses are integrated, timely and effective and ensures that a regional evidence base is developed to inform the local action plans.

The plan shows how the region can gain competitive economic advantage by taking action now to adapt to the effects of climate change and to lessen their effects by reducing our greenhouse gas emissions. It identifies the key actions that are needed at a regional and local level and, where possible, who should take the action and when. It also highlights some actions which do not yet have an agreed way forward so that agreement can be reached on who will lead on these activities as a first step in delivering them.

Barriers to 2016 and recommendations for Government action

A number of research reports have highlighted barriers/problems for Government to address in order to ensure the 2016 target is achieved.

The House of Commons Communities and Local Government Committee have published a report Existing Housing and Climate Change (2008) looking into ways of minimising and reducing the carbon footprint of the existing housing stock in the UK. The research emphasises the problem in spreading energy efficiency measures, is in engaging individual householders. Recommendations are made for the Government to consult with local authorities on how area based programmes for basic home improvements (such as cavity wall or loft insulation) might be offered across sections of the housing stock, therefore being more efficient and cost effective for households who wish to participate.

The report identifies barriers to householders making housing improvements and suggests Government has a key role in helping householders overcome these barriers. The two main barriers include lack of information and financial issues. In order to overcome these, the report suggests the provision of finance through grants and schemes and widespread provision of accurate information for householders to use and act upon with confidence. Furthermore it recommends Government investigate the potential to subsidise feed-in tariffs to encourage more uptake of home micro generation technologies.

Research by WWF-UK (2008) 'How Low, achieving optimal carbon savings from the UK's existing housing stock' argue that UK's poorly insulated energy inefficient housing stock could easily be transformed into cheaper to run, low carbon homes by the end of the next decade, but this would require a radical shift in Government policy. In order to achieve the Government targets by 2020, it would be necessary to deploy significant numbers of low and zero carbon technologies and solid wall insulation. Additionally a stronger set of policies and financing mechanisms to support the deployment of sustainable energy measures would be needed.

Current Government policy is heavily reliant upon homeowners installing measures it defines as 'cost-effective' such as cavity wall, loft, and hot water cylinder insulation, draught proofing, efficient boilers, and heating controls. The report recommends Government introduce a range of financial incentives to motivate home owners to improve the energy efficiency of their homes. Suggested incentives include low interest loans, council tax rebates or stamp duty relief tied to home energy efficiency refurbishments and feed-in tariffs which reward homeowners who generate their own electricity through micro-renewables. Some of these schemes have already been successfully introduced elsewhere in Europe.

The report highlights that nationwide installation of low and zero carbon technologies will require a significant programme of training, investment, and policy support by the Government but this will more than pay back, both in terms of increased efficiency of the housing stock, and a greater skilled workforce. In tandem with these support policies, it is vital that homeowners are provided financial support to help them afford the installation of technologies such as solar heating and ground source heat pumps. There should also be a revision of the obligations on energy suppliers to ensure they support the roll out of solid wall insulation and low and zero carbon technologies

The report concludes that even if all homes did install these measures, household CO_2 emissions would be reduced by just 22%, failing to meet the Government's own 2020 climate change targets. However it is feasible for the UK to meet CO_2 emission reduction targets of 80% in the domestic housing sector by 2050. This would require a rapid and extensive roll out of micro-renewables, the decarbonisation of electricity supply by roll-out of large-scale renewable energy projects and application of carbon capture and storage technology. It would also require an improvement in the energy efficiency of appliances, and more carbon-conscious behaviour in the home.

A major report by consultants Element Energy for the Renewables Advisory Board (RAB, 2007) states the government needed to substantially boost the use of on-site renewable energy if it was to have any hope of achieving its much-vaunted zero-carbon homes policy from 2016.

The report suggests the market for equipping zero-carbon homes with energy from renewables could easily be worth more than £2bn a year but that, under current policies, there will not be nearly enough firms supplying biomass boilers or solar panels in nine years' time, which could slow down the pace of house building.

Gaps in research

A thorough academic literature search was undertaken to locate articles (from the last 5 years) discussing the impact of the Code for Sustainable Homes, using NORA; BIDS (Bath information and data services) and searching a number of specific journals. The journals searched, via the UNN library electronic journals resource included: Housing Studies; Housing Policy Debate; Journal of Housing and Built Environment; Planning; Planning Practice and Research.

No articles were found discussing the impact of the Code for Sustainable Homes, suggesting a gap in the research, due to it being quite soon to when the Code has been introduced and no research being undertaken.

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Chapter Two: Behavioural aspects

Gill Davidson

Introduction

In the UK, almost 60% of our individual contributions to carbon emissions comes from using energy in the home. Of this, three quarters come from heating space and water, and one quarter from lights, fridges, ovens, washing and dishwashers, TV etc (IPPR, 2007). Population growth, increasing demand for new housing and an ever-increasing standard of living means that domestic energy use – and the level of carbon emissions - is rising.

Individual householders can have a key role in reducing domestic carbon emissions by using less energy, and using it in a more efficient way. Behaviours that could help to achieve this include adopting new technologies aimed at improving energy efficiency, buying energy efficient products, and changing everyday habits.

This paper looks at the ways in which householders are encouraged to change their behaviour, the extent to which consumers understand and are engaged with the zero carbon debate, and the barriers and enablers that exist with regard to changing people's behaviours. It goes on to consider possible future steps that could help to achieve reductions in domestic carbon emissions through behavioural change.

Innovation

What people can do to reduce their carbon emissions
People can take the following actions to reduce the carbon emissions in their homes:

- Choose efficient, low energy electrical equipment and energy efficient light bulbs.
- Improve insulation in their homes (cavity wall and loft), which makes homes cheaper to heat and reduces wasted energy.
- Switch tariffs to green electricity.
- Switch fuels, e.g. change from electric heating to gas central heating.
- Use micro generation technologies such as solar heating and wind turbines.

The Green Alliance recommended a number of headline pro-environmental behaviours for consumers in a report to Defra (Green Alliance, 2005), relating to food and drink, personal travel, homes and household products, and travel tourism. Defra has gone on to refine this list, and published its latest version in 2008. The two areas that relate to zero carbon homes are shown in the table below.

From Green Alliance’s 9 Headline Behaviours	From Defra’s 5 priority behaviour groups
1) Tackle Energy Efficiency in the Home Actions: • Buy energy efficient appliances • Install a smart energy meter • Install micro generation • Insulate	1) In the Home: Energy Efficiency/Energy Usage Actions: • Install insulation* • Better energy management in the home* • Micro-gen* • Energy efficient homes (new) • Energy efficient homes (old) • Green tariff • Switch heating system
2) Tackle Water Efficiency in the Home: Action: • Install a water meter	2) In the Home (and Garden): Water Efficiency Actions: • Better water management* • Install water efficient products

* = final headline goals

Installing (or improving) insulation in the home is one of the most accessible behaviour goals, partly because it is a common and therefore normative behaviour, and also because it is known to reduce energy bills (Brook Lyndhurst, 2007). Defra (2008) distinguishes different behaviour types, such as one-off purchasing decisions (e.g. installing insulation or micro generation), occasional purchases (e.g. buying energy efficient products), and habitual everyday behaviours (e.g. better energy management and responsible water usage).

Informing people

The energy systems used in low and zero carbon housing are likely to be more complex than existing systems. Schnieders and Hermelink (2006) stress the importance of providing information and training householders to make sure that the energy systems can achieve best performance. The Code for Sustainable Homes (DCLG, 2006) includes plans to provide homeowners with better information about the sustainability and running costs of their homes.

Energy efficiency labelling on white goods and boilers provides information to householders about the energy efficiency of products. Shorrock et al (2005) report that energy labelling has helped energy efficient products to have a greater market share in the UK, although this has also partly been a result of the introduction of minimum standards for appliances.

The *Act on CO2* campaign has been developed to inform the public about the Government’s stance on carbon emissions. One of its aims is to show people that the government is setting the right example, and encourage them to follow. The Defra ‘Footprint’ TV campaign began in summer 2007 and resulted in an increase in awareness of carbon footprints (from 54% to 82%), and led half of viewers to say that *‘they either had or planned to take action as a result of the campaign’*. (Defra, 2008, p50)

Providing feedback on energy use

Scottish and Southern Energy has piloted a scheme in a village near Perth to fit homes with interactive smart electricity and gas meters, with display units that show householders how much power is being used at any one time. People can also use the meters to find out about previous energy use, so they can find out, for instance, how much power they have saved through actions such as fitting low-energy bulbs. The aim is to encourage householders to find ways to use less power so as to reduce their bills (reducing carbon emissions at the same time). Smart meters have been used since 2005 in Italy, and there has been an annual 5% drop in energy use. Electricity display units are simpler and cheaper devices than smart meters (e.g. £30 as opposed to £150), that simply show householders how much electricity their home is currently using. These also aim to encourage people to cut their electricity use, although they may be less effective than smart meters because the information they provide is less detailed (The Guardian, 20th February 2008).

Controls, rewards, and incentives

The Government has created a number of incentives to encourage consumers to adopt energy efficiency measures. The Energy Efficiency Commitment (EEC) programme is a scheme that obliges energy suppliers to install energy efficiency measures and promote reductions in carbon emissions for households. Its latest phase, Carbon Emissions Reduction Target (CERT), was announced in the 2008 Budget. It will oblige energy suppliers to direct at least 40 per cent of carbon dioxide savings to a priority group of people on low incomes and the over 70s. Measures will include cavity wall and loft insulation, providing energy-efficient light bulbs, and fuel switching from electric to gas central heating. Energy suppliers can lose their licences if they do not meet the targets. The Government also offers fuel poverty programmes and grants for microgeneration. Retallack et al (2007) blame the limited impact of these incentives on their being *'rather cautious'*, compared to the *'very low effective price of carbon'*.

Schemes have been devised to encourage householders to reduce their carbon emissions, such as the Homes Insulation Scheme, Energy Conservation Programme, Energy Efficiency Standards of Performance and Home Energy Efficiency Scheme/Warm Front. These have included grants for loft and cavity wall insulation and condensing boilers. Warm Front is the Government's main grant-funded programme for tackling fuel poverty. It was launched in 2000. The scheme fits packages of measures including insulation and heating systems. Grants are offered for up to £2,700 for families and the disabled, with up to £4,000 for installing oil fired central heating.

A number of schemes and systems have been proposed to help consumers to reduce the impact of their lifestyle in terms of carbon emissions.

The introduction of a **carbon tax** or energy tax by central Government could be used to alter householders' behaviour by giving them an incentive to reduce their domestic carbon emissions in order to pay less tax. This has been introduced in some Scandinavian countries, and Larsen and Nesbakken (1997) reported that it had led to a 3% reduction in household carbon emissions in Norway. Dresner and Ekins (2006) proposed a scheme involving energy audits for homes, combined with surcharges to council tax and stamp duty for homeowners who fail to make cost-effective energy efficiency improvements within a specified time. Grants and loans would be offered to low income households. Such a scheme is seen as an interim step, which would later be succeeded by a targeted carbon tax.

Personal Carbon Allowances (PCAs) are a suggested mandatory scheme to reduce carbon emissions by introducing a quota or ration per person (Hillman and Fawcett, 2004). The allowance per person relates to household and transport energy use, with free-carbon shares being spent on electricity, gas, petrol and flights (Fawcett, 2005; Bottrill, 2006). Shares can be traded or sold. The annual allowance would be gradually reduced so as to cut carbon emissions over a period of years.

Domestic Tradable Quotas (DTQs) are a similar scheme to PCAs, in which the Government would set an overall carbon budget (to be reduced over time), with carbon units being issued to adults and organisations. All adults would get the same amount. There would be a national market where low users could sell their surplus units, and high users could buy extra (Anderson and Starkey, 1999).

People can voluntarily purchase **carbon offsets** to mitigate their own carbon emissions from transportation, electricity use, and other sources. Carbon offsets commonly include: renewable energy (wind power, solar power, hydroelectric power and biofuels), methane abatement, energy efficiency (which seeks to reduce overall demand for energy), destruction of industrial pollutants, tree planting and reforestation.

Engagement

Consumer understanding
It appears that some people still have fairly poor awareness and understanding of the issues related to energy use and carbon emissions. For instance, a 2006 study revealed that almost four in ten people questioned (39%) believed that nuclear power causes climate change (Poortinga et al, 2006).

A survey by Defra (2007) reported that over three quarters of people thought an impact could be made on climate change if most people in the UK cut down on gas and electricity use at home and improved domestic insulation.

Consumer engagement
Energy consumption can vary widely between different consumers, with *'wide differences observed between similar households in nominally identical houses'* (Banfill and Peacock, 2007).

Sale Owen (2005) surveyed over 1000 North East residents about their habits with regard to the issue of climate change, and found that people had adopted the following behaviours:

- 'Around 8 in 10 claim to be doing some easy everyday actions already, for example only boiling water needed rather than a full kettle and turning the heating down a little;
- Significant numbers are also already doing some actions which involve an upfront financial investment/contribution (install insulation, buy energy efficient white goods, use energy efficiency light bulbs). Moreover, the overwhelming majority of North East residents are supportive of this, as many others say they would be prepared to do these for climate change.

- For example, 44% claim to have already bought more energy efficient white goods, and another 44% would be prepared to do so
- In the case of switching to a green energy supplier, only 5% say they have already, while two-thirds claim they would be prepared to do so.'

More than two-thirds of people living in homes with cavity walls say that they have some cavity wall insulation. Nine in 10 households say they have at least one of the following: double or secondary glazing, loft insulation, hot water tank insulation or cavity wall insulation (where they have cavity walls) (Defra, 2007).

Less than 1% of the electricity market share is held by 'green' suppliers, with just over 200,000 consumers having switched to a green tariff (Retallack et al, 2007).

Around 100,000 microgeneration units have been installed in the UK, covering less than 0.4% of households (Retallack et al, 2007).

A survey by Defra (2007) found that up to 1 in 5 people said that they often or always indulged in wasteful behaviours such as leaving the TV on standby overnight, leaving the tap running when brushing their teeth, and taking a bath instead of a shower.

There are some signs of changes towards more sustainable consumption patterns, such as more 'ethical' spending, but the overall picture is of increasing consumption, due principally to rising incomes and smaller households (Defra, 2008).

Motivations for consumer behaviour

Low or Zero Carbon (LZC) models often assume that consumers are self-centred pleasure seekers who over-consume with no regard for the environmental consequences of their actions. Such assumptions underpin many sustainable development policies (Murphy and Cohen, 2001; Paavola, 2001). It is assumed that: people are self-centred and motivated only by what will increase their personal welfare; that increases in people's consumption will lead to increases in their happiness; and that people's preferences and consumption are unaffected by what others consume (Murphy, 2007).

Material goods also play an important role in defining and communicating our identity and status to others in society, as described by Veblen (1899) in his description of '*conspicuous consumption'*.

However, other factors may also affect consumer choices. For instance, the future implications of consumption may be important, as may other outcomes beyond improved personal welfare. Consumers' personal beliefs may also motivate their consumption decisions (Paavola, 2001). Zavestoski (2001) discusses the issue of 'downsizing' and voluntary simplicity, suggesting that some people choose to adopt a simpler lifestyle and consume less because they believe that this will improve their quality of life, rather than because of environmental considerations. This may be a result of people seeing a negative link between consumption and happiness, rather than a positive one.

Retallack et al (2007) identified a series of internal and external influences on individual behaviour. Examples are shown in the table below:

Internal influences	External influences
Psychological motivations	Behaviour and attitudes of other people
The need to define one's status and identity	Dominant social and cultural norms
Emotions	Our experiences (direct and otherwise)
Habits	Rewards and penalties (including price
Mental shortcuts used to decide how to act	
A sense of responsibility	

Research by Shove (1997, 2004a and b) shows how social norms and technology can influence each other. For example, room temperature is often determined by social norms, plus interaction between people and technology. Social norms such as clothes washing can also influence technology.

Consumer attitudes

Research commissioned by Wolseley (2006) found that nearly a quarter of people surveyed (24%) said they would be prepared to pay £1-5000 on top of a property's asking price for an energy-efficient home, while 11% would be happy to pay up to £10,000 more. 67% of those surveyed said they would be willing to pay more for energy-efficient products and appliances in the home. The Energy Savings Trust corroborated this and reported that *'rising fuel prices and greater environmental awareness are encouraging buyers to pay closer attention to a home's running costs and its impact on the planet'* (EST, 2006).

Public acceptance is considered to be an important factor determining how successfully renewable energy technologies can be implemented (Ekins, 2004). For instance, there has been strong opposition to developments such as wind turbines, usually at a local level (Toke, 2005; Warren et al, 2005), and to nuclear power (McGowan and Salter, 2005). Public attitudes to different types of low carbon technology tend to be focused on their wider impacts or 'side effects', such as the visual impact and noise levels for wind turbines, and the smell and volume of heavy trucks for biomass. Therefore, levels of public acceptance of different types of renewable energy technology are quite variable. Solar technology is generally considered to be the most publicly accepted, for instance, while wind power is more controversial (DTI, 2006).

Devine-Wright (2007) discusses the relationship between levels of acceptance of different renewable technologies and factors such as age, gender, social class, and political and environmental beliefs. Findings in this area have been mixed, but a selection is summarised below:

- Older people tend to be more supportive of nuclear energy than young people (Populus, 2005);
- Older people are more aware of micro-scale renewables such as solar panels, but less likely to install them than younger people (London Renewables, 2003);
- People in higher income and class groups are more supportive of alternative energy sources than those in other social groups (MORI, 2004);
- People who expressed support for the Conservative party were found to be more supportive of nuclear power, and less supportive of renewable energy, than Labour or Liberal Democrat supporters (Populus, 2005);
- People with high levels of concern about the environment are more likely to support renewable technologies (Poortinga et al, 2006);

- A Norwegian study about a new hydropower development found that attachment to particular places affected by technological developments was a more significant factor than other characteristics such as age or gender in explaining public acceptance or opposition (Vorkinn and Riese, 1998).

There is a suggestion from both researchers and consumers that the Government has a responsibility to discourage high carbon lifestyles, for instance by introducing legislation to ensure that electrical appliances that create high levels of emissions are not available, and making it easier to buy low impact goods (e.g. Defra, 2008; Ipsos MORI, 2007). In the words of a North East resident: '*if it was mandatory from the Government or Council would we not just do it automatically? If they change the product spec and we can't buy it then we won't!*' (Sale Owen, 2005, p10). Banfill and Peacock (2007) also suggest that Government intervention may be useful in encouraging people to think more carefully about their own consumption.

The results of consumer research emphasise the need for pro-environmental behaviours to fit within people's current lifestyles (perhaps along with a long-term goal of gradually changing their behaviours); implicit in this is the need for a tailored approach that understands and addresses the lifestyles and life stages of different population groups (Defra, 2008).

Defra's research has led to the identification of seven different types of consumer with distinctive attitudes and behaviour:

Segment 1: 'Positive greens' 18% of the population (7.6 million)
"I think we need to do some things differently to tackle climate change. I do what I can and I feel bad about the rest"

Segment 2: 'Waste watchers' 12% of the population (5.1 million)
"'Waste not, want not' that's important, you should live life thinking about what you're doing and using"

Segment 3: 'Concerned consumers' 14% of the population (5.7 million)
"I think I do more than a lot of people. Still, going away is important, I'd find that hard to give up..well I wouldn't, so carbon offsetting would make me feel better"

Segment 4: 'Sideline supporters' 14% of the population (5.6 million)
"I think climate change is a big problem for us. I suppose I don't think much about how much water or electricity I use, and I forget to turn things off..I'd like to do a bit more"

Segment 5: 'Cautious participants' 14% of the population (5.6 million)
"I do a couple of things to help the environment. I'd really like to do more..well as long as I saw others were"

Segment 6: 'Stalled starters' 10% of the population (4.1 million)
"I don't know much about climate change. I can't afford a car so I use public transport..I'd like a car though"

Segment 7: 'Honestly disengaged' 18% of the population (7.4 million)
"Maybe there'll be an environmental disaster, maybe not. Makes no difference to me, I'm just living my life the way I want to"
Defra, 2008

Defra is working on a tailored approach to target these types of consumer in a variety of different ways, with the aim of encouraging pro-environmental behaviours.

Media and information sources
People tend to rely on TV and national and local newspapers as sources of information on climate change and energy efficiency. They also expect that there would be a national advertising campaign if the issue was considered to be particularly important (therefore if there was no campaign, this would be likely to make people believe that the issue was not critical). People were cynical about the media creating scare stories around environmental issues. The internet is most used as a source for environmental information by young people (73% of 18-24 year olds mentioned it, compared to 17% of those aged 55+ years) and people in higher socio-economic groups. Relatively few people mentioned their local Authority or Council, Energy Efficiency bodies, the Library or environmental charities/pressure groups as a source of advice (Sale Owen, 2005).

Retallack et al (2007) conducted an analysis of media messages about climate change, and their effects, and found that most coverage fell into one of three groups:

1. Media alarmism about climate change may imply that it is beyond human control, therefore discouraging individuals from making any changes to their own lifestyle.
2.
3. Sceptical messages that assume 'it'll be alright' suggest that there is no need for people to change their behaviour.
4.
5. Pragmatic messages that assume 'it'll be alright as long as we do something' are the least damaging. However, these tend to focus on the small things people can do to make a difference, which may lead people to doubt how such small, easy actions can achieve anything.

Barriers and Enablers

Barriers
Energy demand
Between 1990 and 2005, energy consumption rose by 40% in the household sector (Retallack et al, 2007).

Current housing trends such as smaller average household size and the formation rate of new households, along with inward migration and longer life expectancy, point to the need for more housing and consequently higher levels of CO_2 emissions in the domestic sector. It is estimated that an increase of 120,000 private sector and 26,000 social homes per year over present supply is needed (Barker, 2004).

Residential energy demand is still growing (Boardman, 2007). The Government report 'Building a Greener Future' notes that if existing lifestyle trends continue, such as the growth of home entertainment, large-screen televisions, more brightly illuminated homes and more consumer electronics, then domestic energy demand is likely to continue to increase accordingly (DCLG, 2006).

Sanders and Phillipson (2006) note that better insulation tends to result in higher internal temperatures rather than a reduction in energy use.

There is evidence to suggest that carbon dioxide emissions savings following the installation of highly efficient condensing gas boilers have been lower than expected because the householders do not understand how to operate the controls (Banfill and Peacock, 2007).

Some new household products use more energy than the items they replace, e.g. plasma TVs use 4.5 times more energy more energy than cathode ray tube TVs (Retallack et al, 2007).

Defra (2007) found that people cited the following reasons for not using energy saving light bulbs: they do not fit their light fittings (27%); they are replacing old bulbs as they go (14%); they have not got round to it yet (14%); the new bulbs are not as bright as ordinary bulbs (11%); and they are too expensive (9%).

Measures which rely on gas and electricity providers to take action to encourage consumers to reduce their energy demands may be difficult to put into practice, as it is not in energy suppliers' best interests to reduce demand for their product.

Gas and electricity are an example of an 'inelastic demand' in economics, in that consumers do not respond to an increase in price by using less. Over time, households have not changed their level of energy consumption very much in response to changes in prices (Hunt et al, 2003), and gas and electricity use has not fallen as a result of recent price increases (Retallack et al, 2007).

Costs associated with microgeneration

It is hard for consumers to compare the prices offered by different companies for selling electricity back to the grid. Consumers also need to consider how much electricity they will use and how this fits with the generation profile of the microgeneration unit, the costs of metering etc. It may take 20 years or more for microgeneration units to 'pay for themselves' (Ofgem, 2008). The 2008 Budget announced plans to provide information to consumers about this issue.

Controls, rewards, and incentives

Households do not pay for the wider costs of carbon emissions on society and future generations when they consume energy, except when energy prices reflect the wider costs of carbon due to current interventions such as EU Emissions Trading Scheme and Climate Change Levy (DCLG, 2006c).

Carbon taxing could worsen the problem of fuel poverty among the poorest households in the UK (Dresner and Ekins, 2006).

A report to Defra by the Policy Studies Institute (2007) reported that consumers are not in favour of environmental taxes, either because of opposition to government-led top-down initiatives or because they are suspicious of how the money will be used.

Consumers would need help, support or education to enable them to fully understand PCAs (or a similar system) and therefore be able to use them effectively (Fawcett, 2005).

Carbon offsets are usually indirect and it is difficult to verify or measure their effectiveness. Carbon offsetting has been criticised as a way for people to absolve their guilt about their lifestyle while carrying on with '*business as usual'* (Monbiot, 2006). The voluntary market for carbon offsets is not controlled or regulated. People more commonly associate carbon offsetting with one-off events such as aeroplane journeys, rather than everyday domestic energy use.

Dodds and Dobson (2008) found the following barriers to the take up of energy efficiency measures as part of a programme to address fuel poverty: lack of awareness of appropriate schemes; insufficient partnership working between the agencies involved; lack of trust in the schemes among householders; confusion over eligibility; and inapplicable property and tenure types (e.g. communal heating systems).

Changing behaviour

People feel that it is not their responsibility to take action, or that they alone cannot make a difference: 'The public clearly think that influence to limit climate change is directly liked to size – they as individuals have very little influence, but the Government and big business can have a major influence. In the groups, the international dimension was also very clear – the US, China and India are major contributors/polluters, so requiring international change' (Sale Owen, 2005, p10). Only 4% of research participants in the North East felt that they personally could have a large influence on climate change.

Apathy is a factor, with consumers openly admitting to 'their personal laziness, greed and disinclination to change' with regard to behaviours such as the use of cars and general lifestyle factors (Sale Owen, 2005, p11). The extra costs, effort, and inconvenience involved in making changes were seen as a key barrier. 'The suggestion that people should change their lifestyle, in particular car and flight usage, sparked considerable hostility from some' (Sale Owen, 2005, p12).

Defra (2008) describe the 'value action gap' - the gap between consumers' high level of concern about the environment and their actions.

'There are deep barriers relating to time and hassle, as well as initial costs, that hinder levels of uptake of insulation products'. (Defra, 2008, p30)

Defra (2008) lists the following common barriers to pro-environmental behaviours:

- External, practical limits such as infrastructure limitations, financial constraints, working patterns, or demands on time (1 in 3 people felt time was a barrier. 1 in 5 said it was only worth doing environmentally friendly things if it saved you money);
- Believing that changing will have a negative impact on current lifestyle (particularly time) and restrict current freedoms (particularly convenience);
- Habitual behaviour, apathy towards change and effort needed (1 in 3 felt the difficulty of changing habits was a barrier and about 1 in 5 agreed that effort was a barrier);
- Maintaining one's self-identity and negative perceptions of 'green' lifestyles and products (one-third felt being green is an alternative lifestyle not for the majority);
- Scepticism around the climate change debate and distrust of both government and industry (e.g. a quarter don't believe their behaviour contributes to climate change);
- Disempowerment – a sense that individuals cannot make a difference (one third said it was not worth Britain acting, as other countries would cancel its actions out. More than half claimed if government did more, they would too).

Defra (2008) identifies a number of barriers associated with different pro-environmental behaviours, as shown below:

Behaviour	Barriers
Install insulation products	• Lack of funding and promotion to overcome lack of interest/hassle
Better energy management and usage	• Habits hard to shift • Cost of intervention (e.g. audits) • Cost to household • Resistance to HIPs • Non-standardisation or accreditation across all household audits
Install domestic micro-generation through renewables	• Poor product performance/installation • Lack of funding • Planning and other admin restrictions
Increase recycling and segregation	• People think they do enough already • Consumer backlash against stronger measures • Lack of infrastructure (e.g. in flats)
More responsible water usage	• Fears of added costs, e.g. for large families • Feasibility of extending labelling in a coherent way
Buy energy efficient products	• Price • Demand for new (unlabelled) high energy consumption products

Disbelief
There is doubt and disbelief among some consumers that their actions are negatively affecting the environment (Ipsos MORI, 2007). In addition, *'the ongoing scientific debate is sometimes misunderstood by the public, or misrepresented in the media'* (Defra, 2008). The long term nature of environmental damage has led around one in five people to believe that the effects of climate change are too far into the future to worry them (Defra, 2007). There is also a lack of trust in the motives of government, local authorities and industry relating to pro-environmental behaviour (Policy Studies Institute, 2007). For instance, the government is suspected of 'using' the environment to increase general tax revenue; industry is perceived as having no reason to act unless environmental issues help them raise profits; and local authorities are seen to be asking people to do more themselves while not reflecting this in lower council taxes.

'There is also some disbelief about the scale of the actions people are being asked to undertake in relation to the magnitude of 'global climate change'. People do not believe these small actions will have a significant effect on tackling climate change: this may be because of the small scale of the activity, or suspicion of what happens down the line (e.g. recycling, with the mistrust partly fuelled by some media stories of recycling going to landfill)' (Defra, 2008).

Leadership
Only about a quarter of people think the government is doing a lot to tackle climate change. This lack of action has the effect of making people believe that the crisis is not that serious,

because if it was, then climate change would be the subject of major government spending and profile and government would be more pro-active in making businesses do more (Defra, 2007). Of the issues that people thought government should be dealing with, environment was the fourth most commonly mentioned in 2007 (unchanged from 2001), behind crime, health and education (Defra, 2007).

'Do as I do': The actions of the government (e.g. airport expansions and new road systems), high profile 'green' politicians, experts and celebrities (who are often frequent flyers with associated high carbon impacts) is seen to set a poor example for ordinary consumers. This is a particular problem in the light of the approach that if we all do small things, together we can make a difference. If others are not doing their bit, then why should we? (Defra, 2008)

Enablers

Controls, rewards, and incentives

Budget 2008 announced funding for the Green Homes Service, launched 1 April 2008. The service will help people improve the energy efficiency of their homes, choose lower emissions transport, reduce waste and conserve water. It will direct people to the practical steps they can take, and to the full range of support available. Budget 2008 pledged £26 million to the Green Homes Service in 2008-09 and there will be a Green Homes Forum in the autumn.

In the Pre-Budget Report 2006 the government announced a time limited Stamp Duty Land Tax exemption for new zero-carbon homes from 1 October 2007. Budget 2008 announced that the Government will extend the Stamp Duty Land Tax exemption to new flats, retrospectively from 1 October 2007, and will make changes to provide for government departments to charge a fee when assessing whether a dwelling meets the zero-carbon standard.

Personal Carbon Allowances will encourage consumers to take personal responsibility for their carbon emissions, so will be likely to ultimately lead to a greater understanding of the sources of carbon among consumers. People will be able to choose how they spend their credits, e.g. a balance between flying, driving and installing microgeneration (Fawcett, 2005). PCAs will act as an incentive to make sure that homes are as low carbon as possible for those consumers who wish to e.g. go on holidays abroad.

Changing behaviour

Sale Owen (2005) reported their findings that people in the North East were motivated to take action to reduce climate change by the following factors: simplicity, convenience, clear benefits (e.g. saving money), and understanding the climate problem. Saving money on energy bills was an important motivator for up to 70% of participants, while around one in five people cited each of the following reasons: *'for the sake of your children, grandchildren, and future generations'*; and *'to do your little bit/care for the environment'*.

Defra (2008) described the following common motivators for pro-environmental behaviours:

- Getting the 'feel good factor' or a sense of altruism and some social currency (cited by over 50% of research participants).
- To fit within current lifestyle and/or are expected by society (nearly 50%).
- Individual benefits e.g. improved health, lower financial outlay, alleviates guilt (over 50% said they sometimes felt guilty about harming the environment).
- Because it is easy to do (e.g. if facilitated through local authority schemes or grant funding).

- Because people understand why they are being asked to act and what difference their actions will make; people want to be 'part' of something.

Conclusions and Recommendations

The government needs to take action to help people to green their lifestyles: 'there is an expectation amongst consumers that government and business should take responsibility for helping people to close the gap between their values/concerns and their ability to act' (Defra, 2008, p48). The government can achieve this by working with manufacturers and retailers to make sure that people can buy the best products for a low carbon lifestyle, by setting a good example through its own actions, and by taking the initiative regarding collective action by government and industry (Defra, 2008).

Household environmental audits may have a role in helping people to change their behaviour (though this would probably be small and gradual changes rather than radical ones). One advantage of such audits is that they would involve personal contact, which may have a vital role in educating and encouraging people to use more sustainable behaviours (Defra, 2008).

Retallack et al (2007) suggest that a combination of interventions can be (and have previously been) successfully used to alter people's behaviour. These include:

- Providing people with convenient and affordable alternatives to their current behaviour;
- Asking them to make a public commitment to change – to raise their consciousness of the issue and give them a sense of responsibility;
- Giving feedback, support, face-to-face engagement and encourage group-level activity, to allow people to see the impact of their behaviour;
- Offering incentives, rewards, and penalties;
- Communication, in order to make behaviour changes seem socially desirable, and also to repeat the message consistently so that it gets embedded in people's thoughts and behaviours.

Retallack et al (2007) has drawn up a series of proposals to change consumer behaviour and therefore reduce the carbon emissions associated with domestic heating and hot water. These are summarised below:

- Raising people's understanding of carbon emissions and how they can be reduced (e.g. by the use of smart meters, feedback from energy companies, energy audits, and providing more information to consumers on energy efficiency and microgeneration);
- Improving the image of 'green' lifestyles through green home makeovers, celebrity endorsement, and product design competitions;
- Social proofing (normalising this type of behaviour) by ensuring Government departments, local authorities, public buildings, schools etc are adopting the desired behaviours;

- Setting attractive rewards (e.g. council tax rebates, fair price for energy bought back by energy suppliers from microgeneration units, and financial incentives to install microgen);
- Making measures more affordable;
- Ensuring group support and technical advice to householders;
- Providing convenience;
- Committing householders to change (e.g. by signing up to an agreement, or by requiring households to meet energy standards).

Defra has pointed to the need to encourage and support more sustainable behaviours among consumers through a combination of *'labelling, incentive and reward, infrastructure provision and capacity building (e.g. through information, education and skills)'* (Defra 2008, p21). Alongside this, Defra suggests that unsustainable behaviours can be discouraged via a mixture of: minimum standards; taxes, penalties and grants; and restrictions on consumer choice, including voluntary action by producers and retailers.

Defra (2008) has identified several areas of work that it will focus on over 2008 with regard to making people's behaviour more sustainable. Priority areas are: water efficiency in homes; the Act on CO2 campaign; personal carbon trading; product road maps (to highlight 'food miles'); and energy efficiency.

Defra is planning to establish a research centre to focus on pro-environmental behaviours. It is also planning to fund research into the social and economic costs and benefits of pro-environmental behaviours, amass further evidence in support of its segmentation model of consumer types, piloting and evaluating new initiatives, community-level interventions and innovative projects, and with the third sector in order to reach consumers (with the aim of both influencing their behaviour and receiving feedback about what is currently being done).

Potential future research directions in this area include:

- Monitoring and evaluating the effects of household energy audits, interactive smart meters and electricity display units on domestic energy use at household level;
- Research into the effects on households of having installed micro-generation technologies (e.g. residents' experiences of having the technology installed, using the technology, and perceptions of – and actual - financial costs and savings);
- Qualitative research into the experiences of people living in zero and low carbon homes, with regard to the impact this has on their lifestyles;
- Further exploration of the various 'enablers' for people's pro-environmental behaviours (e.g. incentives and rewards) and their effects;
- Further study of the relationships between social norms and energy use, building on the work of Shove (1997, 2004a and 2004b).

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Chapter Three: Supply chains: linking policy and practice in the construction industry

Paul Chan

Introduction

Contemporarily, one of the most ambitious aspirations of the UK government is the delivery of zero-carbon housing by 2016. The introduction of the Code for Sustainable Homes (DCLG, 2006), which is a voluntary standard built on BRE's EcoHomes system that seeks to improve the sustainability of new homes through a single framework for the housebuilding sector to design and construct to higher environmental standards, represents a significant development in this area. More recently, it was mandated that new homes, if assessed, will be rated according to this code (DCLG, 2008). The purpose of this paper is to explore the nature of supply chains in the industry and to examine the connections between policy and practice, in particular the appropriateness of existing design and construction processes in meeting the aspirations of zero carbon homes. A preliminary review of the literature reveals that the aspirations could potentially be threatened by a number of issues, namely the lack of prescription of methods and the confusion created by a plethora of policy guidance, and a lack of political will in regulating in this arena. Furthermore, from an operational perspective, supply chains for delivering the Zero Carbon Homes agenda are currently inadequate; skills shortages continue to thwart progress in this respect.

Innovation

Much of the literature on design and construction processes have been focussed on producing more efficient outcomes through better integration of stakeholders involved in the design, construction and even facilities management of the built environment (Gray and Hughes, 2001). Consequently, much work has concentrated on enabling the construction sector to increase profitability whilst delivering the requirements of various stakeholders, most notably the client. The central tenet of most design and construction processes has been about addressing the fragmentation of the industry, and developing a common language for various professionals to communicate more effectively with one another (Coles and Barritt 2000). Models such as the Generic Design and Construction Process Protocol, developed in the 1990s through collaboration between academia and industry, espouse to bring various professionals closer together, especially at the front-end of the design stage (Tzortzopoulos *et al.*, 2006), which is often constrained in such traditional approaches as the RIBA plan of works. In many respects, the adversarial nature of the sector has improved and integrated team-working (Latham, 1994) between designers and contractors are progressing. Hamza and Greenwood (2007) observed that the changes to Part L of the Building Regulations have resulted in the integration of services engineers at the early stages of the project as well.

Despite the sanguine outlook portrayed in the process literature, the integration of building users and facilities managers within the design and construction process remains elusive in practice. Tzortzopoulos *et al.* (2006) found that with new procurement routes that necessitate integrative working at the front-end of the design process, the involvement of facilities management can be disappointingly non-existent. Saxena and Hinnells (2006) proposed an alternative to supply relations when progressing with the Zero Carbon Agenda, as they suggested that housebuilders should contract out the entire energy infrastructure to energy service providers. Recent history of integrative working (e.g. in design and build, and more currently, on procurement implications in changes to Part L of the Building Regulations) indicates that there is usually a period of learning and acculturation of roles within such a framework. Therefore, the efficacy of such proposals would stand to be tested.

Even if the process is made adequate, existing tools to measure performance in the design process still excludes energy consumption measures in the discourse. In particular, two tools are presented here, namely the ADePT and Design Quality Indicators (DQI). The ADePT model, again, is largely about efficiency gains. "Once processes have been effectively captured and analysed, wasteful activities can be identified and removed; productive activities can be refined, honed and integrated; and through repeated implementation, significant process improvements can be achieved (ADePT, 2007; see Figure 2 below)."

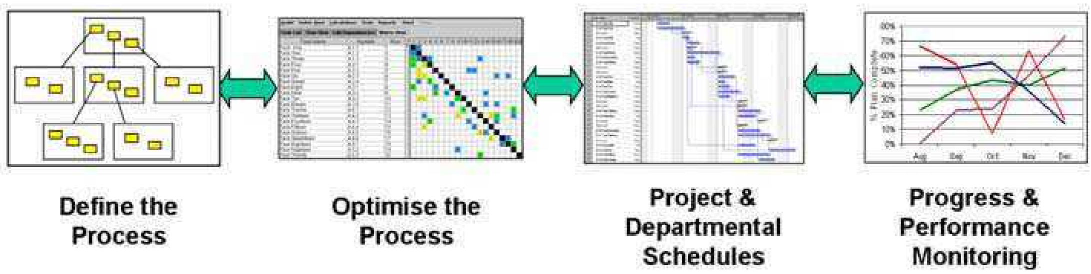

Figure 2: ADePT Model process

On the contrary, DQI is a tool that seeks to address not just functionality and built quality, but also impact on society (see Figure 3 below). The DQI model is constantly undergoing revisions, as the notion of value and impacts on society becomes better defined. Macmillan (2005) noted that there is a greater role to integrate intangible measures of value to society when discussing design quality.

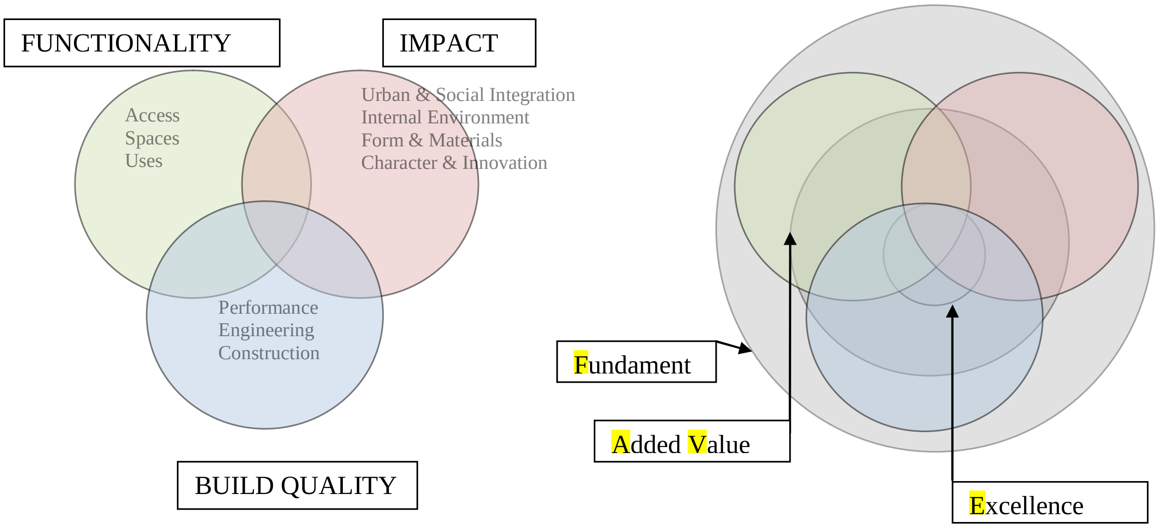

Figure 3: DQI Model

From the models briefly outlined above, it is clear that the consideration of sustainability is less dominant. Of course, the situation is improving with the inclusion of environmental measures in the Key Performance Indicators (KPIs) agenda, and through voluntary ratings such as BREEAM and the Code for Sustainable Homes. Nonetheless, this further demonstrates the plurality of performance measures that the sector has to work with. This perhaps account for the resultant pluralism in technical solutions available to deliver the Zero Carbon agenda.

Finally, in terms of build quality, there is the added issue of skills shortages to deliver the shortfall in housing that is needed (stemming from Barker, 2004), let alone Zero Carbon homes. The Callcutt (2007) review indicated that skills shortages could potentially thwart the progress of delivering the government's aspirations, as they mapped out the complexity of skills development in the sector. Indeed, this mirrors the issues raised by Chan and Moehler (2007) who argued that the landscape of organisations involved in skills development is too complicated for resolving the skills shortages problem. According to Callcutt (2007), there should be better coordination of skills development in delivering sustainable homes; currently the Academy for Sustainable Communities is responsible for this, although Callcutt (2007) suggested that the new Homes and Communities Agency should take charge of this.

Barriers and Enablers

The delivery of zero-carbon housing is one of the most recent aspirations of the UK government in the pursuit of greater energy efficiency and the Kyoto protocol targets (Lowe, 2007; Banfill and Peacock, 2007). The residential sector in the UK accounts for about 30% of the UK's total carbon emissions (Boardman *et al.*, 2005; Banfill and Peacock, 2007). Some commentators have argued that this aspiration stems from the fear that current levels of energy consumption are untenable, both in terms of economic viability and environmental responsibility.

Interestingly, Boardman *et al.* (2005) reported, "Contrary to experience in most countries, UK carbon emissions have fallen in recent years, being around a fifth lower in 2003 than in 1970 (p. 11)." Therefore, whilst reduction in carbon emissions is vital, curtailing of energy consumption is more important in the formulation of UK energy policy. Afterall, as Banfill and Peacock (2007) argued, one of the major impetus driving public policy and regulatory change in the UK is the security of energy sources to maintain projected energy-intensive lifestyles: "The proposals […] assume that existing lifestyle trends will continue, with the growth of home entertainment, large-screen televisions, more brightly illuminated homes and more consumer electronics, and that these must be catered for (p. 429)." Thus, this lends support to the argument that consumption growth is what drives public policy and that the attainment of strong sustainability, where the replenishment of natural resources is paramount, remains to be an elusive aspiration (Wackernagel *et al.*, 2004; Herring, 2006; Spash, 2007). It is therefore unsurprising that the Code for Sustainable Homes remains a voluntary standard since convincing the public to alter their energy consumption remains a sticky political issue that requires time for behavioural change.

Despite the boldness of the policy proposals (which are laudable), the reality appears disconnected. Schiller (2007) suggested that debates surrounding the contribution of construction towards sustainable development had hitherto been emphatically framed around the aspects of new buildings. Schiller (2007) maintained that attention needs to be given to the provision of urban infrastructure, which he argued is as resource-intensive as new-built projects, if policy-making were to derive a long-term view. What Schiller highlighted is the incompleteness of knowledge surrounding the construction industry's contribution to sustainable development (see also Meikle and Dickson, 2006). Furthermore, there are still debates as to whether the focus should be on individual homes or on communities (i.e. the eco-towns agenda). Progress to date has been made largely on the basis of individual homes, with a special emphasis on micro-generation and ad hoc inclusion of technology solutions. According to Shaw (2007), there is the potential that "eco-towns offer important opportunities to bring together environmental, economic and social sustainability [;…] to formulate and demonstrate robust planning in the face of climate change, providing a test-bed for different methods of delivering zero-carbon development that look beyond the individual home or building – important in achieving value for money and the most effective responses possible to climate change (p. 6)." He added, however, that this would necessitate a change in the planning system, both in terms of the planning process and leadership abilities of those who steer it: "planning must attract and retain high-calibre people not just with appropriate skills but also with an ability to look beyond the bounds of planning as an individual discipline. They must be able to see planning as an activity at the heart of delivering a sustainable future, and they must be able to inspire others to view it in the same way (p. 7)."

Whilst planning of new houses is of high political priority, there is also the issue of refurbishing and adapting the existing building stock, although current research is under way to address this[1]. Boardman and colleagues (2005) concluded, as part of the 40% house project, that there needs to be an increase in the demolition rate to 80,000 dwellings per annum across the UK, a rate last achieved in 1975. There are indeed concerns as to whether current industry's capacity can cope with such scale of demolition (Lowe, 2007). Similarly, Banfill and Peacock (2007), when critiquing the policy on zero-carbon housing, suggested that both institutional mechanisms and the industry's supply chain were currently inadequate to meet the proposed targets by 2016. Lowe (2007) was optimistically cautious: "The conversion of the UK house-building industry and supply chain to one capable of delivering 160,000 to 200,000 passive houses per year by the middle of the next decade will be an enormous task. If the UK is ultimately successful, it will have achieved more in the next seven years than Germany, where the standard has been developed, has achieved in the last 17 (p. 347)." To succeed, there needs to be political urgency and a strong will for implementation to milestones in a set timescale (Boardman *et al.*, 2007; see Callcutt, 2007 and Figure 1 below). However, recent experience of the changes to Part L of the building regulations that govern energy efficiency of buildings (Lowe, 2007; Hamza and Greenwood, 2007) and the vagaries of performance-based building regulations (Gann, 1998; Meacham *et al.*, 2005) suggests that success of political will remains to be seen.

[1] A collaborative project between E.On and Nottingham University seeks to rebuild a 1930s semi-detached house to identify what technological solutions need to be done to achieve zero carbon. There is also a research programme at Loughborough University examining adaptable buildings and the role of retrofitting.

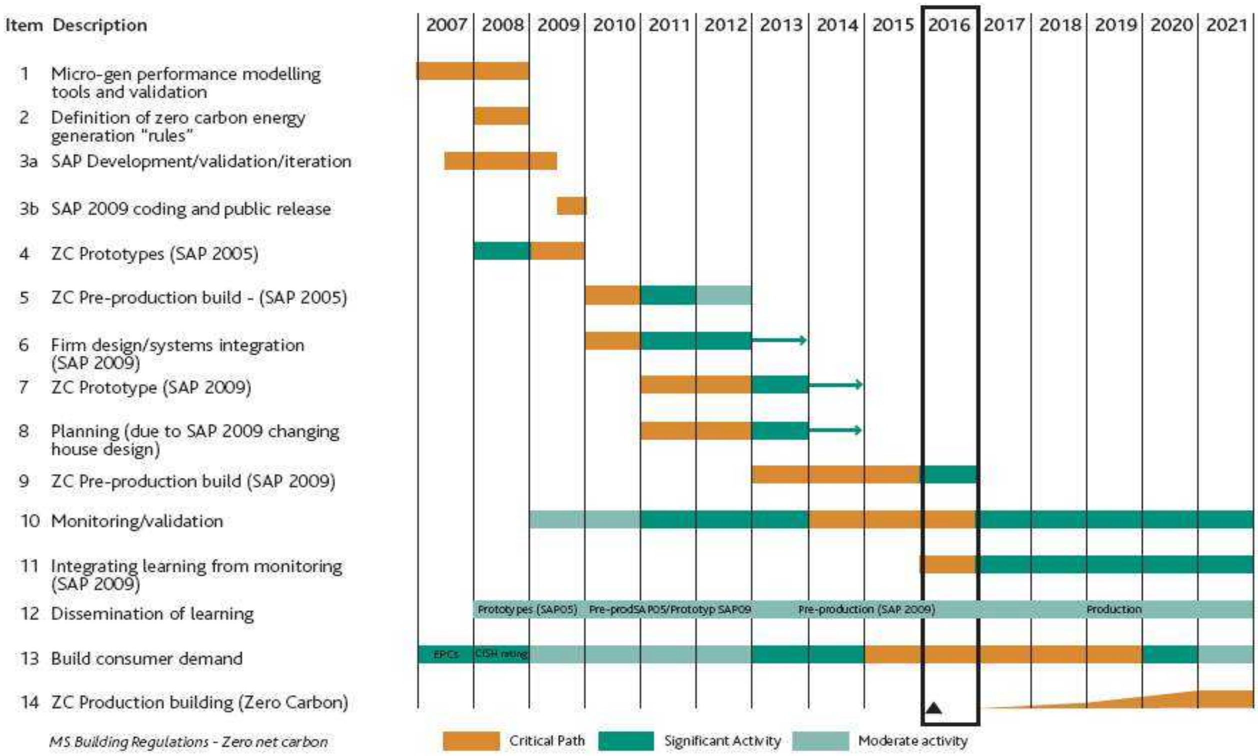

Figure 1. Roadmap to delivering Zero Carbon Homes by 2016 (Callcutt, 2007: 95)

Recently, the Callcutt (2007) review into the delivery of housebuilding in the UK drew from experiences with Modern Methods of Construction (MMC). Callcutt (2007) suggested that the benefits of MMC is somewhat well publicised in the sector and argued that there is greater readiness among designers, contractors and suppliers to embrace MMC. However, the lead-in time in the adoption of MMC goes to suggest that a similar lead-in time is required for the industry to learn and accept technologies that contribute to the Zero Carbon agenda. Evidently, there is still no definitive concept of what the agenda is about, and as Callcutt (2007) observed, until there is clarity in government policy and legislation in this area, the industry will remain reluctant to invest in such technologies if there is a general perception that policies/legislation would change.

In a sense, this resonates with Pett (2004), who argued: "there is a framework for sustainable housing although it is neither complete nor established. It is also more of a policy framework than a regulatory one, although some elements are prescribed and few are proscribed […] The Housing Corporation provides a comprehensive framework that […] now includes the promotion of local sustainable development strategies, local commitment to sustainable development in planning policy, as well as clarity in planning statements, even if this does not easily translate into 'what to do' on a technical basis. The technical approach is under consideration through the Code of Sustainable Building, and best practice networks such as Sustainable Homes that are available to spread knowledge for those that wish to know (p. 243-244)." Therefore, whilst the political rhetoric is strong, there is a lack of specific details as to how the rhetoric can be operationalised and political will.

If the challenge of political will is not enough, there is the battle to change the hearts and minds of consumers. As mentioned previously, consumption growth has been the underlying assumption driving public policy. Arguably, this somewhat pessimistic approach is due to the fact that the knowledge on current consumer behaviour regarding to the use of buildings from an energy perspective remains patchy (Chappells and Shove, 2004). Still, there is a growth on work in this area. Wood and Newborough (2003) investigated how the use of domestic appliances can lead to potential savings in energy. Pett and Guertler (2004) examined how people actually use energy efficient systems installed in their homes. And ongoing work at University College London (http://www.bartlett.ucl.ac.uk) should shed light on how occupant behaviour in relation to air-conditioning could impact on energy consumption. However, these studies captured a static snapshot of consumer behaviour through such techniques as surveys and interviews (Pett and Guertler, 2004) and controlled experiments (Wood and Newborough, 2003). More research needs to be done to examine consumer behaviour from a holistic and dynamic approach; and until such evidence is available, researchers can only rehearse the need for adjustments in taxation/incentives (Banfill and Peacock, 2007) and the education of consumers (Boardman et al., 2007) at an abstract level.

Conclusions and Recommendations

- The definition of sustainable homes and the specific knowledge in terms of how to achieve Zero Carbon Homes Agenda is currently incomplete. This results in a plethora of policy guidelines, with very little impact on practices and a lack of regulation/legislation in this area.
- Supply chains are currently not adequate to deliver the aspirations, simply because policies, legislation and regulation in this area are uncertain.
- There is a lead-in time for learning and accepting technologies that will lead to achievement of Zero Carbon Agenda.
- The Zero Carbon Agenda has not seeped into the discourse of design quality; currently ratings are purely voluntary and engages with ‘the enlightened’.
- Skills shortages potentially threaten progress in this area. There is also confusion in terms of which organisations (at the high level) should coordinate these efforts.

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Chapter Four: Supply Chains 2

Chika Udeaja

Introduction

There is now clear scientific proof indicating that emissions of greenhouse gases, particularly CO_2, are the main cause of climate change (DCLG, 2006). In construction, the industry faces ever-increasing problems in managing and dynamically responding to changes in the environment (climate changes) and the needs of their clients, particularly in the housing sector (Meikle, 2008). This area is given particular attention because of the Stern Review (2006) and other reports have shown that there is now overwhelming evidence that indicates that buildings consume over 45% of the UK's energy demand and generate approximately over 50% of greenhouse gas emissions.

The government understands the importance of these issues and have set targets and also recognises that it will require collaboration from all the stakeholders in the industry. Credible strategies together with determined implementation will also be needed if the set targets are to be met within the timescale. Furthermore, studies in this area have already acknowledged the climate change issue and, seemingly, have begun to tackle it by reducing energy demand through various initiatives as reported by (Luo *et al*., 2005; Abidin and Pasquire, 2007; Revell, 2007; Joseph and Hamilton, 2008 and Jensen and Gram-Hanssen, 2008). However, Srivastava (2007) identifies that various literatures covering green supply chain implementation have not been adequately developed. He argues that there is a growing need for integrating environmentally sound choices into supply chain management research and practice.

Recent reviews by various proponents in the industry suggest that the problems could be overcome by using more "collaborative" and "teamwork" approaches, with the intention being to add value to the chain. The major issue facing the construction industry is knowing what can be done, by whom, to improve the efficiency and effectiveness of the supply chain process. In the industry, some organizations have started to look at how the construction procurement is delivered to the customer as an integrated process rather than a number of independent transactions. To capture the full complexities of the procurement process and to obtain a more holistic view of the process, therefore, organizations are increasingly starting to consider the big picture of the whole supply chain. Reducing the carbon emissions of construction supply chain is therefore a major challenge in the context of sustainability but this has to be carefully balanced with the other sustainability issues, such as social, political and economic issues as it relates to the different stakeholders in the supply chain. The purpose of this review is to provide a context to the research issues relating to zero carbon homes from the perspective of supply chains. The review will argue for a more holistic approach, looking at the zero carbon issues from the perspective of sustainable development in the supply chain.

Supply chain concept

Conceptually the supply chain is not particularly well understood. However, it provides a useful mechanism for analysing the construction process (Ofori, 2000). In providing a topology of the supply chain concept, this research supports Harland (1996) and Handfield and Nichols (1999) contention that within the supply chain literature there is a confusing profusion of overlapping terminology and meanings. As a consequence, in the literature many labels can be found referring to supply chain as Value chain (Cox and Thompson, 1998), Supply Network (Harland, 1996), Supply Pipeline (Farmer and Ploos Von Amstel, 1991), Demand Chain (Blackwell and Blackwell, 1999), Logistics (Christopher, 1998) and more recently design chains (Austin *et al.*, 2001).

New (1997) argues that the idea of the supply chain owes much to the emergence from 1950s onwards of system theory, and the associated notion of holism. This may be summarized by the observation that the behaviour of a complex system cannot be understood completely by the segregated analysis of its constituent parts. In an increasingly complex and dynamic world, organizations are changing their ways of exchanging goods; they cooperate with other organizations rather than internalize and control their activities and resources through vertical integration, or buy and sell remotely through arms length procurement (Steven, 1991). In reality, the process is often characterized by horizontal relationships, therefore, links between organizations at the same level or tier. There may also be other relationships, such as customers and suppliers vice versa, and customers with direct access to second tier suppliers.

To capture the full complexities of the flow of goods and to obtain a more holistic view of the process, therefore, organizations are increasingly starting to consider the big picture of supply chain. Grounded in the illustration by Harland (1996) and other proponents in this area, this research defines a supply chain as:

"*A number of entities, interconnected for the primary purpose of supply of goods and services required by end customer."*

This definition implies that the entities are somehow interconnected; consequently, a supply chain is not merely a group or a cluster of entities. What characterizes a supply chain is that the entities are connected through transactions of goods and services.

Structure of the Construction Supply Chain

The traditional supply chain structure has shifted, transformed and extended itself into dynamic and ever-changing processes. The transformation transcends the physical boundaries of the whole enterprise and reaches into the global and rapidly evolving series of network (Harland, 1996). Apart from broadening the perspective from single supply chains to networks, which results in a more holistic and strategic view of the process of supply. The use of the term 'supply chain' can also be linked to the growing complexity of the process. There are a number of ways of structuring the supply chain; one of the most useful is a node and link model, with plots usually representing movement over distance and nodes representing places/organization where goods are stored or processed (DETR, 1998). It is an easy criticism to argue that the idea of supply chain structure is simplistic. This is because the process by which raw materials are turned into end products and services is rarely a simple linear process chain, and much more like a spaghetti or spider web of complex interconnecting relationships. To argue in this way is, however, to miss the point, as the supply chain structure is a powerful metaphor. It simplifies a complex and dynamic reality. Furthermore, it provides an understanding that there must be a complex interplay of business to business relationships within the process that links raw material manufacture with the end products and services that are created to energize business relationships.

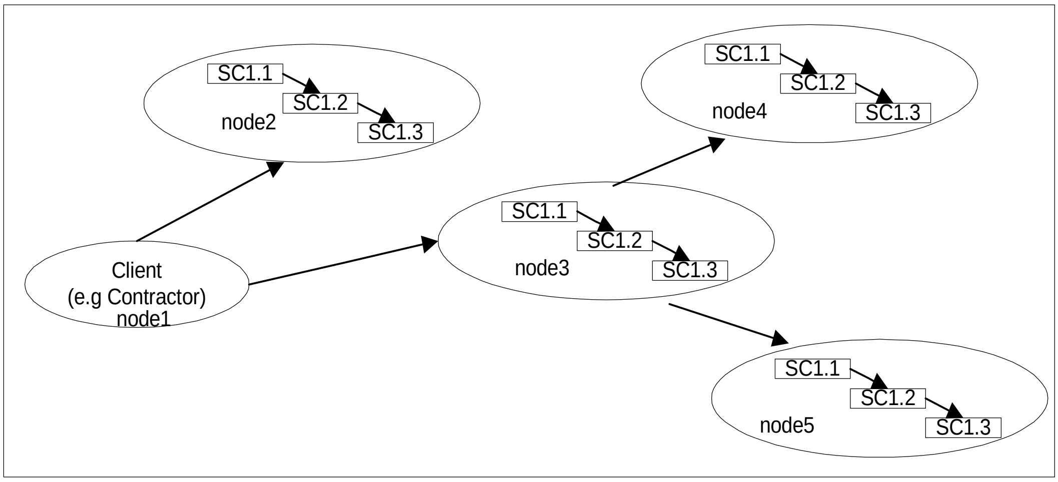

Figure 1: The Supply Chain Structure.

In the construction sector, the supply chains are extremely complex, particularly on a large project where the number of separate supplying organizations will run into hundreds, if not thousands (Elliman and Orange, 2000). Most organizations are simultaneously members of multiple supply chains. An organization in each chain typically offers a number of products and services, purchasing materials from a wide range of suppliers, and selling to multiple customers. From the perspective of a typical organization, each of its supply chains will have both internal and external linkages. Figure 1 displays the main elements of a typical construction supply network, with the main contractor at the center of the hub. There are links to the client, main supply agencies and to both design and any specialist management services, which are provided externally (Vrijhoef and Koskela, 2000). The illustration is a simplification of a real world network. Clearly, the principle supply organizations will also be dependent on many other organizations that provide raw material and component inputs to their production. Similarly, the main trade contractors will have their own supply chains and many of these will further subcontract out smaller work packages. The specialist construction subcontractors will usually be much smaller firms, small to medium size enterprises, and several of these may be providing labour-only services. The composition of the network will tend to be unique to a specific contract, although some favoured suppliers would be used repeatedly by any given main contractor (Briscoe *et al.,* 2001). The figure illustrates a supply chain structure via its production graph. Node 1 is the client enterprise, whereas nodes 2, 3, 4 and 5 are its suppliers.

Environmental Issues

Having discussed, albeit briefly, the evolution and concept of supply chain, the purpose of this section is to discuss the concept of zero carbon homes as it relates to the construction supply chain.

The theme of the Zero Carbon Home has become a much discussed subject (Boardman, 2007). A zero Carbon Home is one that generates as much energy as it uses over the course of a year and has a net zero carbon dioxide emissions (Wiedmann and Minx, 2007). Recent works in this area argue that zero carbon building will pay back the carbon invested in its construction through exporting zero carbon energy back into the national grids. In the context of a supply chain, Horvarth (2004) described carbon emissions as the use of renewable and non-renewable materials production and consumption; the energy needed to extract, transport and prepare them for further use; and the corresponding emissions, wastes and the potential for depletion of viable stocks. In a more recent discussion, Kibert

(2007) argues that the physical boundaries of carbon emissions are quite extensive. He proposes that it includes the extraction of materials, the manufacturing of products, the assembly of products into buildings, the maintenance and replacement of systems, and ultimately the building structure. He also includes the energy consumed during all phases of the product and building life cycle as one of the carbon emission issues. In this study, the carbon emission issues will be viewed from the perspective of the upstream and downstream of the construction supply chain and can be classified into three main headings as shown in Figure 2 (source reduction, waste elimination & embodied energy in building. Research in the source reduction and waste elimination are well documented under the sub-headings shown in the figure. However, the carbon emissions in embodied energy in building research are limited.

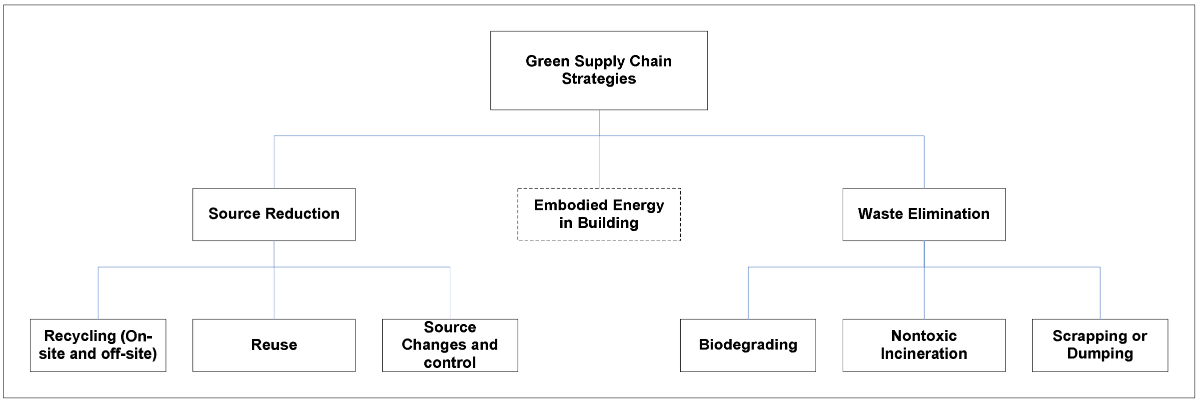

Figure 2: Classification of Green Supply Chain Strategies.

However, in order to address Zero Carbon Home issues in the construction supply chain, the various professions of the construction industry need to embed the principles in their day-to-day operations. In the light of existing processes, it is understood that a change in culture and other issues are required. The construction industry inevitably must address certain consequential issues in the process of achieving sustainable development, because it consumes a considerable amount of natural and physical resources and as such has a significant impact on the environment (Barrett et al., 1999). Thus, current and future procurement methods need to be altered to accommodate requirements for zero carbon Home Agenda. This procurement approach should ensure a better quality of life, not just now but for the future generations as well (Bourdeau, 1999). It should combine protection of the environment, sensible use of natural resources, economic growth and social progress.

Barriers and Enablers

Having introduced the concept of zero carbon in relation to construction supply chain, the following section of the review will report some related work in this area. The research projects cut across various disciplines and sectors including construction, manufacturing and other engineering areas and employs variety of strategies and concepts. Consequently, this section outlines a number of issues that has been applied in construction and other industry to make them more sustainable. The discussions are presented in Table 1 below.

While the list of related works in the area of sustainable construction in this review are not exhaustive, they do indicate the wide range of proliferation of research projects that should be considered in determining a more sustainable course of action for a zero-carbon home research.

Perceived Barriers to Change

From the literature, the potential barriers or resisting forces are well documented both in construction and other industries (Ofori, 2000; Abidin and Pasquire, 2007; Srivastava, 2007; Kibert, 2007 and Fawcett *et al*., 2008). As they have identified, the resisting forces to supply chain implementation come both from the nature of the organizations, the people that compose the organization. These barriers can be classified under one of the two supply chain issues: inter- and intra- organizational issues. However, the perceived barriers to change include:

High capital cost of carbon emission – because the industry already operate on low profit margin, it will be difficult to convince the various supply chain members to buy into the idea;

Lack of integration in the industry – construction remains a traditional environment (resistance/suspicion toward innovation in new materials/methods) will always be resisted by the industry because of fragmentation of the industry;

Resistance to change and mind-set of the industry – In material and component procurement particularly on housing sites, over-ordering is a common problem. As identified in the literature, it is a big issue and it is difficult to get people out of that mind-set;

The regulation at present are considered as a soft touch – Under the current regulation, the design team have been able to attain excellence by paying lip service to low energy design. This goes to prove that the current regulations are not tough enough to implement some of the key issues of zero carbon in the supply chain; and

Lack of knowledge and training in the part of project team – Evidently, there is serious lack of knowledge of the zero carbon issues in the supply chain as identified in the literature. Consequently there is no formal training mechanism in organization or learning from other industries on how to reduce carbon emission in the supply chain.

Author(s)	Focus of study	Triggers of sustainable procurement	Enablers
Walton et al (1998)	Furniture Industry	• Increasing government regulation & stronger public mandates • Lower cost & better service to customers	• Integrating suppliers into environmental management processes • Extending total quality management (TQM)
Ofori (2000)	Greening the construction supply chain in Singapore	• The increasing environmental consciousness & commitment of businesses, governments, groups & individuals	• Extending supply chain management
Preuss (2001)	Paper making, chemicals & electronics industry	• Compliance with legislation • Reducing materials costs	• Applying just-in-time supply techniques • Value analysis & joint design activities
Kashyap et al (2003)	Sustainability in construction projects through concurrent engineering	• This is mainly caused by the following: decreasing cost through standardisation, increasing demand & sophistication of clients and recommendations in UK-initiated reports	• Concurrent Engineering
Horman et al (2005)	Project delivery in Real Estate & Facilities division of Toyota motor sales	• Driven to deliver LEED gold rating • To identify instances of value and waste • To identify actions taken during project delivery that are critical to success	• Lean production
Luo et al (2005)	Prefabrication in Green Design-Build project	• Saving in Construction costs through improved production & productivity • Eliminating the waste & creating healthier environment through design & management	• Lean production • Standardisation of building components that leads to; shorten lead time, improved quality control & reduced material waste
Revell (2006)	SMEs in UK's Construction industry	• UK policymakers urging companies to undertake voluntary environmental measures	• Ecological modernisation policy strategies are driving the greening of SME's
Bae & Kim (2007)	Sustainable value on construction project	• Means of reducing initial costs & eliminating waste • Economic needs & value of the customers • Achieving "Triple bottom line" of environmental, social & financial performance for the strategic decision making	• Lean construction increases environmental benefits by eliminating waste, preventing pollution & maximizing the owner's value • The contract type & delivery method of a construction project indirectly effects the environmental issues (examples – Integrated product team & performance-based contracting
Srivastava (2007)	Green supply chain management	• The escalating deterioration of the environment – that is the diminishing raw materials resources, overflowing waste sites & increasing levels of pollution • It is about good business sense & higher profit • The regulatory requirements & consumer pressures	• Reverse logistics • Extension of the supply chain management to include environmental issues

Table 1: Some recent studies examining triggers & enablers of sustainable procurement

Conclusions and Recommendations

Some of the issues explored above cannot be considered immediate priorities, but this does not mean that they should be ignored. The choice of which issues to apply to a particular procurement stage, and the decision on the extent to which each chosen principles should be applied, reflects value judgments. Thus, the emphasis, therefore, should be on ensuring procurement which seeks to achieve consensus among interested parties on which issues are more and which are less important (Hill and Bowen, 1997). The UK construction supply chain aims to contribute to zero carbon homes by adopting new policies and practices, which have a more positive impact on economic, social and environment systems. Improvements are sought in all stages of the construction procurement process, such as land use, replenishment of natural resources, transport networks, construction processes, embodied energy of building whilst in use, social interaction and economic benefits for the whole supply chain.

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Chapter Five: Building Technologies for Adapting Existing Dwellings to Meet the Target of Zero Carbon Emissions: increasing thermal mass in lightweight buildings using PCM wall boards

Minnie Fraser

Introduction

As set out in DCLG document "Review of the Sustainability of Existing Buildings – the energy efficiency of dwellings – initial analysis" (November 2006):

"With Government's commitment to increase housing supply, around two-thirds of homes standing in 2050 are likely to have been built before 2005. New build represents only approximately 1% of the total stock each year. Building Regulations have raised energy efficiency standards of new homes significantly in recent years – current (April 2006) standards are 40% higher than for properties built in 2002; 70% more than in 1990. So most of the existing stock, and a significant proportion of those that will still exist in 2050, were constructed to lower, often much lower, standards than new build today. The existing stock, therefore, accounts for the great majority of carbon emissions from dwellings, both in terms of their lower energy efficiency and their numbers."

There is a clear need for measures to improve the carbon emissions from existing dwellings in order to achieve the Government's targets over the coming years. There are various methods of improving the thermal performance of the fabric of a building in order to improve energy efficiency, including the following measures:

- Thermal insulation retro-fitted to roofs, walls (internally, externally or within cavities) and floors.
- Glazing in the form of double or triple glazing in replacement windows and doors including the use of low emissivity glass and specialised coatings.
- Phase change material (PCM) drywall lining installed to lightweight buildings to improve their thermal mass.

Due to the limited amount of time available for the current research, it was decided to focus on the use of PCM drywall lining as the number of lightweight houses being constructed is increasing and the PCM dry lining products have only come onto the market very recently. There has been a significant increase in the quantity of timber framed housing being built in the UK over the past few years. UK Timber Frame Association (UKTFA) figures show that timber frame market share of new build housing has risen from 10.1% in 1999 to 20.5% in 2006 and that more than 51,700 timber framed houses and commercial units were built in 2006 (UKTFA, 2007). There has also been an increase in lightweight steel framed housing; particularly those constructed using modern methods of construction including off-site manufactured panellised or modular systems.

Timber frame is considered to be sustainable and environmentally friendly as the structure has a low embodied energy and comes from renewable sources and as such its use has been encouraged. However, these types of construction are considerably more lightweight than modern traditional built brick and block housing and although newly constructed housing is well insulated, internal temperatures can fluctuate. This can lead to a lack of thermal comfort, particularly in summer; resulting in increased use of electricity for comfort cooling in the form of electric fans or air conditioning.

As a result of climate change, there is considerable and growing interest in methods for reducing carbon emissions in the built environment. Research into the use of PCMs as thermal storage has been ongoing for several decades for applications such as storage of solar thermal energy for power generation, solar water heating and thermal storage for heat pumps among others. Recently there has been a renewed interest in the use of PCMs as thermal buffers to promote energy efficiency and occupier comfort in buildings.

Innovation

The significance of thermal mass

Thermal mass is, in simple terms, the ability of a material to store heat; this ability depends on the density, specific heat capacity and thermal conductivity of the material. In buildings, materials such as concrete and masonry are good providers of thermal mass; these materials absorb heat from the air as the ambient temperature rises and release heat into the air as the ambient temperature falls. The thermal mass acts as a buffer so that temperatures inside the building rise and fall more slowly than external temperatures and maximum and minimum temperatures are less extreme. This reduces the amount of heating and cooling required and therefore reduces fuel consumption. To be effective the surface of the material must be sufficiently exposed to allow heat transfer. The greater the amount of these materials that are exposed to the internal environment in a building, the greater the benefits in thermal mass. Hence one of the most comfortable places on a hot day is a cathedral with its thick exposed stone walls. Dry lining and suspended ceilings separate the thermal mass from the internal atmosphere of the building considerably reducing the beneficial effect.

The value of thermal mass in dwellings has been demonstrated by Hacker et al (2008) who carried out a study using computer modelling of a typical two bedroom semi detached house with four levels of thermal mass as follows:

1. Lightweight – timber frame with brickwork external skin

2. Mediumweight - traditional brick and block exterior wall, with lightweight timber upper floor and partitions and dry lining throughout.

3. Medium-heavy - as mediumweight but with blockwork partitions and precast concrete hollow-core upper floor with dry lining throughout.

4. Heavy - dense concrete block inner leaf and partitions, with precast concrete hollow-core upper floor and first floor ceiling. Fair faced finish to inner leaf and partitions as well as stone tiles to the solid concrete ground floor.

The most lightweight version of the house is typical modern timber frame construction and the medium weight version is currently the most common form of new-build house construction. The medium-heavy weight house is less common and the heavyweight house is not typical.

The four variants of the house were modelled to be identical apart from the parts of the construction contributing the thermal mass and the model included occupancy of two adults and a small child over a projected lifecycle of 100 years. The climate for the 100 year period was modelled for climate change using data from the UKCIP02 medium-high emissions scenario Tyndall Centre for Climate Change Research at UEA (Hulme et al, 2002; cited by Hacker et al, 2008).

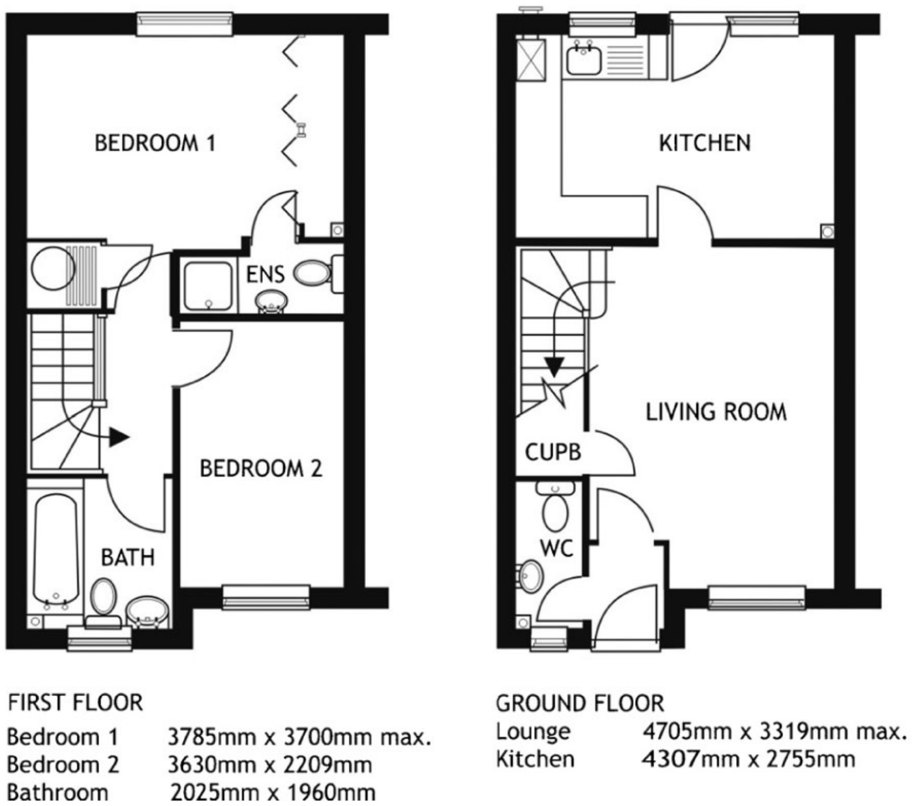

Figure 1: The Case Study House (Hacker et al, 2008).

The study found that the heavier weight cases all showed reduced operational CO_2 emissions. The largest benefits were found for the heaviest weight considered over the lifetime of the building which included savings in air conditioning which was installed in the model following overheating in 3 consecutive years. The initial carbon emissions (ECO_2) was greater in all the heavier weight cases, but by a relatively small amount in the context of the total lifecycle emissions. No clear “optimum” weight was found, with the heaviest weight case showing best performance over the 100 year lifecycle. (Hacker et al, 2008)

A similar exercise was carried out for 13 different building scenarios including offices and schools as well as dwellings in London, Manchester and Edinburgh in research carried out for CIBSE (CIBSE, 2005). This showed similar benefits of thermal mass, but demonstrated the importance of sufficient ventilation to prevent build up of heat over time in summer causing heavyweight elements to lose their passive cooling potential.

Holford and Wood (2007) also show the benefits of thermal mass in buildings and how it can be exploited in naturally ventilated buildings to achieve energy efficiency. They review other research into the subject including several case studies before assessing the factors that limit thermal buffering and describing their mathematical model for predicting the effects.

Guidance for designers and other professionals is provided by the BRE in digests 454 parts 1 and 2 (2001) on thermal mass in office buildings and also Information Paper IP6/01 *Modelling the performance of thermal mass* (2001). Although these publications are aimed at the design of offices, much of the information is also applicable to dwellings.

Phase Change Materials (PCMs)
Thermal mass as described above requires dense materials with sufficient specific heat capacity and conductivity to store sensible heat. Clearly, it is not practicable to install large amounts of concrete or masonry into existing lightweight buildings in order to improve their thermal mass; the solution to this problem would need to be unobtrusive and easy to install. Much research has been done in recent years into the possibility of using PCMs to store latent heat and improve the thermal mass of lightweight buildings.

Kuznik et al (2008) give a good explanation of how PCMs store and release latent heat:

"An interesting feature is that they can store latent heat energy, as well as sensible energy. As the temperature increases, the material changes phase from a solid to a liquid. As this physical reaction is endothermic, the PCM absorbs heat. Similarly, when the temperature decreases, the material changes from a liquid to a solid. As this reaction is exothermic, the PCM releases heat."

There is a wide variety of applications that may potentially use PCMs for latent heat storage and as a result, a great amount of research has been carried out over the years. Zalba et al (2003) review research into many applications including solar power plants; thermal protection of food; thermal comfort in vehicles, engine cooling and spacecraft thermal systems.

There is also a variety of materials that can be used as PCMs depending on the application. Sharma et al (2008) classify PCMs into organic, inorganic and eutectic materials. Voelker et al (2008) identify paraffins (organic) and salt hydrates (inorganic) as being suitable for use in building materials for thermal buffering.

Review of the Research
As previously mentioned, there has been a considerable amount of research done in this area over the years. This study is limited to recent research carried out from 2000 to the present concerning building materials that can be used to upgrade the thermal performance of existing lightweight buildings. The research generally falls into three categories – literature reviews, research using theoretical models and research using experimental data. Some of the papers reviewed cover two or all three categories.

Zalba et al (2003) give an idea of the scale of the available literature on PCMs for thermal energy storage generally, listing over 230 references. Sharma et al (2008) is also a general review of PCM materials and applications but includes a substantial review of building applications. Khudair & Farid (2004) and Pasupathy et al (2008) limit their review to PCMs used for energy conservation in building applications which include use in concrete blocks, plasters solar and under floor heating and PCM filled double glazed windows as well as in wallboards.

Suitable PCM Materials
Khudair & Farid (2004) explain that PCMs suitable for building applications should have a high heat of fusion, good thermal conductivity, high specific heat capacity, small volume change, be non corrosive, non-toxic, exhibit little or no decomposition or supercooling and have a phase transition close to human comfort temperature. They also list 9 potentially

suitable materials including hydrated salts, paraffins and fatty acids. Pasupathy et al (2008) describe the development of PCMs for heating and cooling of buildings explaining that salt hydrates are cheap and abundantly available, but they have several disadvantages and that researchers now label them “limited utility PCMs”. Farid et al (2004) state that salt hydrates are “corrosive to most metals and suffer from decomposition and supercooling, which can affect their phase change properties”. However, despite these problems, there is one product using salt hydrates as PCM that has recently come onto the market, “Delta-cool 24” manufactured by Dörken GmbH & Co. KG. Paraffin waxes seem to be the PCM of choice for those researching PCM wallboards as although they are more expensive than salt hydrates, they are more stable, non-corrosive and do not have problems with supercooling.

Encapsulation
Although the theory of PCMs storing latent heat as temperatures rise and releasing it as temperatures fall is very promising, the research done over the years has not resulted in commercially viable products until relatively recently. Schossig et al (2005) explain that since the 1970s several researchers have tried incorporating PCMs into building materials by immersion processes or macro-capsules. Where PCMs were not encapsulated, there were problems of leakage and interaction between the PCM and the matrix material. Macro-capsules had several disadvantages including the necessity to protect them from damage, the work required on site, the expense of incorporating them into a building and inefficient heat transfer. This last problem is explained well by Pasupathy et al (2008): “*When it was time to regain the heat from the liquid phase, the PCM solidified around the edges and prevented effective heat transfer*”.

Khudair et al (2004) and Pasupathy et al (2008) both review research which shows the beneficial effects of micro-encapsulation of paraffin waxes for use in building products. Micro-encapsulation is where small spherical or rod-shaped particles are enclosed in a thin polymeric film. The very small size of these capsules overcomes the problems of inefficient heat transfer. These micro-capsules can be incorporated simply and economically into construction materials (Pasupathy et al, 2008). Khudair & Farid (2004) cite research by Hawlader, Uddin & Zhu (2002) showing the resilience of the microcapsules and also research by Hawlader, Uddin & Khin (2002) demonstrating that they have high energy storage and release capacity.

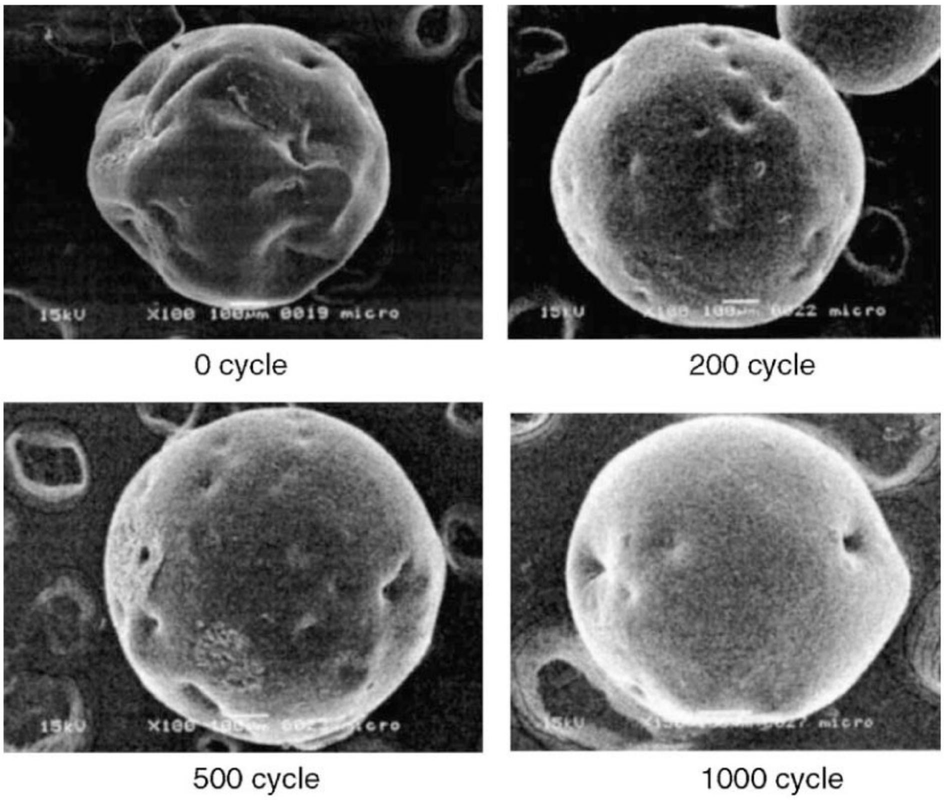

Figure 2: Microencapsulated paraffin profile evaluated by scanning electron microscope at different thermal cycles (Hawlander, Uddin & Zhu, 2002, cited by Khudair & Farid, 2004)

PCM Plaster and Wallboards

Various researchers have carried out theoretical and experimental analysis of PCMs for use in walls. Darkwa (1999) and Neeper (2000) analyse numerical models that indicate benefits but require experimental validation. Darkwa & Kim (2005) tested and compared gypsum plasterboard with randomly distributed microencapsulated paraffin PCM with a laminated board and found the laminated board to perform significantly better. Carbonari et al (2006) developed a theoretical model which was then experimentally validated for PCM sandwich panels for use in prefabricated buildings. The PCM used was eutectic salts, sealed into rigid plastic containers and inserted into sandwich panels. They found that their model was accurate and the PCM panels performed well.

Schossig et al (2005) undertook a project over 5 years funded by the German government, which is probably the most comprehensive study undertaken so far. Initially, they simulated the thermal performance of a typical lightweight office using a numerical model with PCM mixed with the interior plaster. Samples of plaster were then tested under various conditions to validate the model.

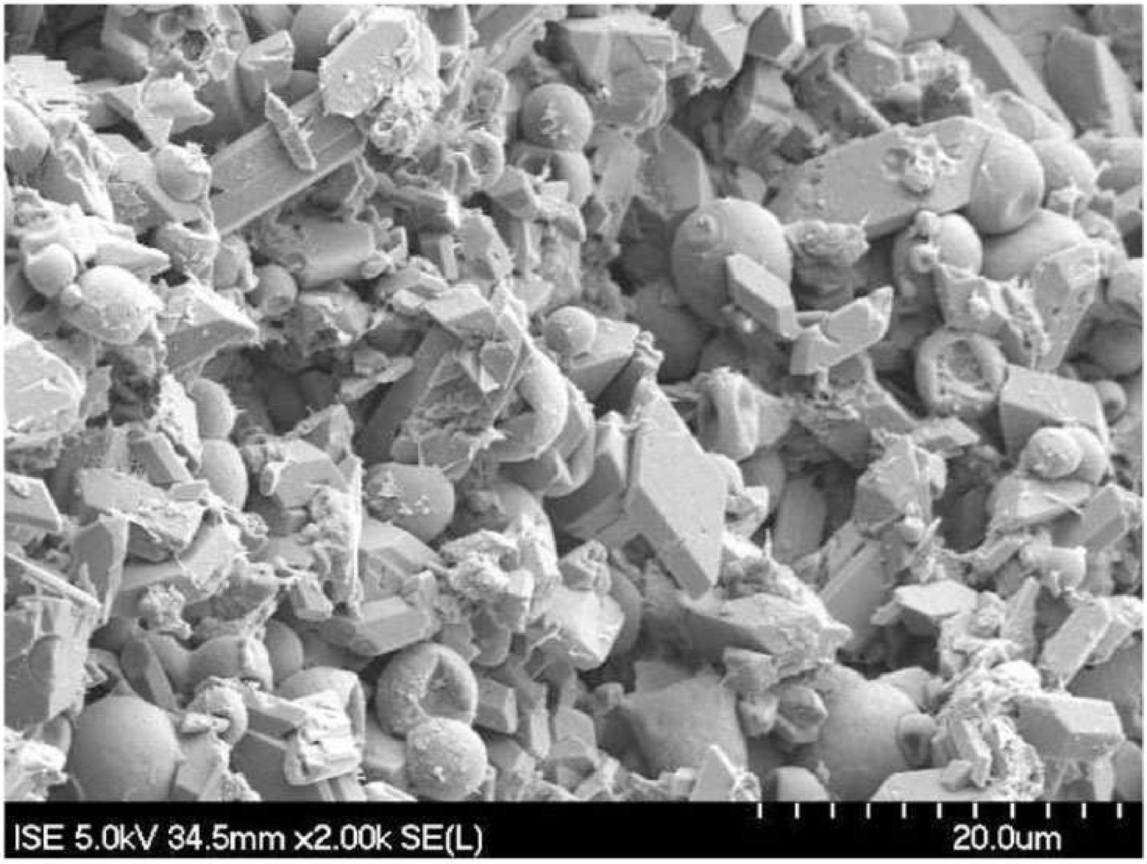

Figure 3: Scanning electron microscope image of PCM micro-capsules in gypsum plaster (Schossig et al, 2005).

Then unlike most of the other researchers who have carried out similar work, they tested the material in full sized offices. Unfortunately, when real offices were tested, it was not possible to make adequate comparisons because of the different behaviour of the occupants, so they built 2 full sized test rooms with lightweight construction for test and control as shown in figure 4. They tested 2 different PCM products each for a period of a year with identical conditions in the PCM and control rooms.

Figure 4: Fraunhofer ISE façade testing facility. The test offices are the two rooms at the left hand end of the building (Schossig et al, 2005).

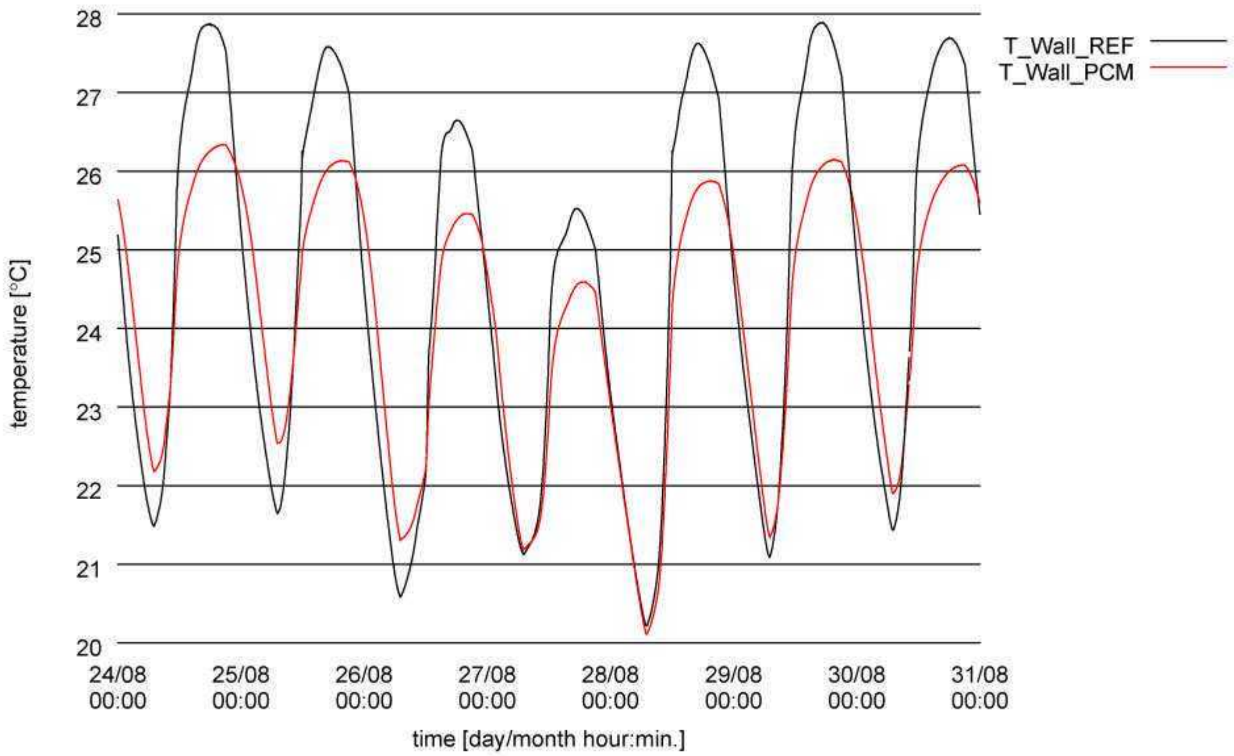

Figure 5: Results from the testing by Schossig et al (2005) showing difference between test room with PCM plaster (red) and with non-PCM plaster (black). The lines indicated wall temperatures in the two test rooms with night ventilation and solar shading. The number of hours above 26°C in the PCM room is significantly reduced. An interesting result is that during one 3 week period during the project, the temperature in the non-PCM test room exceeded 28°C for more than 50 hours, whereas the temperature in the PCM room was only above 28°C for about 5 hours.

Schossig et al (2005) found that microencapsulated PCMs have the advantages of easy application, good heat transfer and no need for protection against destruction. The results showed potential for reduced cooling demand and increased thermal comfort in lightweight buildings. However, they stressed the importance of sufficient night ventilation to ensure the stored heat is fully discharged over night. They do not state what the PCM material is although it implied that it is a paraffin and they do give the melting range of 24 - 26°C.

Voelker et al (2008) carried out an investigation with two test rooms and investigated microencapsulated paraffin PCM incorporated into wall plaster and later the addition of tubes below ceiling level filled with salt hydrate PCM. Both PCMs were found to be effective, however their beneficial effects were negated after a few hot days when the heat was not fully discharged over night. They contend that this can be avoided by effective night ventilation.

Kuznik, Virgone & Noel (2008) tested a sample of material produced by DuPont de Nemours (presumed to be DuPont *Energain*) and using a numerical model and specially adapted software called CODYMUR, investigated the optimal thickness of the wallboard material. The wallboard was a flexible sheet containing 60% microencapsulated paraffin PCM and their reference case consisted of a single wall consisting of timber, insulation PCM board and plaster facing. They found that the optimal thickness for this PCM material is 10mm.

Kuznik, Virgone & Roux (2008) investigated the efficacy of the same wallboard material using an experimental test room with simulated summer conditions including solar simulator consisting of spotlights shining through a glazed façade. The other 3 walls of the room had walls with PCM behind plaster (control without PCM). The construction of the test room walls is shown in Figure 6.

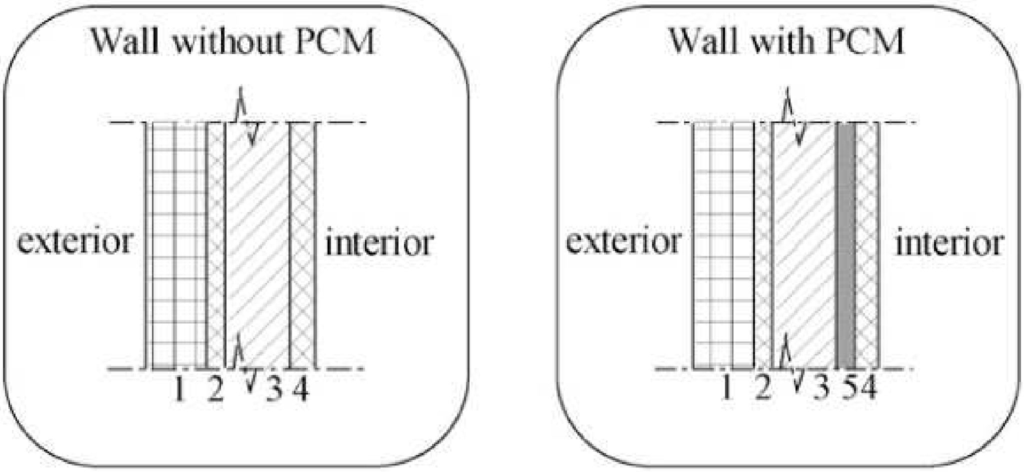

Figure 6: Wall compositions in Kuznik, Virgone & Roux's experimental test rooms. 1 – 50mm wood plate; 2 – 10mm plaster; 3 – 50mm polystyrene; 4 – 13mm plaster and 5 – 5mm PCM

They found that the air temperature fluctuated between 18.9°C and 36.9°C in the control and 19.8°C and 32.8°C in the PCM room. So temperature fluctuations were reduced by 4.7°C in the PCM room.

In every case reviewed, testing has demonstrated that PCM materials can provide thermal buffering. The research has been directed to reducing cooling load and increasing thermal comfort in summer. This is obviously an important benefit, particularly to lightweight framed housing where overheating in summer is likely to be a major problem. However, there is a lack of data to show whether any significant savings can be made to heating costs in winter. Research by Pasupathy & Velraj (2008) indicates benefits of a double layer of PCM materials in a building roof where two layers of PCMs have melting points 6-7°C apart. This helps thermal buffering performance all year round in different climatic conditions. However, this research was focussed on the climate in India, which is very different to the UK.

Engagement

Although research into the performance of PCM wall linings has been ongoing for many years in various countries, the results have not been encouraging enough for products to be produced commercially until recently. BASF Construction Chemicals introduced "*Micronal*" microcapsules of wax PCM in 2004 for use in the manufacturing of building products such as plasterboards or floor screeds (BASF, 2004) and this product was incorporated into a commercially available plasterboard for the first time in 2005 (BASF, 2005) it is also available in a wet applied gypsum plaster called "*Maxit Clima*". BASF claim that "*a 3cm layer of Maxit Clima plaster corresponds approximately to the thermal mass of an 8 cm-thick concrete wall, a 13 cm-thick plasterboard, or a 29 cm-thick lightweight brick wall*". Schossig et al (2005) state that a commercially available product has been installed into two office buildings shown in figure 7 – this is presumed to be *Maxit Clima* as the pictures are acknowledged to "Maxit".

Figure 7: Office buildings in Germany where PCM plaster has been installed (Schossig et al, 2005 “Source: Maxit”).

DuPont launched a board product (Energain) in December 2006 also containing paraffin wax (Kucharek, 2007) although this product comes in the form of aluminium laminated panels that are installed behind plasterboard dry lining rather than having PCMs within the plasterboard itself.

There is also a salt hydrate product available called “Delta-cool 24” which comes in various forms of macroencapsulation including pouches that sit on top of suspended ceiling tiles, translucent panels and dimple sheets for use in underfloor heating systems.

Figure 8: Delta-cool 24 comes in various forms of encapsulation (Dörken, Delta-Cool 24 brochure, no date).

From the research reviewed here, it is not possible to say whether the development of commercially available products is due to the innovations in technology such as micro-encapsulation of PCMs suitable for incorporating into wallboards or whether it is due to the social and economic influences of carbon emissions and climate change.

The testing of these products and the case studies shown on the manufacturers' websites are all in Germany and France, where the summer temperatures tend to be higher than in the UK.

Barriers and Enablers

As with many innovative materials, PCM wall and ceiling linings are expensive and this is probably a major barrier to their use at present. Kucharek (2007) quotes Marco Schmidt of BASF admitting that their plasterboard lining is 10 times more expensive than ordinary plasterboard. Clearly, this would be a significant cost to upgrade a building were it to be retrofitted. Another barrier is that despite the wealth of academic research and testing of PCM materials, there have not yet been many buildings in use that have demonstrably benefitted from it and many clients are averse to taking the risk or being "guinea pigs" for new and apparently untried technology.

The manufacturers of the materials have persuasive examples on their websites and in their product literature of how thermal mass can be improved and energy costs reduced. However, prospective users would have to look at the websites or access the product literature to see this information. A question remains as to whether potential users of this technology are likely to be directed to the information. As an example, there is no advice on the use of PCM technology to improve thermal mass on the Energy Saving Trust website, including their pages for housing professionals (http://www.energysavingtrust.org.uk/). Clearly, lack of knowledge of the technology would be a barrier to its use and further research is needed to investigate industry knowledge and how to improve dissemination of information.

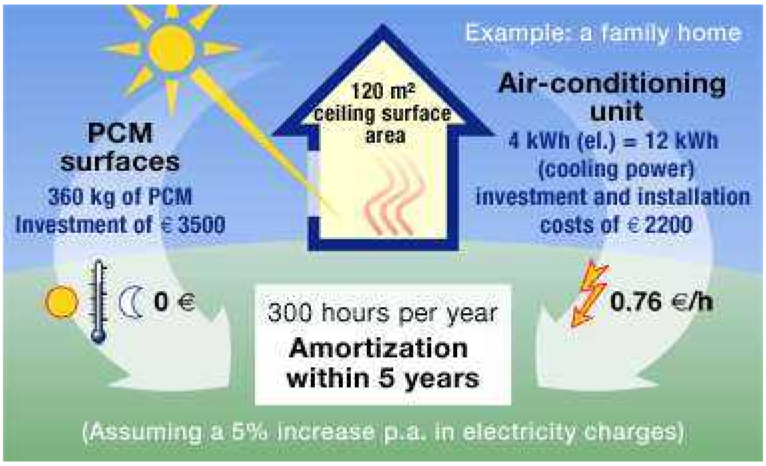

Figure 9: Illustration from Micronal PCM Smartboard product literature and BASF website (BASF, no date)

DuPont give details of testing of their *Energain* boards on their website (DuPont, 2008). This testing involved two test rooms, one with the product and one without, tested over 3 seasons in France in association with EDF France (Electricité de France). They claim that this was a "*unique real-life test – the longest and most scientific test ever conducted with a phase change material".* However, this claim would be difficult to substantiate as Schossig et al

(2005) carried out extensive testing of 2 PCM materials for a full year each as part of a 5 year study in Germany. DuPont's research does not seem to have been published in any academic journals although it does bear some resemblance to the research carried out by Kuznik, Virgone & Roux (2008). The publication of information relating to this research on the website may be helpful in influencing people to install the product in their homes, but attitudinal research would be required to verify this.

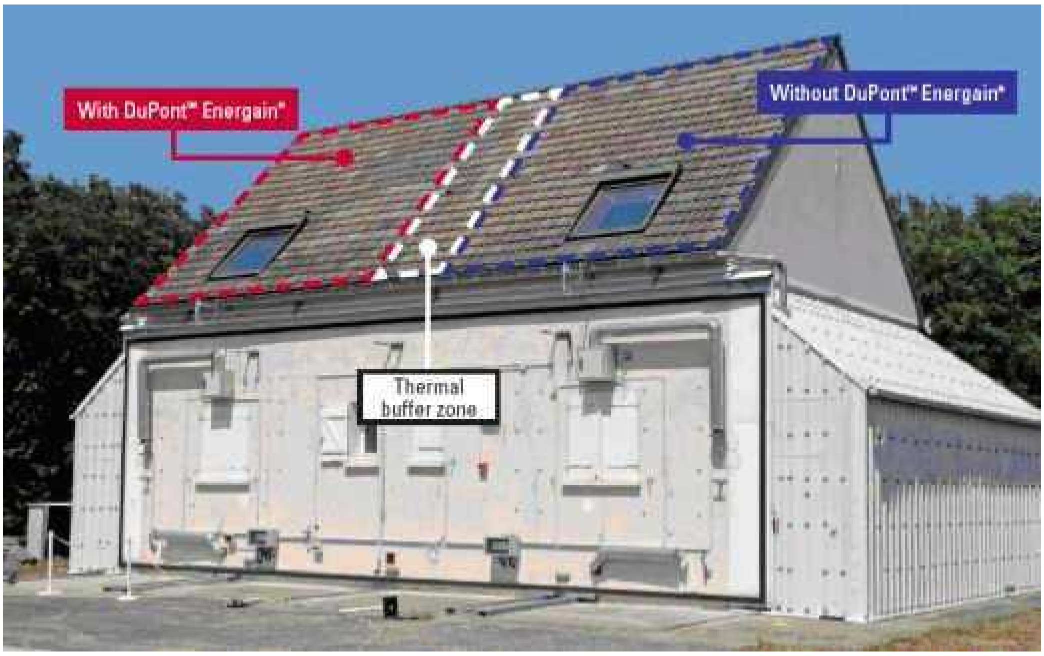

Figure 10: DuPont's test house in France (DuPont, 2008)

The provision of software models to help designers predict the benefits of using PCM materials and the requirements for heating and cooling in a building containing these materials will also encourage their use. Several of the researchers have developed models that have been validated through testing and Kuznik, Virgone & Noel used a software called "*CODYMUR*" and found it to be effective. DuPont are now marketing the software "*CoDyBa*" for use with their *Energain* product, which may be helpful in encouraging uptake.

At present the major barrier to uptake of this technology in the UK is the lack of knowledge of the products and their benefits and the lack of availability of the products* to be verified.

Conclusions and Recommendations

Much research has been carried out over the years into the use of PCMs to increase the thermal inertia of lightweight buildings; recently research has shown the potential benefits of PCM wall boards using microencapsulated paraffins. Some research has also shown potential benefits of salt hydrate PCMs. It is clear that these materials can be effective in increasing energy efficiency, particularly by reducing cooling loads in summer, providing sufficient ventilation is afforded at night to allow the heat built up during the day to fully discharge overnight.

Numerical models and software have been developed that can be useful to designers in predicting the performance of the materials in use and these may help to influence their uptake.

Although the aim of these materials is to provide benefits in the form of reduced energy consumption, reduced carbon emissions and improved thermal comfort, it would appear that there is very little guidance to inform people or influence their decisions to use the products, other than marketing by the manufacturers of the products.

The following recommendations are made:

- Further research including large scale case studies of buildings in use, their energy consumption and thermal comfort of occupants.
- Research on existing lightweight buildings and attitudes of their owners towards upgrading thermal mass.
- Research into the likely savings in UK dwellings for heating as well as cooling.
- Improvement in the advice available to homeowners and RSLs regarding PCM products available and their benefits.
- Availability of PCM products in the UK.

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Chapter 5: Conclusions and future research priorities

As described in the introduction to the report, the aim of the project was to examine, in a systematic and holistic way, the critical issues, drivers and barriers to building and adapting houses to meet zero carbon targets. The project involved a wide range of subject specialisms within the built environment and took a multi-disciplinary approach.

The focus of the work was to review the academic and policy literature on the built environment sector and its capabilities to meet zero carbon housing targets. It was not possible within the resource limitations and timescale (6 months) to undertake a detailed review of energy efficiency or micro-generation technologies, and the focus of the research was instead in four focussed areas: policy and regulations, behaviour, supply chain and technology.

Barriers/enablers identified as key issues by workshop delegates

A number of barriers and enablers were identified in the mini-reviews, and these were categorised into 4 areas: policy, behaviour, technology and supply chains. These were then presented at the practitioner workshop for further discussion and feedback (see appendix 3 of this report). The key issues emerging from all the group sessions were the problems of cost of the technologies and payback periods; the importance of financial incentives, both from a behavioural perspective and for the further development of technologies; the need for development of appropriate skills and training in this area, and, linked to this, the role of the regional development agency in facilitating, supporting, and funding training and skills development. A central point raised a number of times was the role to be played by government, not only in providing financial incentives, but in leading by example.

Recommendations for future collaboration/research priorities

A number of recommendations for future actions and research priorities have emerged from the mini-reviews and further developed in the workshop:

- Technology – concept of insuring long term performance
    - Established technology
    - Factor changes into the technology
    - Integration of various technologies
- Retrofitting – how do you add new technologies into old buildings?
    - Knowledge issues
    - Education issue

    - Examples from other industries/Countries

- Flexibility of design for new homes
    - Measurement
    - Developing toolkits

- Need for robust payback data, research into mechanisms to reduce the value action gap, and research into ways to manage behaviour.

- With regards to financial incentives, it was felt that people responded well to such “carrots”. Sometimes this response was better with an immediate cash reward rather than with long term future savings. The discussion also touched on the difference between perceived maintenance costs versus savings.

- When discussing the need for leadership and clarity of roles, many of the workshop participants felt there was duplication of roles in the sector, and that their own experience of projects showed there were a vast number of organisations active in the sector. The consensus was that a co-ordinated and simplified approach was necessary.

- Need to look at structures of financial incentives in the construction/domestic sector and potentially in other sectors, to see what currently works and could be transferred to the housing energy sector. Research into case studies of effective leadership would be of value. Also more research into the lifecycle cost savings of CO_2 reduction would be useful.

- It was agreed that a first step is for key organisations/agencies working in the region in this area of policy to forge a more strategic approach to lobbying One North East on this issue. The approach should be to influence the way in which ONE develops this area, through focusing on the broader targets for reducing CO2, the cost of meeting these, and the need to plan across the region. In particular further action needs to be taken to encourage ONE to consider how it allocates the training fund, which traditionally focuses on sector skills, but doesn’t fit with the holistic approach needed to address the zero carbon agenda. We should also look to the European Structural Funds for money to develop skills and for development of the technologies on the ground. ONE has a role in making this happen.

- Need for further collaboration between the university and practitioners/policymakers, and importance of developing partnership to pursue research priorities in the region and seek funds (particularly from regional bodies such as One North East, and European funds). This could be led by research-active staff within the School of the Built Environment, and could link with already established regional partnerships such as SUSTAINE and industry-led networks. One area of particular interest to a number of the delegates was the work being developed in virtual reality in the School and the potential application of visualisation and communication to developers/government/the public using VR software and techniques.
- During Autumn 2008 SCRI researchers will work with Built Environment academics in developing these links and investigating appropriate funding programmes and funding bodies with the aim of submission of a bid by early 2009.

Appendix 1: Building and adapting homes to meet the target of zero carbon emissions – advice on Virtual Reality aspects

Margaret Horne

Introduction

This investigation has systematically reviewed the current activities in Virtual Reality research that could be of significance to the social strand of building and adapting homes to meet the target of zero-carbon emissions. Virtual Reality is still a relatively emerging technology. Although the history of VR can be traced back to the early 1950s, most of the advances in the technology came about only in the 1980s and 1990s and it is still perceived by many as being in its infancy. However the constant increases in computer performance and major advances in graphics card technologies are resulting in VR becoming more accessible and affordable and some interesting applications are beginning to emerge. This review explores the current activities in VR research related to zero-carbon emission targets by reviewing articles in those journals which have already published papers related to Virtual Reality applications. Journals selected included:

- ITCon
- CONVR
- International Journal of Architectural Computing
- Building and Environment
- International Journal of Design and Construction
- Automation in Construction

Searches were conducted using ScienceDirect database and CuminCAD, a cumulative index of publications relating to computer aided architectural design and Virtual Reality, with bibliographic information of over 8,500 records from journals and conferences such as ACADIA, CAADRIA, eCAADe, SiGraDi, CAAD futures, DDSS and others.

Innovation

Virtual Reality has been defined as being a user-interface that allows humans to *visualise and interact* with *computer-generated environments* through *human sensory channels* in *real-time* (Construct IT, 2003). It has been described as that interactive computer technology that attempts to create a completely convincing illusion of being immersed in an artificial world that exists only inside a computer (Rheingold, 1991). It can be categorised into three types; immersive VR, semi-immersive and desktop VR, the latter opening up VR possibilities to larger numbers of users from disciplines other than computing. The potential contribution of Virtual Reality for the assessment of design implications of projects prior to commencement was recognised by Sir Michael Latham (1994) who stated: *It is rarely satisfactory for clients to be shown conceptual drawings, still less outline plans of rooms.*

The design team must offer the client a vision of the project in a form which it can understand and change in time.

The IT industry has long forecasted that as the price of technology decreases, Virtual Reality will become more common. Software will describe the look, sound and feel of an artificial world, down to the smallest detail (Gates 1996).

Engagement

Much of the earlier research related to VR has been concerned with the advancement of the technology itself, but more recently the benefits and constraints of Virtual Reality as a visualisation tool for the construction industry have been analysed (Bouchlaghem et al 2000) and further case studies have been reported, (Bouchlaghem et al 2005, Whyte J, 2002). Aouad et al (2000) have also illustrated the potential of integrated web-based virtual models to support and improve collaboration in a multi-disciplinary industry. More recent research identifies the new issues that digital collaboration raises for multi-discipline collaboration (Rosenman 2007) and in particular for the management of knowledge in the context of sustainable construction (Shelbourn et al 2006).

Research is beginning to develop which is specifically exploring how Virtual Environments can contribute to home design by providing three-dimensional immersive experiences as opposed to the traditional two-dimensional representation of a three—dimensional structure. (Cowden et al, 2008, Kitchens et al 2007). VR and other 3D modelling tools are being evaluated for the role they play in environmental impact assessment studies (Loh et al, 2007) as well as in new construction technologies (Johnsson et al 2006, Tatum 2005).

The use, development and future potential of Information and Communications Technologies (ICT) in relation to the Leadership in Energy and Environmental Design (LEED) rating system is being considered (Andrews et al, 2006, USBGC, 2003) and examples of computer aided sustainable design can be found in research literature (Bennadji et al, 2004, Camarata et al, 2006).

The availability of advanced design tools for energy conscious design has been researched for over two decades (Clarke and Maver 1989) but the recent emergence of building information modelling (BIM) software and its interoperability between energy performance simulations and Virtual Environments is resulting in increased research, particular in relationship to data integration issues (Chaisuparasmikul, 2006, Hamza and Horne 2007, Manessatid and Szalapaj, 2006, Mourshed et al, 2003, Tarabieh and Malkawi, 2007). The IT industry is responding to the challenge by developing a number of tools for the simulation and modelling of many aspects. Tools which can systematically evaluate environmental conditions based on the materials used in the buildings are expected to be developed in the future (Autodesk 2008).

The communication of issues relating to sustainable construction is beginning to emerge using games to simulate various scenarios (Shivshankar and Thirumavalavan, 2007, Torres and Macedo, 2000). The National Energy Foundation, in partnership with British Gas and Logicom, has launched a virtual-reality computer game to be used across schools in England as part of a programme to increase awareness of climate change (Logicity 2008). Leonardo Energy has developed a 3D Forum which offers a virtual environment on sustainable energy issues, where users can browse, interact and ask questions (Leonardo Energy 2005).

Barriers and Enablers

Research has indicated that the main barriers to implementation of VR in the construction industry are more connected to organisational and human issues rather than the technology itself (Bouchlaghem et al 2005). There is still a perception in the industry that VR technologies are inaccessible and unaffordable. Whilst many visualisation techniques are being used in the industry (two-dimensional drawings, physical scale models, three-dimensional computer models etc) VR extends such forms of representation by offering an interactive, immersive environment of a building prototype. It can play an important role in helping to explain and communicate often complex ideas and behaviours in a short period of time. The reasons to move from 2D to 3D modelling are increasing, and:

- advancing computer performance
- easier to use 3D modelling software
- emerging exemplar projects from industry
- university education – computer literate graduates
- clients' expectations
- building legislation
- energy conscious design

have all been identified as playing a part.

Conclusions and recommendations

There is much VR related research concerned with the interoperability of the new three-dimensional tools emerging, but little concerned with the role Virtual Reality can play as an effective communication technology for new and adapted zero-carbon homes. *We need to work together and show the public what an adapted house looks like, how much it will cost, and what the long-term benefits will be* (Arup 2008). In the US the Green Building Council is producing visualisations based on photography and web technologies to inform lay people on what constitutes a green home. In the UK the Green Building Council has developed a Sustainable Homes web site, focusing on training and advisory consultancy in the field of sustainable housing and many case studies are emerging and being recorded. A simple animation to show what a zero-carbon house could look like in 2016 can be found on the e-on UK web site. However Virtual Reality technology could further enhance these representations, and play a major part in the communication process between stakeholders, increasing understanding for both new home owners and those whose homes require adaptation. Key players should be brought together to define a project brief that will enable the impact of building and adapting homes to meet the target of zero carbon emissions to be clearly and visually communicated to householders. There are a growing number of VR models being used for environmental impact assessment studies, and public consultation meetings. Such simulations need to be based on accurate, credible data and with full consultation and collaboration with all interested parties.

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Appendix 2: Technologies available for meeting the Zero Carbon Homes Target

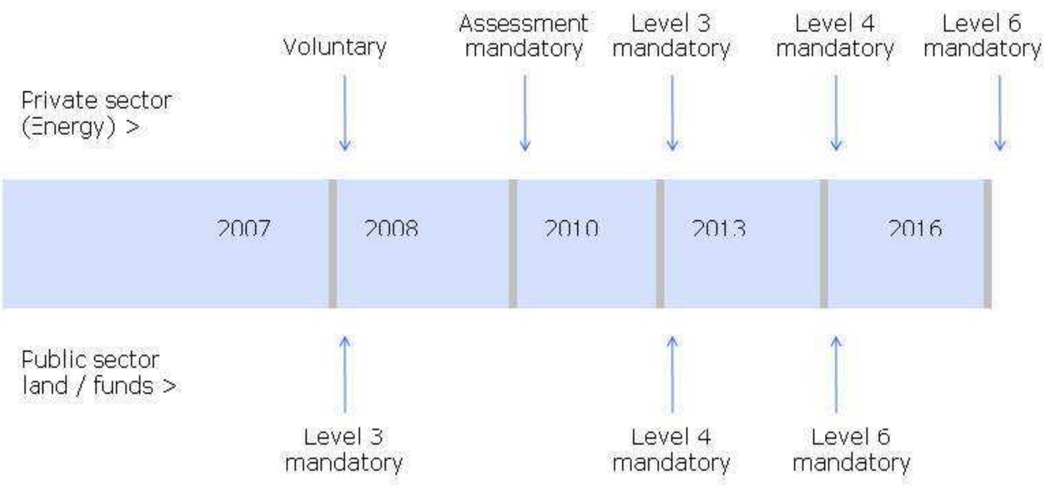
Zaid Alwan

The Code for Sustainable Homes uses a six-star rating system to grade a building's environmental performance.

- Level 1 is set just above current 2006 Building Regulations.
- Level 6 is 'net-Zero Carbon' for homes in use, including appliance and occupant energy use.

An increasing proportion of credits are needed to satisfy each level, of which a mandatory proportion are energy and water, reflecting the growing importance of climate change and potable water availability.

There is In addition, an ambition for all new non-domestic buildings to be zero carbon from 2019 (see image below) with consultation on the timeline and its feasibility and new public sector buildings from 2018.



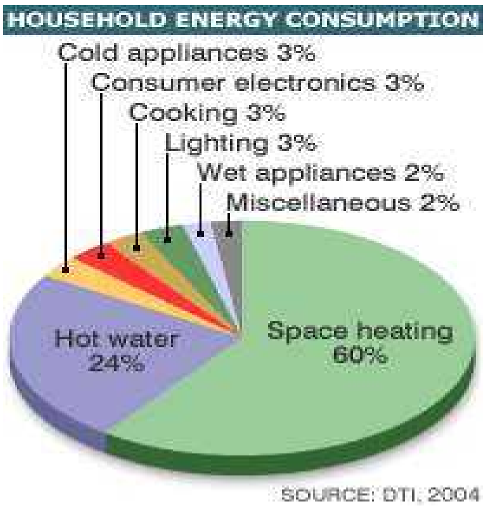
Route Map for the Code for Sustainable Homes (Kingspan, 2007)

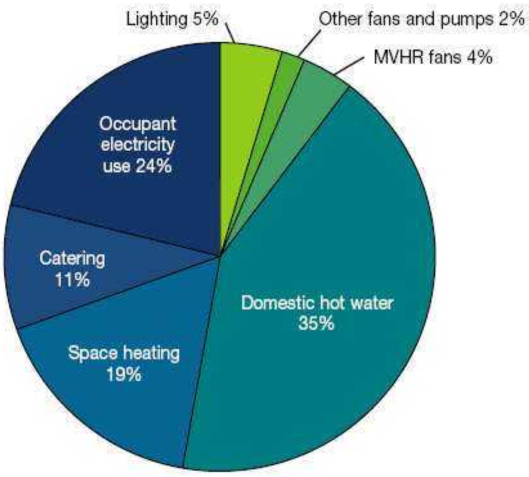
Current domestic vs zero carbon homes energy usage

It is important to consider the existing gap between current housing stock, and the challenges required achieve zero carbon homes

The illustration below and bar charts show a typical UK semi-detached and kingspan (first production zero carbon prototype) house has the following characteristics.

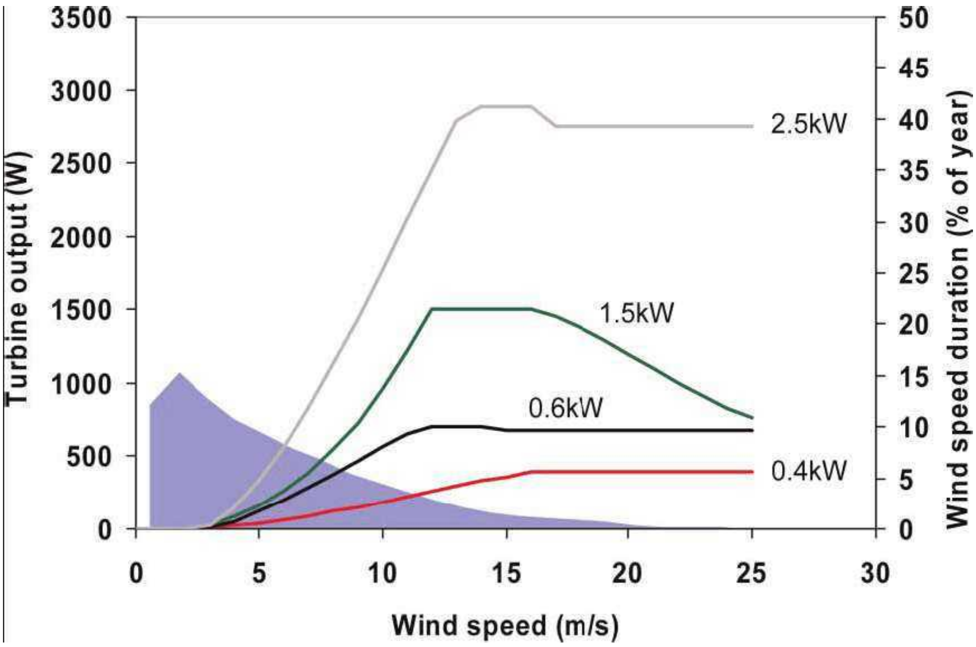
Traditional		Zero Carbon	
• 3 bedroom • Approximately 90 m2 • Built around 1935 • Some loft insulation • Some DG • Standard efficiency boiler • Some hot water tank insulation • Heating thermostat		• Flexible living space • Modern design and built • Low embodies energy • Selective thermal mass • Very high insulation • Triple glazed • Remewable energy onsite • Natural ventilation	
U values Walls	1.5	U values Walls	0.11
Roof	0.4	Roof	0.11
Floor	0.8	Floor	0.11
Windows	3.7-4.0	Windows	0.7





Installation of PV, solar thermal and micro-wind

Cost and reliability issues dominate, both for PV in the adoption of the second- and third generation technologies and for all the wind turbine technologies, whose working life is still unclear. Payback periods on the investment in these technologies are still to be established, but may be a large proportion of their working life. For **wind**, the method of assessing yield is wholly inadequate because it depends on a mean wind speed estimate that does not account for the surface roughness factors typical of urban and suburban environments. The flaws are compounded because of the non-linear relationship between wind speed and power output. The diagram below shows the actual wind speed, measured at 10-min intervals over a one-year period at a suburban site in Edinburgh with a relatively high mean wind speed, superimposed upon the power output curves of some typical micro-wind turbines. It suggests that in this case significant electricity generation is likely for less than 15% of the year. Hence the real actual power yields are likely to be considerably lower than those estimated from the open-site wind speed data available from weather stations. The inability to forecast the yields expected from urban wind generation masks a further concern regarding its applicability, mainly that yields are likely to be extremely low. Its ability to contribute to the zero carbon target is therefore likely to be limited to rural and perhaps coastal locations, which are likely to represent only a small proportion of the new built stock.

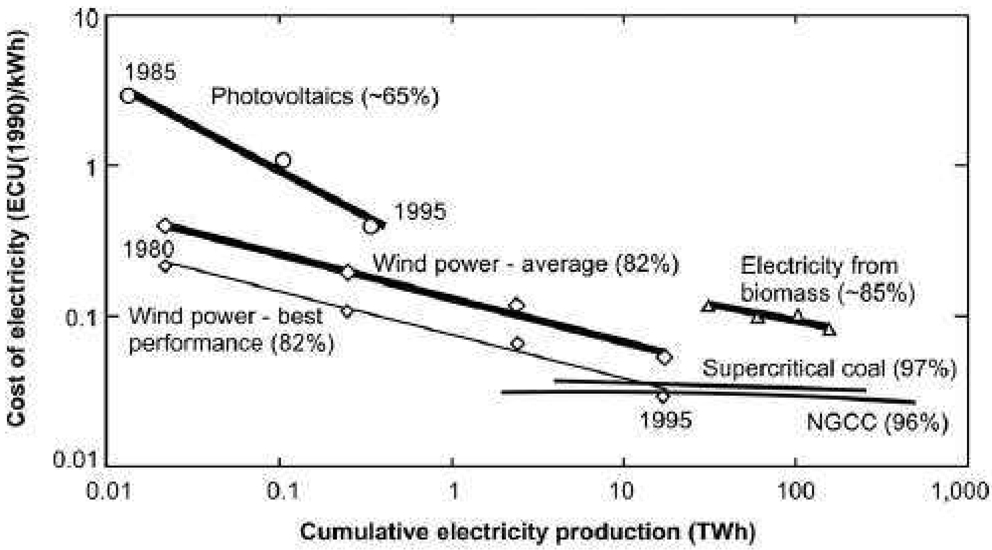


Power output from wind turbines compared with the distribution of wind speeds measured at 10-min intervals on a site withmean wind speed of 4.9 m/s,0.4,0.6 and1.5 kWroof-mounted turbines, and a 2.5 kWpole-mounted turbine

A key problem is that of matching electricity supply and demand and its impact on economics, payback periods and CO2 emission savings. This is exemplified by the following scenario. A first generation **solar** cell rated at 3.4 kW would produce approximately 3400 kWh in the existing London climate. In a typical UK dwelling, this would meet only 25–30% of demand with 70–75% of the electricity generated being exported Similarly, the 2.5 kW pole-mounted turbine used in Fig. 2 would produce 4900 kWh of electricity from the site with a mean wind speed of 4.9 m/s. This would meet only 40% of demand and export 71% of the electricity. This paradox of a shortfall in demand combined with an excess for export arises from the mismatch between the times of **supply and demand**, issues which are central to the aspiration of zero carbon housing.

Costs of energy production

The actual costs of electricity from sustainable sources has been generally high. The graph below indicate costs in relation to energy production over a 15 year period, which tend to fall the more electricity is generated. Costs in the renewable energy industry have always been a barrier in terms of preventing greater uptake with the residential sector.



A curve of cost for electricity generation technology in the EU, 1980-1995 (Allen, 2008)

Barriers to Electricity storage

The issues of the balance between imports and exports could be solved by using on-site storage to accommodate the excess production of electricity. Using current technology, this is more likely to involve chemical energy in the form of electric batteries. In the simplest of systems this would be lead acid cells, which are well developed, available, predictable and robust, but take up space. For more sophisticated applications, Redox batteries are becoming available, and development will continue. Alternatively, surplus electricity could be used to produce hydrogen by electrolysis, which could then produce electricity in a fuel cell to match demand from the dwelling. **Storage technology** will add **substantial cost** to an energy system, will increase the area required to house a system, and will be likely to increase risk as they add to the degrees of freedom required for control options. Reliance on low-cost electrolysers, whilst in development, would also represent a risk to the completion of the desired policy outcome by 2016 (Banfill, 2007).

Other incentives and enablers

The changes implemented in the national micro-generation targets that can be set in 2008/2009 under the Climate Change and Sustainable Energy Act will encourage energy suppliers to support the micro-generation industry. Proposals in the recent Review of Distributed Generation [44] include clearer export-rewards from suppliers and new market arrangements for distributed generators, which will benefit the industry as a whole.

TheLCBP (capital grants) is currently the major support mechanism for micro-generators, but it is frugal in comparison to the capital costs of some technologies, and has suffered significant administration problems leaving many potential customers unable to obtain grants. Below is a diagram of projects supported by the scheme and associated costs (Allen, 2008).

Number of installed micro-generators and future projects funded by the LCBP (adapted from [9,40])

Micro-generation technology[a]	Total number installed (2005)	Estimated total cost	Avg. cost per install	Projects funded by the LCBP		
				Funds allocated	No. projects	Avg. fund allocated per project (historic)
Solar thermal	78,470	£357,696,065	£4558	£848,067	2122	£400
Solar PV	1301	£20,145,012	£15,484	£3,721,598	510	£7297
Micro-wind	650	£11,137,463	£17,135	£1,730,739	1493	£1159
Ground source heat pumps	546	£5,156,751	£9445	£327,536	274	£1195
Micro-CHP	990	Not known				
Micro-hydro	90	£2,385,084	£26,501	£14,300	4	£3575
Biomass room heaters				£7841	16	£490
Wood fuelled boilers				£168,002	116	£1448

It is clear from the table that the cheapest technologies tend to the ones that attract most funding and are the most popular, PV/solar thermal is by far most popular

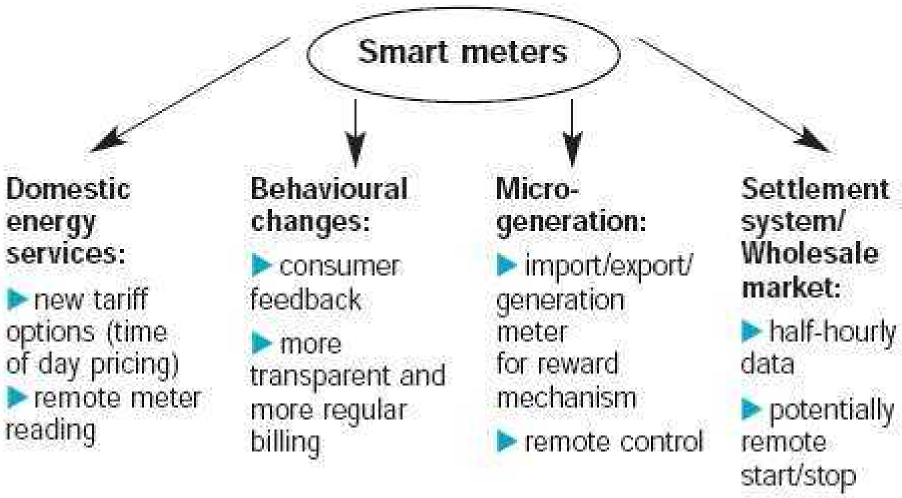
Innovation to reduce energy losses from houses

The following have been emphasised by the BRE as some of the key non technical drivers for acheving Zero carbon as part of the design and construction process.

Smart Metering and monitoring systems

A Smart Meter records energy consumption, to help occupants identify any wastage and to promote more environmentally aware lifestyles. There are practical methods by which the management of demand and microgeneration could be performed with very little initial investment because it builds on the existing Radio Teleswitch system, and the processes for collecting-generating plant data and predicting demand that are already being performed.

Smart meters should not be seen as an optional extra that some consumers might wish to buy, but as an essential element in a reoriented energy market based on services rather than supply, below is a good illustrative example of impacts of smart metering.



The potential impacts of smart metering (adapted from unlocking the power of the house)

Ventilation
Understanding how the ventilation and passive system operates.

Heating
The building envelope specification will deliver high levels of thermal insulation and air tightness so that the home will only need to be heated for a couple of months in mid-winter. However there is a fine delicate balance in a well insulated house between comfort and overheating in the summer.

Reducing solar gain
External shutters can be used in summer to reduce the build up of heat. They block out all direct sunlight.

Reduced glazing
Complying with the U-values of the Code, the glazing is 5-10% less than that in the traditional home. The living space of the Lighthouse is adapted to accommodate this with a large double height volume on the upper levels with sleeping accommodation below.

Airtightness
Lobby areas design to the front and back of the house to maintain the high level of the air tightness in the build.

Water
Increased awareness about what water to use where - rainwater for the garden and washing machine, shower and bath water for the WC. Technology to Generate Renewable Energy For Code Level 6, the mandatory heat loss parameter standard is very high placing more demands on the building envelope such as Insulation, glazing and shading and how these operate with the technological systems of the house.

High thermal mass
The key to an energy efficient house is that it has high levels of "thermal mass" – the ability of a material to absorb and release heat slowly. This can provided by the extremely thick insulation around the walls. Further temperature control is provided by a heat exchanger in the ventilation system, which does not require any power.

This section discusses and reviews different renewable energy technologies and the selection of suitable technologies for different household applications. It will also discuss **operating maintenance needs**, **advantages** and **disadvantages** of each It should be stated that many of the technologies have not made huge advances in the last 10-20 years with a few exceptions. For example Heat pump technology has always required a COP of 3 to 4 and that has not changed over that previous 3 decades, what has changed is the need to bring down the cost of the technology peoples' attitudes towards accepting such new technologies driven by cost and/or environmental concerns.

Solar Energy

Solar Hot Water Systems: In the UK there are many installed solar hot water systems. Solar collector works even in the overcast. Solar collectors can provide about 50% of the hot water needed for the UK climate condition. Solar collectors can provide nearly all the hot water required for the summer period. There are three main types of solar collectors. They are:

- Flat plate collectors with non-selective surface
- Flat plate collectors with selective surface
- Evacuated tube collectors with selective surface

Solar collectors can be purchased from many manufacturers and some can provide 2 years installation warranty, 5 years parts warranty and 10 years panel warranty. Generally solar collectors have warranty of 10 years and the functional life periods are about 20 to 30 years. Evacuated tube collectors are costlier than the flat plate collectors, but have an efficiency advantage over flat collectors, because the heat loss by convection is almost totally eliminated. Solar collector systems can be sizeable to any range.

Photovoltaic Systems: In the UK there are many installed PV systems. There are different types of PV modules depending upon the material used. They are:

- Mono crystalline modules
- Multi crystalline modules
- Thin film modules
    - Amorphous silicon modules
    - CdTe modules
    - CIGS modules
- Multi junction cells
- Concentrating cells

Mono / Multi crystalline silicon and thin film type modules can be purchased with a warranty of up to 25 years. Generally PV modules will have 25 years warranty and the life period is up to 30 – 40 years. Multi junction cells are considered as a developing technology. The concentrated PV cells can be purchased, however there is no evidence on warranty and reliability of concentrated type PV systems. Moreover the concentrated PV systems will work better with direct radiation and hence this type is not suitable for the UK. Therefore the multi junction and concentrated type systems were not selected for the remote community applications.

Barriers to PV (industry too small to cope with expected surge in demand)
New build developments are ideal for PV cell installations because architects are able to design the system can be integrated, while existing buildings need a structural survey. Planning permission is not usually required unless the building is listed.

Typically a 1 kW peak solar cell in the UK can produce 700-850 kWh per year, with a PV system of 1.5-2 kW requiring 10-15 m^2 of roof space. The payback period of PV cells is 25 years (Carbon Trust, 2006), however, there may be supply chain issues in the future; “While the installed capacity and installation capacity have grown from the 1,200 PV installations and 56 companies operating in 2005, delivering the products needed to meet the target of 200,000 new homes per year will require very significant further growth in the industry" (Banfill, 2007).

Solar Thermal Systems: There are three main types of solar thermal systems:

- Parabolic trough
- Parabolic dish
- Power tower

Among these types parabolic trough type is the most commercialised technology. The parabolic trough collectors can be purchased but there is no evidence of warranty. Similarly solar dish systems also can be purchased but there is no evidence of warranty. However, these systems use direct sunlight and hence for European market, these systems are suitable for the southern European markets. Hence the solar thermal systems are not selected for the remote communities in the UK.

Wind Energy

In the UK there are many installed wind turbine systems. Recently there are developments in building integrated small-scale wind turbine systems. Small-scale building integrated wind systems need more safety requirements. In rural areas there may not be high raised buildings and in urban areas there may not be sufficient wind flow. Therefore building heights and venture effects around structures must be considered. There are three main types of wind turbine systems:

- Horizontal axis wind turbine
- Vertical axis wind turbine
- Ducted wind turbine

Horizontal and vertical type wind turbines can be purchased with 2 to 5 years warranty. In general the typical life period for a wind turbine system is up to 20 years. There are opposition due to visual intrusion, noise and also there may be problem in getting planning permission in some sites and hence it needs suitable site selection.

Barriers
An on-site rooftop wind turbine in an urban area in the UK is likely to experience an annual mean wind speed of as little as 2 m/s, while the annual mean wind speed experienced by an offshore wind farm reaches 8m/s. There is thus 16 times more energy flux density (W/m^2) available tobig offshore turbines. Two offshore developments proposed for the Thames estuary and North Kent coast are expected to cost about £2 billion and deliver 1.3 GW of electricity. The same installed power would need 866,000 1.5 kW wind turbines (each costing say £2,000) to be mounted on roofs, at a total cost of about £1.7 billion. The cost difference seems insufficient to justify the risk of underperformance associated with on-site generation both in terms of yield and reliability.

Biomass Energy

The main types of biomass technologies are

- Direct combustion
- Gasification
- Pyrolysis
- Anaerobic Digestion

The direct combustion is considered as mature technology. The automatic wood chip burners/boilers can be purchased and available for different sizes from kW to 500 kW. The domestic heating is well established and there is an increasing trend in district heating. Biomass gasifier / pyrolysis equipments are available in different sizes with a warranty of 5 years. The typical life period for gasifier / pyrolysis equipment is 15 to 20 years. Fuel sources for the gasifier are sugar cane, straw, coconut shell and Municipal Solid Waste (MSW). Similarly Anaerobic Digester (AD) can be purchased and fuel sources for the digester can be animal wastes or food processing wastes etc. The typical life period for an AD is around 20 years. Direct combustion can be used to produce only heat while other technologies can be used to produce both the heat and electricity.

Fuel Cells

There are six main types of fuel cells. They are:

- Solid Oxide Fuel Cell
- Molten Carbonate Fuel Cell
- Proton Exchange Membrane FC
- Phosphoric acid FC
- Alkaline FC
- Direct Methanol FC

Among these types SOFC, Alkaline FC and PEM types are commercially available with the size below 100 kW and can be purchased with warranty. Phosphoric acid type fuel cells are available with the size 100 kW but there is no evidence for warranty. Molten carbonate type fuel cells are available but in general the available size is above 100 kW and direct methanol type fuel cells are not commercialised technology. Hence molten carbonate and direct methanol type FC are not selected. The typical life period of fuel cells is 40,000 hours of operation. Fuel cells can be used to produce both the heat and power.

Hydrogen is an input to the fuel cell that can be produced from the following technologies:

- Electrolysis
- Reformation
- Biomass Gasification

- Photo-electrolysis
- From Coal
- Bio hydrogen

Among these technologies electrolysis, reformation and biomass gasification are considered as a commercially available technologies while other technologies are considered as developing technologies.

Ground-source Heat Pumps

There are three main types of ground heat pump technologies. They are

- Electric vapour compression type
- Vapour absorption type
- Gas engine vapour compression type

Electric vapour compression and vapour absorption types can be further classified into air source, water source and direct ground source types.

Among these technologies electric vapour compression type heat pumps are commercially available with the warranty. Gas engine vapour compression type heat pumps are commercially available but there is no evidence about warranty. Vapour absorption devices are available but there is no evidence for suitability for small-scale applications. Typical life period of heat pump systems is about 40 years.

Apart from these technologies there are other technologies like thermo photovoltaic (TPV) and thermo electric technologies that are considered as in the development stage.

Based on the information the table below was developed which looked at current operating need of various systems and the skill level required to maintain the system (see Table 1):

Technology	Operation and Maintenance									Life Span
	Low Skill			*Medium Skill*			*High Skill*			
Frequency	*L*	*M*	*H*	*L*	*M*	*H*	*L*	*M*	*H*	
Solar Collectors	♦			♦			♦			20 – 30 yrs
Photovoltaic’s	♦			♦			♦			30 – 40 yrs
Wind Systems	♦			♦			♦			20 – 25 yrs
Micro Hydro	♦			♦			♦			20 – 30 yrs
Biomass - Direct Combustion			♦			♦	♦			
Gasification / Pyrolysis			♦			♦	♦			15 – 20 yrs
Digester			♦			♦	♦			10 – 20 yrs
IC Engine			♦			♦	♦			
Micro Turbine	♦			♦			♦			60,000 Hrs
Stirling Engine	♦			♦			♦			50,000 Hrs
Fuel Cell	♦			♦			♦			40,000 Hrs
Heat Pump		♦		♦			♦			40 yrs

Table 1: Operating and Maintenance Needs

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Appendix 3: Feedback Report from Practitioners Workshop

Meeting the challenge of Zero Carbon Homes: A feedback report from the practitioner and researcher workshop

19th June 2008

Dr Kate Theobald and Dr Sara Walker, School of the Built Environment, Northumbria University

Introduction

The focus of this report is to provide a summary of the outcomes and key research priorities emerging from the practitioner workshop. In particular the report sets out the main barriers and enablers to achieving the zero carbon homes target, identified in the small group sessions of the workshop.

Workshop aims

The workshop, held on 19th June 2008 at the School of the Built Environment, Northumbria University formed a key part of the zero carbon homes project (funded by the School), and had the following aims:

- To share the findings of the multi-disciplinary literature review with a range of organisations interested in/operating in this area of policy and practice.
- To bring together organisations from different sectors of industry (construction, design, architecture) with government agencies, housing associations, local government, the voluntary sector, and academia.
- To receive comments and suggestions on the findings of our research, specifically the barriers and enablers to achieving zero carbon homes
- To identify additional barriers and enablers not highlighted in the report.
- To identify gaps in the research, and establish future priorities for collaborative research in the North East, involving all sectors represented at the workshop.

Structure of workshop

The agenda in Appendix 1 shows the structure of the workshop. The structure was intended to provide ample time for discussion, through small group sessions, on the barriers and enablers to delivering zero carbon homes, and on ways forward in terms of policy and research priorities.

Sectors represented at the workshop

Approximately 45 people attended the workshop, all from the North East region, and, as the delegate list in Appendix 2 shows, representing a wide range of organisations from the construction industry, government (local government and government agencies, housing associations, voluntary sector, universities).

Key barriers and enablers identified in the group sessions

Five small group sessions were held concurrently, and delegates in each group were first asked to consider the enablers and barriers listed on the posters provided (see barriers and enablers poster s below). The barriers and enablers were listed under 4 headings: policy and regulations, behaviour, supply chain, and technology, which broadly related to the subject areas of the mini-reviews undertaken for the report.

MEETING THE ZERO CARBON HOMES CHALLENGE

ENABLERS

POLICY/REGULATIONS

- Information provision
- Alternative financial support mechanism
- Stronger set of policies
- Consultation by national government with local authorities/housing associations
- Identification of area-based programmes
- Obligations on suppliers to support roll-out of low/zero carbon technologies
- Programme of training
- Leadership and clarity of roles and responsibilities

BEHAVIOUR

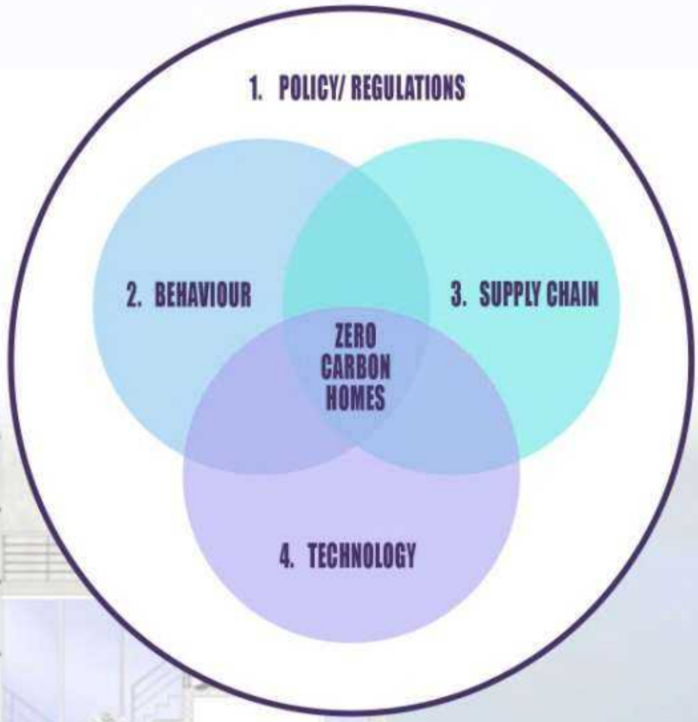
- Financial incentives
- Financial penalties
- Simplicity
- Clear benefits
- Labelling
- Convenience
- Information channels (media)
- Understanding of individual benefits eg to health or 'feel good factor'
- Restrictions on consumer choice
- Sense of community and 'doing your bit'
- Local, regional, national government leading by example
- Provision of appropriate information (technical, cost etc)

SUPPLY CHAIN

- Common language for professionals to communicate
- Bringing together different professions at appropriate points
- Voluntary ratings such as Code for Sustainable Homes
- Changes in planning system to enable community initiatives

TECHNOLOGY

- Conducting of field trials
- Energy Saving Trust to provide information
- Development of software models
- Alternative financial rewards for microgeneration
- More relaxed planning system
- Initiatives by Learning and Skills Council



northumbria UNIVERSITY

MEETING THE ZERO CARBON HOMES CHALLENGE

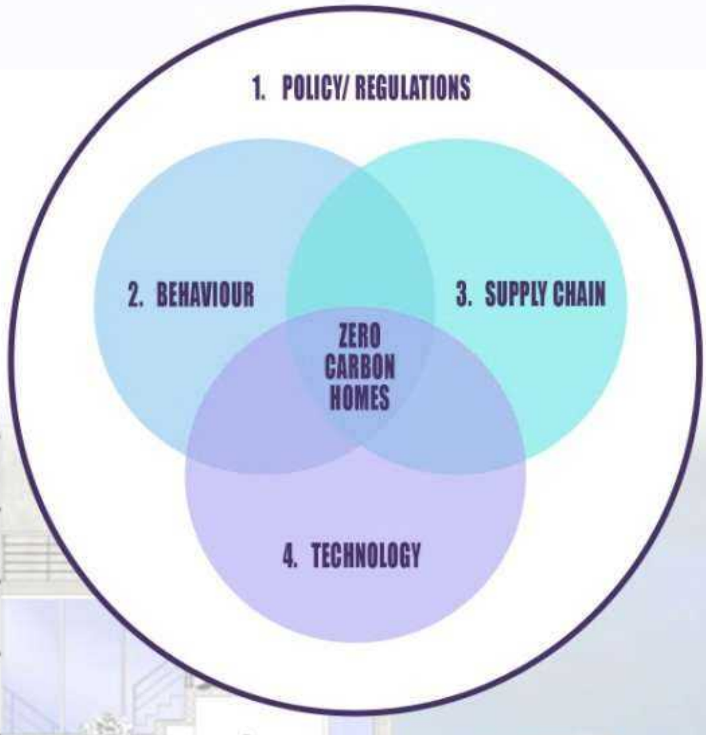
BARRIERS

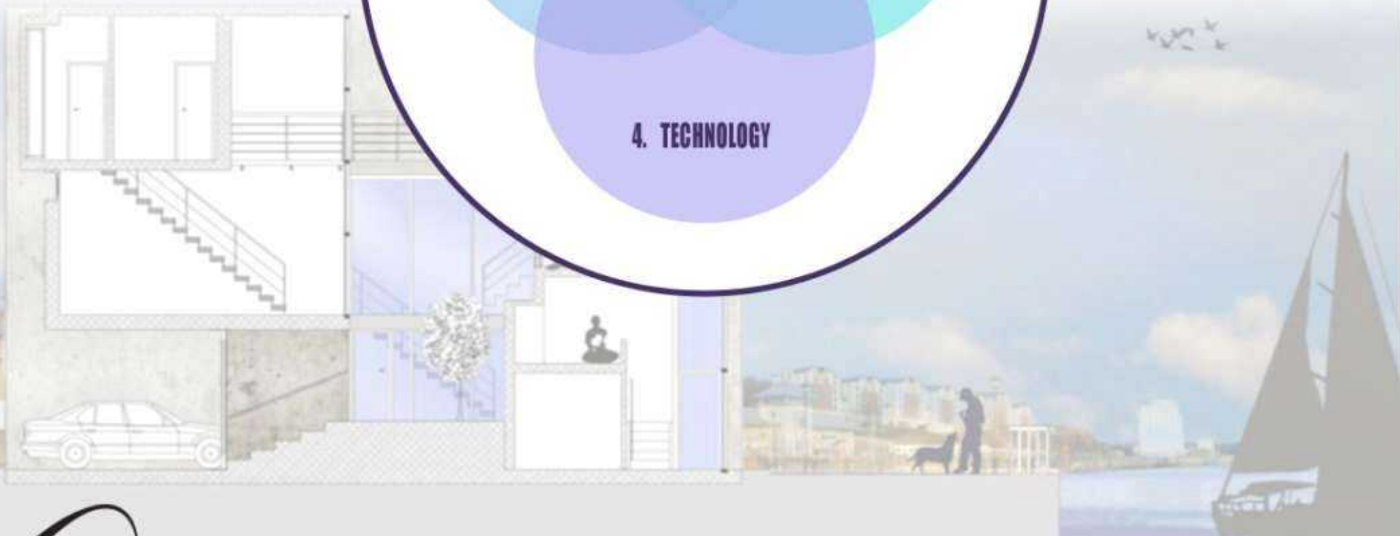
POLICY/REGULATIONS
- Problems in reaching 2016 target
- Lengthy timescale required for each target (as shown by overseas experience)
- Lack of commitment from national government to set an example
- No specific timeline for steps over next ten years to achieve 2016 target
- Perception by industry that legislation is weak and focusing on design end rather than performance
- Lack of planning policy
- Focus on individual rather than large-scale measures

BEHAVIOUR
- Existing lifestyle trends resulting in higher energy consumption
- Difficulty with making comparisons between prices of microgeneration as opposed to traditional energy supply
- Perceived or actual cost of changing behaviour (time/money)
- Carbon taxing unpopular and inequitable
- Lack of information on how individual behaviour can make a difference
- Value-action gap due to
  - Financial constraints
  - Working patterns
  - Impact on current lifestyle
  - Habitual behaviour
  - Inconvenience
  - Distrust of government and industry
  - Feeling of not being able to make a difference

SUPPLY CHAIN
- Organisational structure
- Lead-in time for adoption of new processes/technologies is lengthy
- Training/skills shortage
- Existing tools to measure performance in the design process exclude sustainability
- Emphasis on performance of individual homes rather than communities
- Focus on design performance rather than built performance

TECHNOLOGY
- Cost and associated payback
- Lack of field trial data
- Poor access to information for purchasers and users
- Academic rigour of manufacturer's data
- Lack of skilled professionals
- Planning and connection conditions
- Competing with traditional energy supply





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Delegates were requested to select their top 3 barriers and enablers from across the 4 areas, and to also add any barriers or enablers that they felt were missing from this list. Facilitators for each session recorded the top 3 barriers and enablers, and delegates were encouraged to explain their selection. Further discussion also took place on future research priorities to address these issues, and potential networks/partnerships that could facilitate this.

The top barriers identified in each session were as follows:

Group 1

- Lack of commitment by national government to set an example
- Cost and associated payback
- Perceived or actual cost of changing behaviour (time/money)

Group 2

- Cost and payback (technology)
- Value action gap (behaviour)
- Poor commitment from Government to set an example (policy)

= Focus on individual rather than large-scale measures
= Training/skills shortage (supply chain)

Group 3

- Value-action gap due to
  - Financial constraints
  - Working patterns
  - Impact on current lifestyle
  - Habitual behaviour
  - Inconvenience
  - Distrust of government and industry
- Cost and associated pay-back (technology)
- Training/skills shortage

Group 4

- Academic-industry divide
- Voluntary ratings of codes (perhaps should be mandatory)
- Training and skills shortages (of traditional skills too)
- Lack of field trial data
- Existing lifestyle (perceived versus real costs)
- Planning and connection conditions
- New build versus existing build
- Rules, regimes and networks

Group 5

- Training/skills shortage (supply chain)
- Lifestyle trends and increasing energy consumption (behaviour)
- Poor access to info (technology)
- Lack of skilled professionals (technology)
- Cost and associated payback (technology)

The top enablers identified in each session were as follows

Group 1

- Financial incentives
- Leading by example
- Consultation by government

Group 2

- Financial incentives (behaviour)
- Leadership and clarity of roles and responsibility (policy)
- Alternative financial support mechanism (policy)
- Alternative financial rewards for microgeneration (technology)

Group 3

- Alternative financial support mechanisms
- Financial incentives
- Bringing together different professions at appropriate points

Group 4

- Leadership and clarity of roles and responsibilities and policy/regulatory direction (particularly at local and national government)
- Incentives (especially subsidies for traditional energy systems)

Group 5

- Bringing together different professions at appropriate points (supply chain)
- Financial incentives (behaviour)
- More relaxed planning system (technology)

The key issues emerging from all the group sessions were the problems of cost of the technologies and payback periods; the importance of financial incentives, both from a behavioural perspective and for the further development of technologies; the need for development of appropriate skills and training in this area, and, linked to this, the role of the regional development agency in facilitating, supporting, and funding training and skills development. A central point raised a number of times was the role to be played by government, not only in providing financial incentives, but in leading by example.

Future actions, research priorities and collaboration between sectors

A number of recommendations for future actions and research priorities emerged from the group sessions:

- Technology – concept of insuring long term performance
  - Established technology
  - Factor changes into the technology
  - Integration of various technologies
- Retrofitting – how do you add new technologies into old buildings?
  - Knowledge issues
  - Educating issue
  - Examples from other industries/Countries
- Flexibility of design for new homes
  - Measurement
  - Developing toolkits
- Need for robust payback data, research into mechanisms to reduce the value action gap, and research into ways to manage behaviour.
- With regards to financial incentives, it was felt that people responded well to such “carrots”. Sometimes this response was better with an immediate cash reward rather than with long term future savings. The discussion also touched on the difference between perceived maintenance costs versus savings.
- When discussing the need for leadership and clarity of roles, many of the workshop participants felt there was duplication of roles in the sector, and that their own experience of projects showed there were a vast number of organisations active in the sector. The consensus was that a co-ordinated and simplified approach was necessary.
- Need to look at structures of financial incentives in the construction/domestic sector and potentially in other sectors, to see what currently works and could be transferred to the housing energy sector. Research into case studies of effective leadership would be of value. Also more research into the lifecycle cost savings of CO_2 reduction would be useful.
- It was agreed that a first step is for key organisations/agencies working in the region in this area of policy to forge a more strategic approach to lobbying One North East on this issue. The approach should be to influence the way in which ONE develops this area, through focusing on the broader targets for reducing CO_2, the cost of meeting these, and the need to plan across the region. In particular further action needs to be taken to encourage ONE to consider how it allocates the training fund, which traditionally focuses on sector skills, but doesn’t fit with the holistic approach needed to address the zero carbon agenda. We should also look to the European Structural Funds for money to develop skills and for development of the technologies on the ground. ONE has a role in making this happen.

Appendix 1: Agenda for workshop

MEETING THE ZERO CARBON HOMES CHALLENGE

Zero Carbon Homes Workshop

June 19th 2008
09.15 -14.00
The Hub, 2nd Floor, Ellison Building

Agenda

09.15 to 09.45	Coffee and Registration (The Hub)
09.45 to 09.50	Welcome to Delegates (Keith Hogg, Associate Dean, School of the Built Environment)
09.50 to 10.00	Presentation: The Code for Sustainable Homes- key issues and impacts (John Holmes and Graham Capper)
10.00 to 10.10	Outline of Zero Carbon Homes Project (Dr Sara Walker)
10.10 to 10.20	Key findings from Project :barriers and enablers; introduction to Workshop group sessions (Dr Kate Theobald)

Groups Split into Two

10.20 to 10.40
Group A:
Interactive session on the contribution of the IT industry (Margaret Home, VR suite)
Group B:
Presentation by Mark Siddall (Dewjoc Architects) on his research into zero carbon homes (The Hub)

10.40 to 11.00
Group A:
Presentation by Mark Siddall (Dewjoc Architects) on his research into zero carbon homes (The Hub)
Group B:
Interactive session on the contribution of the IT industry (Margaret Home, VR suite)

11.00 to 11.30	Tea/coffee and networking (The Hub)
11.30 to 12.30	Small group discussions (5 Groups) Each group to discuss barriers and enablers relating to delivery of zero carbon homes
12.30 to 13.00	Final Feedback (from 5 groups), and summing up
13.00 to 14.00	Lunch and networking (The Hub)

Appendix 2: Delegate list for workshop

Forename	Surname	Organisation
Dana	Abi Ghanem	Newcastle University, School of Architecture,
Stuart	Ablett	Frank Haslam Milan
Steve	Bhowmick	County Durham Sustainability and Environment Partnership
Sarah	Black	North Tyneside Council
John	Burns	MacKellar
Owen	Callaghan	SummitSkills
Steven	Caseley	EAGA Renewables
Ed	Derrick	Your Homes Newcastle
Darush	Dodds	Esh Developments
Terry	Flynn	Gentoo Construction
Audley	Genus	Newcastle University
Kate	Coulthard	Newcastle City Council
Barry	Errington	GONE
Victoria	Eynon	NEA (National Energy Action)
David	Foster	North Tyneside Homes
Sarah	French	Groundwork South Tyneside & Newcastle
Cay	Green	CfDR, Northumbria University
David	Halfacre	Dunelm Property Services
Micheal	Henning	Summers-Inman
Alan	Jones	North East ESTAC
Catriona	Lingwood	Constructing Excellence in the North East
Philippa	Hughes	Three Rivers Housing Association
Jeanette	Iddo	North Tyneside Council
Gareth	Kane	Terra Infirma Ltd
Stephanie	Kelley	Gentoo Green
Colin	MacDonald	North East ESTAC
Adrian	McLoughlin	Newcastle City Council - Sustainability Unit
Keith	Meldon	New and Renewable Energy Centre Ltd (NaREC)
Oliver	Moss	SASS, UNN
Nicola	Pearsall	Northumbria University
Barrie	Westbrook	North Star Housing Group
Neveen	Hamza	Newcastle University
Phil	Jensen	North Tyneside Council
David	Lowery	SEQM Ltd
Andy	Mace	Arup
Ed	Marsh	Green Energies
Sean	McKeon	Faithful+Gould

Geoff	O'Brien	Northumbria University
Brian	Peel	English Partnerships
Emma	Pryke	Energy Savings Trust
Ray	Sanderson	Gentoo Green
David	Stapleton	Frank Haslam Milan
Paul	Armstrong	Esh Developments
Ann-Marie	Gibson	NEA (National Energy Action)
Chris	Holt	Ian Larnach Associates
Gary	Pattinson	North Tyneside Council
Brian	Sampson	North Tyneside Council
Mark	Siddall	Dewjo'c Architects
Graeme	Stephenson	Warm Front Partnership
Geoff	Stevens	North East ESTAC
Joe	Thompson	Gentoo Construction
Simon	Williams	Frank Haslam Milan
Ghanim	Putrus	Northumbria University