Zero Carbon Homes

Housing is a major contributor to CO_2 emissions in Europe and America today and the construction of new homes offers an opportunity to address this issue. Providing homes that achieve “zero carbon”, “carbon neutral”, “zero-net energy” or “energy-plus” standard is becoming the goal of more innovative house-builders globally, whilst energy providers seek to decarbonise the energy supply to new and existing development.

Various new technical systems for achieving these goals are beginning to emerge. For example the passive house whose energy requirement for space heating and cooling is almost zero; the smart grid that has revolutionised the management of energy, whilst enabling the connection of small-scale, renewable energy producers and electric vehicles to the grid; or the European super-grid which will enable zero carbon energy to be generated in the Sahara desert and stored in Norway.

This book explores the diverse approaches that are being adopted around the world to delivering zero carbon homes and the different societal systems and geographic circumstances in which they have developed. It postulates a road-map for delivering zero carbon homes, together with a toolbox approach for policy and practice to suit particular national and local circumstances.

A series of case studies are presented that offer lessons for delivering zero carbon homes. These examples are also used to demonstrate how prototype systems can move into the mainstream. The book highlights some of the instruments and mechanisms that could be used to support this transformation and addresses the wider implications of introducing these innovative systems in terms of industry, lifestyle and urban form.

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Zero Carbon Homes

A road-map

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The world's energy system is at a crossroads. Current global trends in energy supply and consumption are patently unsustainable – environmentally, economically, socially. But that can – and must – be altered; there's still time to change the road we're on. It is not an exaggeration to claim that the future of human prosperity depends on how successfully we tackle the two central energy challenges facing us today: securing the supply of reliable and affordable energy; and effecting a rapid transformation to a low-carbon, efficient and environmentally benign system of energy supply. What is needed is nothing short of an energy revolution.

International Energy Agency, *World Energy Outlook 2008*

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Note on copyright

Abbreviations and acronyms

AGR advanced gas cooled reactor
ASHP air source heat pump
BedZED Beddington Zero Emissions Development
BMU Federal Environment Ministry (Germany)
BRE building research establishment
BWEA British Wind Energy Association
CAP Climate Action Plan
CAS compressed air storage
CCGT combined cycle gas turbine
CCS carbon capture and storage
CEC California Energy Commission
CERT Carbon Emissions Reduction Target
CHP combined heat and power
CLG Department of Communities and Local Government
CO_2 carbon dioxide
CS carbon sequestration
CSI California Solar Initiative
CSP concentrated solar power
DECC Department of Energy and Climate Change
DINK dual income no kids
DTI Department of Trade and Industry
EC European Commission
EEA European Environment Agency
EIA Energy Information Administration (USA)
EPA Environmental Protection Agency
ESCO energy service company
ESP edge of service provider
ETF environmental transformation fund
EU European Union
EU ETS European emissions trading scheme
EWEA European Wind Energy Association
FIT feed-in tariff
GDP gross domestic product
GdW Federal association of *German* housing and real estate enterprise
GHG greenhouse gas
GMV Greenwich Millennium Village
GSHP ground source heat pump
GW gigawatt
GWe gigawatts electric
HOA home owners association
ICLEI International Council for Local Environmental Initiatives
IEA International Energy Agency
IOCs international oil companies
IOU investor-owned utility
IPCC International Panel on Climate Change
IVL Swedish Environment Research Institute
Kgoe kilograms of oil equivalent
kWh kilowatt hours
LCBP Low Carbon Buildings Programme
LEED Leadership in Energy and Environmental Design
(USA building accreditation programme)
LEH low energy house
LIP local investment programme

LZC low or zero carbon
MCC Malmo City Council
Mt CO_2eq million tonnes carbon dioxide equivalent
MUSCO multi service company
MVHR mechanical ventilation with heat recovery
MWe mega watts electric
NAHB National Association of Home Builders
NREL National Renewable Energy Laboratory
NSHP New Solar Homes Partnership
OPEC Organisation of Petroleum Exporting Countries
PH passive house
PHS pumped-hydro storage
PIER Public Interest Energy Research
POU publicly owned utility
PPM parts per million
PUC public utilities commission
PV cell photovoltaic cell
PWR pressurised water reactor
RE renewable energy
REE rare earth elements
RO renewables obligation
RPS renewable portfolio standard
SME small and medium-sized enterprise
Toe tonnes oil equivalent
TWh terrawatt hour
WWF World Wide Fund for Nature

Chapter 1

Introduction

Introduction

Housing is a major contributor to CO_2 emissions in Europe and America today. The construction of new homes offers an opportunity to begin to address this issue. Providing homes that achieve 'zero carbon', 'carbon neutral', 'zero-net energy' or 'energy-plus' standard is becoming the goal of more innovative house-builders and energy providers in Europe and America. A diversity of approaches is being adopted. These are inevitably infl uenced by the different societal systems and geographic circumstances in which they have developed. Using case studies from Sweden, Germany, the UK and USA we explore these alternative approaches.

Housing programmes (for example the 'solar homes' and 'zero carbon' housing programmes) have been used in many countries to raise the energy standard and /or reduce carbon emissions from new stock. Low carbon energy systems, developed at a variety of scales, have helped to decarbonise domestic energy supply and reduce subsequent CO_2 emissions from households. Prototype low carbon neighbourhoods have also emerged which combine innovative technological systems, management practices and social capital to achieve longer-term behavioural change amongst residents, thus lowering CO_2 emissions. Examples of innovative low carbon housing programmes, energy systems and neighbourhoods in Europe and USA are introduced in the book.
A series of zero carbon housing models are presented. These offer valuable generic lessons for delivering zero carbon homes (the focus is on new stock, but some of the lessons may equally apply to existing stock), both in terms of policy and practice. These lessons help us to understand how prototype systems can move into the mainstream and how industries will need to transform to assist wider deployment. It highlights some of the instruments and mechanisms that could be used to support this transformation. Finally, the wider implications of introducing these innovative systems in terms of lifestyle and urban form are explored. Overall the book postulates various scenarios for delivering zero carbon homes, together with a toolbox approach for policy and practice to suit particular national and local circumstances.
The observations presented in the book are based on an extensive review of literature and fi eld work in the UK, USA, Sweden and Germany as part of the 'Zero carbon Homes' Project.

Global warming

Tackling global warming is essential in ensuring the long-term future of humanity. Greenhouse gases produced from the combustion of fossil fuels has led to an increase in the global temperature of 0.5°C since the industrial revolution. At the current rate greenhouse gas emissions will double by 2035 (550ppm CO_2 equivalent) and global average temperature will rise 2°C. By the end of the century the quantity of greenhouse gases in the atmosphere could more than treble, resulting in a 5°C temperature rise (Stern, 2006). To put this in context the climate in the last ice age was only 5°C cooler than it is today (Stern, 2006).
A temperature rise above 2°C will have major impacts on the global physical environment. Ecosystems – including coral reefs and rainforests – would be severely threatened. If the temperature rises more than 2°C between 15–40% of species would face extinction. Increased levels of CO_2 in the oceans will lead to acidification and depletion of fish stocks. The number of extreme weather events is also likely to increase and the sea-level will rise. This will threaten many low-lying communities in developing countries, particularly

in south-east Asia. Eventually it will affect islands in the Atlantic and Pacific. A rise in temperature of 3–4°C could also result in the inundation of key global cities – London, Shanghai, New York, Tokyo and Hong Kong. Water supply would of course be affected by climate change. Some areas would suffer from drought and others from floods. Stern suggests around a billion people would be affected in each case. Even with a 1°C temperature increase water supplies will be threatened in more marginal communities. Melting glaciers (initially creating a flood risk and latterly a water deficit) are likely to affect water supply to around one sixth of the population – particularly in parts of China, the Indian sub-continent and the Andes, South America.

With a 1°C temperature rise the failure of crops in arid regions would become more widespread. An increase in temperature of 4°C would produce a significant reduction in yields globally. The coverage of productive land will reduce dramatically and become focused in temperate regions. As the climate warms, food and water will become increasingly scarce. Eventually, without some form of intervention, this will lead to mass migration to the productive regions of the globe, resource wars and population crashes. By 2050, 200 million people are likely to be permanently displaced from their homes by rising sea levels, floods and droughts.

Initially climate change is likely to be a greater threat to the developing world. The marginal nature of the environment, poverty and reliance on agriculture, make developing countries particularly vulnerable to climate change. First, much of the developing world already suffers from drought and thus productivity and crop yields are low. Second, the economies of these regions are largely dependent on agriculture. The impact of global warming on crop yields is likely to be catastrophic for the farmers and national economies based on agricultural production. Third, poverty renders these communities unable to buy the technology to alleviate the problems caused by global warming or to mitigate climate change.

In contrast, the developed world benefits from more temperate climates, greater wealth and a non-agrarian economic base. Thus in the short term it is less at risk from climate change. In fact countries in northern latitudes (Scandinavia, Russia, Canada) are expected to benefit in the short term from temperature rises[1]. However, with a 2°C rise in global temperatures crop yields and water availability is expected to decline by 20% in Southern Europe. Thus, the Mediterranean is likely to suffer from problems of drought even in the short term.

Some of the changes precipitated by global warming are irreversible. For example, even modest climate change (i.e. an increase in temperature of 1.5 °C) will result in the irreversible melting of the Greenland ice sheet. It would also reduce natural carbon absorption and increase methane releases, which in turn results in temperature rises. Thermal oceanic circulation may also be disrupted. All three processes are irreversible and increase the risk of very abrupt changes in the global climate.

Globally around 65% of greenhouse gas emissions are energy related. The majority of emissions are produced from power generation and distribution (24%). However, transport (14%), industry (14%) and buildings (8%) also contribute significantly to greenhouse gas emissions (largely CO_2 emissions). Thus the way in which we plan new and existing communities, the transport infrastructure, the built environment, the energy systems will have a signify -cant impact on CO_2 emissions and climate change.

Energy security

Energy security poses a growing global threat. Increasing demand for energy, scarcity of resources, increasing prices, political confl icts and economic instability all combine to reduce energy security. Energy supply is integral to the economy of a country and thus it is fundamental to national security. Energy is also essential to achieve basic levels of comfort and wellbeing. Demand for energy is increasing globally more recently driven by the emergence of new economic powers – particularly China. Yet stocks of coal, oil, gas, uranium and rare earth elements (REE) are declining.

Most countries are reliant on energy imports which make them very vulnerable to shortages and price rises. Uncompetitive markets resulting from the dominance of energy-superpowers (e.g. Russia) or formation of cartels (e.g. OPEC) threaten energy security. For example, price manipulation to maximise group revenue by OPEC in 1973 led to soaring energy prices. It resulted in many countries reviewing their reliance on oil and taking proactive measures to reduce their future dependence (for example Sweden boosted its investment significantly in renewable energy after the oil crisis). The share of oil supply coming from the OPEC nations in the Persian Gulf is expected to increase from 26% in 1997 to 41% by 2020 (Geller, 2003). Given the existence of the OPEC cartel and political instability in the Gulf region oil-importing nations are destined to face even greater economic and security risks in the future (Geller, 2003).

Disputes amongst suppliers and transit nations may prevent supplies from reaching consumers. For example, the ongoing disputes between Russia and the Ukraine between 2006 and 2009 resulted in 18 countries in the European Union having their gas supply cut-off.[2] In 2006 Russia claimed the Ukraine was not paying for gas, and siphoning off gas exported to the European Union from the pipelines crossing the Ukraine from Russia. In 2007 and 2009 further disputes occurred over Ukrainian gas debts. For the European Union this meant a reduction in gas supply during the coldest months of the year, which made it very vulnerable to price hikes in the gas market.

Geopolitical factors influence investment in energy and scarcity of resources. Depletion policies, resource nationalism and political instability affect the quantity of energy available on the world market. Some countries – Saudi Arabia, Kuwait, Venezuela – have introduced depletion policies to preserve energy resources. Depletion policies ensure that resources are released slowly in order to provide a wealth fund for future generations or simply increase the value of the energy resource. Other countries operate resource nationalism which prevents or restricts access to energy reserves for international oil companies (IOCs). One side effect of this is that resources are not extracted as efficiently. Political instability and military action in regions also affects energy supply. It can impact on foreign investment and hamper operations. All three mechanisms reduce the energy supply available globally.

Yet there is rapid growth in demand for energy from developing nations, the most voracious being China. China has realised the need to expand its resource base to ensure continued economic growth. Thus during the period of global economic recession, the Chinese have begun to invest in energy resources overseas. The Chinese have invested in oil reserves in Russia, Venezuela and Brazil in exchange for long-term commitments to supply oil. They have also invested in a scheme to develop an area beneath the Persian Gulf sea-bed which holds 8% of the world’s reserves of natural gas. With the emergence of these new economic powers, Europe and America face greater global competition for finite energy resources.

There has been growing interest in renewable energy globally. This generated markets for green technologies. China currently produces the majority of the rare earth elements (REE) critical to the manufacture of many green technologies (e.g. wind turbines, low energy light bulbs, hybrid cars, catalytic convertors). Chinese mines currently account for the majority of global REE supplies. China is trying to ensure that all raw REE materials are processed within its borders. During the past seven years it has reduced the amount of REE materials available for export by 40% (Milmo, 2010). The restriction on supply of the REE materials has created a serious problem for those producing green technologies globally. There is now an effort to set up mines for REE materials in the West, but they are 5–10 years away from significant production, which is likely to slow the deployment of green technologies (Milmo, 2010).

To overcome problems of energy security a nation, or groups of allied nations, must become more self sufficient. The response to this is two-fold. First countries need to address energy consumption through efficiency measures. This might include reducing generation and transmission losses using combined heat and power, localised supply networks and smart grids. It could involve increasing the energy efficiency of building stock or encouraging a change in consumer behaviour through pricing policies. Once demand is reduced it becomes more feasible to substitute finite sources of energy (oil, gas, coal and uranium) with renewable resources. Thus the second part of the response is to move away from the import of fossil fuels towards domestic generation of renewable energy. Ideally countries will eventually export renewable energy through means of super-grids. Thus, countries become less reliant on a few fossil fuel cartels and are less affected by global shocks, regional disputes, depletion policies and resource nationalism. Fortunately this also gels nicely with an agenda to reduce greenhouse gas emissions.

Carbon emissions from housing

Key drivers of emissions from energy use include activity drivers (total population growth, increase in households, building stock), economic drivers (total GDP, income, and price elasticity), energy intensity (energy intensity of energy systems, appliances, housing), and carbon intensity (fuel mix). These factors are in turn driven by changes in consumer preferences, energy and technology costs, settlement and infrastructure patterns, technical progress, and overall economic conditions (IPCC, 2000).

Buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the European Union (significantly more than globally). Of that 413 million tonnes of CO_2 was produced by the residential sector in the EU27 nations during 2007, 10% of total CO_2 emissions for EU27 (European Environment Agency, 2009). The average European resident produces 983 kg of CO_2/ capita (the world average for the residential sector is 308 kg of CO_2/ capita). In the USA CO_2 emissions from buildings approximately equal the combined carbon emissions of Japan (Department of Energy, 2009). The residential sector produces around 20% of CO_2 emissions in the USA (1264.9 kg of CO_2/ capita), which equates to 4% of the total global output of CO_2 emissions (Department of Energy, 2009). Globally residential heating, lighting, and appliances use accounts for 11% of total energy consumed[3] (Energy Information Administration, 2007).

Today CO_2 emissions from the residential sector in developing countries is relatively low 143.5 kg of CO_2/ capita, compared with 967 kg of CO_2/ capita in developed countries (IEA, 2006). However, these figures mask the reality that population is far larger and rapidly expanding in developing countries, putting increasing pressure on energy supply and resulting in a rapid increase in CO_2 emissions. In the developing world a process of rapid urbanisation is taking place.

In 1800 only 3% of the world's population lived in cities. By 2030, 60% of the global population will live in cities (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2005). In 1975 there were five megacities – Tokyo, New York, Shanghai, Mexico City and São Paulo. In 2001 there were 17 megacities with 13 in the developing world. In 2015 there will be 23 megacities with 18 in the developing world. Today the five largest cities are Tokyo, Mexico City, São Paulo, New York City and Mumbai (Bombay). By 2015 they will probably be Tokyo, Dhaka, Mumbai, São Paulo, and Delhi. This will translate into rapid expansion in housing stock in these countries, and as households become more affluent it will result in the growth of associated CO_2 emissions in the residential sector, unless there are radical changes.

As global population expands, more households form, more accommodation is built, more energy is consumed and carbon emissions produced by the residential sector. In affluent societies reduction in household size, further increases demand for new accommodation. It also results in a less efficient use of resources in the home, including energy. Small households produce more CO_2 emissions per capita, than larger households (Williams, 2006). More affluent households also consume more energy. Thus, demographic trends will result in an increase in CO_2 emissions from the residential sector. Economic drivers also affect CO_2 emissions from the residential sector. There is a strong positive relationship between GDP and CO_2 emissions. Absolute decoupling through dematerialisation and substitution has not yet occurred. Whilst some decoupling of economic growth from energy use have been noted in the European Union (European Environment Agency, 2005), it is not clear to what extent changes in consumption patterns have contributed to this since most high-impact consumption categories (transport and household energy use) are actually increasing. Within these categories, growth in consumption has more than offset benefits from improved technological efficiency. Increasing affluence and lowering energy prices both have a profound effect on energy consumption and associated CO_2 emissions. The lower the relative cost of energy, the more is consumed. For example, in the United Kingdom between 1970 and 2000 the energy efficiency of buildings improved significantly, with carbon dioxide emissions from the domestic sector only reducing by 22% (Lowe, 2009). However, during this period the stock mean temperature rose by six degrees as the real cost of energy declined, with the cost of space heating dropping by a factor of two and affordability (a function of price and affluence) rising by a factor of five (Lowe, 2009).

During its life-cycle a house (or in fact any building) will consume approximately 15–20% of its energy budget during construction and disposal phases, whilst the majority of energy will be consumed during operation. The quantity of CO_2 produced by a household during the operational phase of its life-cycle will depend on scale of activity (duration and intensity of activities), energy intensity (dependent on the energy efficiency of the building, appliances and energy system) and carbon intensity (fuel mix). For example, energy consumed for space and water heating in Spain is significantly lower than that consumed by Sweden due to climatic conditions (scale of activity). In Denmark significantly more energy is consumed by space heating than in Sweden (with similar climatic conditions) where more stringent building regulation has imposed high energy efficiency standards on buildings (energy intensity). In Sweden more energy is consumed

per person in the home than in Germany yet CO_2 emissions in Germany are significantly higher[4] (World Resource Institute). This is because the carbon intensity of Germany's fuel supply is significantly higher than in Sweden (2.45 tonnes CO_2 /toe in Germany compared to 1.03 tonnes CO_2 /toe in Sweden – US Energy Information Administration, 2010) resulting from greater dependence on imported fossil fuels.
Housing and households have a significant impact on the global production of CO_2 emissions. This is set to increase in coming decades with growth in the number of households, reduction in household size and increase in affluence. Thus, finding low carbon (preferably zero carbon) housing alternatives could play an important role in tackling climate change. New housing in particular is seen as a 'low-hanging fruit'. Certainly it will be easier to tackle CO_2 emissions from new housing than from existing stock, car travel or aviation, as long as suitable technical systems are put in place.

The zero carbon homes policy

In 2006 the UK Government decided to launch a target requiring that all new homes would be zero carbon by 2016. This target was introduced as part of a wider push to achieve a reduction in carbon emissions from the domestic sector. It was hoped that the target, in combination with a major new housing programme, could significantly reduce domestic CO_2 emissions without major public subsidy. However, it was met with a great deal of opposition from the UK house-building industry and limited interest from the market, and progress so far has been exceedingly limited. Solutions are sought to enable the delivery of zero carbon homes in the UK.

The European Union has also introduced a zero-net energy target for new buildings and major refurbishments from 2020 in Europe. In some European member states buildings are already relatively low carbon emitters, due to energy efficient design, connection to decentralised energy networks and low carbon energy sources. Some examples of good practice already exist, which could provide a useful template for future development. However, these examples tend to be isolated even in Europe. The question here is how can these innovative systems be scaled up and what policy instruments have been used to support them.

Currently the USA has no plan to introduce a zero carbon target for new homes. Some more progressive states have introduced a less demanding target to deliver net-zero energy homes by 2020 (e.g. California). This has produced a number of interesting housing models, which could inform the technical solutions for achieving zero carbon homes. In addition, valuable research into mechanisms for deploying net-zero energy housing models in the USA can help to inform deployment strategies for zero carbon homes in Europe (including the UK).

Of course the majority of new build housing development will constructed in the coming decades in the developing world. Certainly the Chinese are starting to integrate zero carbon systems into new mega-cities. More generally, targets to achieve zero carbon or even net-zero energy in new buildings have not been introduced in developing countries. However, the technical solutions and possibly the policy lessons learnt from Europe and the USA may be transferable. Certainly factors influencing industrial and market transformation, the impact of zero carbon policy on development patterns and lifestyles investigated through European and American case studies in this book could provide valuable insight for those wishing to encourage the development of zero carbon homes in the developing world.

The research

For the academic audience a very brief outline of the theoretical framework on which the research and conclusions of the book are based is presented here. In addition a brief overview of the research methodology and data sources are given. Systems theory provides the theoretical framework from which this book draws. Zero carbon homes are a socio-technical system embedded in a wider complex system. Many actors are involved in the supply of zero carbon homes. These actors are inter-dependent. They are also influenced by the wider landscape in which they operate. This landscape is composed of a number of inter-dependent social, environmental, economic, technical, institutional and political sub-systems.

Changes in one sub-system or even actors will have ramifications for the system as a whole. This will impact on the supply and demand for zero carbon homes. To understand the factors influencing the deployment of zero carbon homes one must endeavour to understand these inter-dependencies and interactions in a holistic way. This can help to inform suitable policy instruments for encouraging deployment. Thus, systems theory provides the basis for the research.

A combination of sub-fi elds within systems theory – innovation, diffusion, transition and socio-technical theories – underpin specific areas of research in the book. Innovation theory is applied in order to explore how zero carbon homes (and their component systems) have emerged. It is used to investigate the factors influencing industrial and policy innovations that have led to the development of new systems of production, products, services and institutional structures needed to deliver zero carbon homes (Chapters 7, 8 and 9).

Diffusion theory is applied in order to explore the transmission of zero carbon technical systems through the social system. It is used to investigate current and future markets for zero carbon homes, as well as how these markets might be encouraged and developed (Chapter 6). Diffusion theory is also utilised to examine how policy instruments can support the wider deployment of zero carbon homes and how these policy instruments change over time as markets mature (Chapters 9 and 10).

Transition theory (the multi-phase concept) underpins the assessment of where system transitions are most likely to begin, within industrial regimes or in empowered niches (Chapters 7 and 8). It can be used to analyse the barriers (institutional, social, technical, infrastructural, economic) to transitions within industry and society. This provides greater understanding of where policy instruments should focus, if systemic transitions are to occur and zero carbon homes are to be delivered (Chapters 7, 8 and 9).

Socio-technical systems theory is used to explore how social and technical systems jointly evolve. It is used in the book to explore how energy systems, household preferences and behaviour have co-evolved. It is utilised to investigate how the co-evolution of social and technical systems could enhance the operation of zero carbon homes and promote zero carbon lifestyles (Chapter 11).

The book is based on extensive research conducted from 2007 to 2010 by the author. It draws on a review of literature, databases and detailed case studies. The literature review provided the basis for the research. It helped to begin to identify technical options for delivering zero carbon development, the factors influencing supply and demand for zero carbon homes, the potential impact of living in a zero carbon home on individual well-being and lifestyle and the policy instruments that could be used to encourage zero carbon development.

The research also drew upon the analysis of a number of large data sets produced by national and international bodies from research institutions, the construction industry, energy industry and government (Table 1.1). These databases provided the information needed to begin to identify examples of good practice – low energy/carbon housing programmes, low carbon energy systems and local low carbon development projects.

The research developed several in-depth case studies in four countries Sweden, UK, Germany and the USA. A combination of secondary data (post-occupancy surveys, research reports, publicity documents, local data sets, etc) and primary data collected through detailed guided interviews with key players was used to develop each case study.

The case studies were chosen because they provided a diversity of state-of-the-art technical solutions to delivering zero carbon homes (Table 1.2). Thus, they could highlight the range of factors influencing the deployment and successful operation of LZC technologies. The case studies also provided a range of contexts (political, economic, cultural, institutional and environmental) in which zero carbon systems could be embedded. Thus, it was possible to determine a variety of technological options that might be most appropriate in different contexts. The case studies also demonstrated an assortment of policy instruments for delivering zero carbon homes, appropriate to a diversity of political systems.

Guided interviews were conducted with key stakeholders including: academics, environmental consultants, research institutions, government officers (national and municipal), built environment professionals (architects, planners, engineers), house-builders, utilities, ESCOs, property agents, financing bodies and residents. This added greater depth to the secondary data collected for each case study. The guided interviews sought to determine the following:

- Technical solutions for delivering zero carbon homes;
- Factors influencing demand for zero carbon homes and deployment;
- Factors influencing the supply of zero carbon homes and scaling-up examples of good practice;
- The policy instruments used to encourage the deployment of zero carbon homes and the role of government;
- The impact on built form and development patterns of introducing a zero carbon policy;
- The role of planning in delivering zero carbon homes;
- The impact of living in zero carbon homes on residents' lifestyle and well-being.

The feed-back from the various key stakeholders was collated and analysed. Table 1.3 below shows where the feed-back from the interviews helped to inform the research questions posed.

The book

This book provides a strategic overview of all of the issues surrounding the introduction of a zero carbon home policy, the implications for government, industry and households. It critically analyses existing projects – identifying both strengths and weaknesses. It also assesses the transferability of the successful elements of these projects between regimes and landscapes, the ability to scale up and the generic lessons to be learnt for zero carbon development. Nowhere in the literature has there been a discussion about the wholesale changes that would be needed in both the energy and house-building industries to deliver zero carbon homes universally. Nor have the spatial implications, post-occupancy problems, issues of market creation and resilience been discussed. This book addresses all of these issues.

It also has an international dimension. It presents the experiences of four different countries in delivering LZC development. The UK, Germany, Sweden and USA offer very different policy approaches to delivering zero carbon, energy-plus (solar, zero-net energy) and low-energy houses as well as a LZC energy supply (heat and electricity). The regulatory, institutional, economic, cultural, political, physical and technical context in each case is very different, yet many common barriers and solutions to overcoming those barriers are demonstrated by the case studies. These more generic lessons are drawn out in the book. This book should appeal to a very wide audience. It can be read by academics, students, practitioners and lay readers as a critical analysis of the perils of introducing a very progressive environmental policy within a market context. It could be used by policy-makers to identify more successful political strategies, instruments and institutions for delivering low-carbon development. For practitioners it might provide insight into the ownership and management structures, processes, partnerships and expertise required to deliver zero carbon homes. For planning practitioners it will provide guidance on the models for zero carbon homes, spatial implications and offer insight into how the planning system can become more proactive in facilitating zero carbon development.

The book divides into three parts. Part 1 provides an outline of possible technical options for delivering zero carbon homes. Part 2 is largely descriptive, presenting the international case studies. Part 3 analyses what is needed to successfully deliver zero carbon homes in the future, drawing on the case studies presented in Part 2, the experience of the key stakeholders interviewed, databases and literature.

The book is organised as follows:

Part 1

Chapter 2 discusses various generic technological options for achieving zero carbon emissions from housing. It focuses on improving the energy effi - ciency of stock and decarbonising the energy supply (using decentralised and centralised infrastructural systems). It discusses how technological systems might be combined effectively in different locations and at different scales to deliver zero carbon housing.

Part 2

Chapter 3 discusses four national programmes that have produced low/ zero carbon (LZC) housing in Sweden, Germany, the UK and USA. These programmes represent a range of technical models (low-energy, passive and solar houses) and offer a variety of approaches to deployment (from regulation and large state subsidies to green mortgages and tax incentives). Some generic lessons for industry and policy-makers for the development of LZC housing and refurbishment of existing communities are drawn from the case studies.

Chapter 4 presents a variety of LZC energy systems from Europe and the USA. These examples represent a range of LZC energy systems that can be adopted at a variety of scales. Potential demand for and deployment of the systems are discussed. The scale of industrial transformation required to deliver the systems is evaluated. The policy instruments needed to drive this transformation and the impact on lifestyle are investigated. Some generic lessons for industry and policy-makers planning to develop LZC energy systems in new and existing communities are drawn from the case studies.

Chapter 5 introduces various examples of LZC neighbourhoods from Europe and the USA. The neighbourhoods display a range of technological systems to reduce carbon emissions. In each case these systems are managed, operated and maintained in different ways. The resident also adopts a variety of roles from being a passive consumer, to a being actively involved in the management and production of energy. This chapter touches on how residents interact with new technical systems to reduce carbon emissions and demand for LZC neighbourhoods. Some generic lessons for industry and policy-makers for the creation of LZC neighbourhoods are drawn from the case studies. The extent to which these demonstration projects have scaled up or informed future developments is also discussed.

Part 3

Chapter 6 analyses the factors influencing demand for zero carbon energy and low-energy, passive, energy-plus, solar, zero-net energy and zero carbon houses based on the European and American case studies. It identifies the current characteristics of the market and the current position in terms of deployment of these new technical systems. It postulates how demand can be enhanced and deployment encouraged, using a variety of marketing, publicity and costing strategies.

A revolution in the house-building and energy industries will be needed to deliver zero carbon homes (discussed in Chapters 7 and 8). It will require that new supply chains, construction processes, expertise and partnerships are developed. It will result in a cultural shift and institutional changes within both industries. The role of players within industry may change and new players may emerge. Longer-term horizons for fi nancial reward and level of resident involvement in the production process will also fundamentally change the nature of both industries.

Rarely will markets for new products develop without some form of intervention. Chapter 9 compares policy instruments that could be used to encourage the delivery and the creation of markets for zero carbon homes, drawing on experience from the case studies. The appropriateness of policy instruments varies significantly depending on the contexts in which they operate, ranging from market-based to more interventionist systems. Policy instruments adopted internationally, nationally, regionally and locally are considered and the relative benefits of each in terms of encouraging innovation are evaluated. The merits of focusing instruments on increasing supply or demand are discussed, as is the need to use a combination of fiscal, regulatory and educational instruments.

In Chapter 10 the spatial impacts of achieving zero carbon are discussed and illustrated by the case studies. The geography of zero carbon development and impact on urban form are discussed. Planning offers a spatial regulatory tool for delivering zero carbon development. The strengths and weaknesses of planning as a tool for delivering zero carbon development are evaluated and innovative planning approaches are presented.
In chapter 11 zero carbon lifestyles are discussed. The conflicts between quality of life and zero carbon technical systems are assessed. The difficulties encountered at the user-technology interface are investigated. Options for

encouraging a paradigm shift, moving passive consumers towards becoming engaged energy citizens (living zero carbon lifestyles in zero carbon homes), are explored using lessons drawn from the European and American case studies.

The final chapter concludes with an overview of the key changes needed in industry, society and policy to support movement towards zero carbon homes and lifestyles. It reflects on the progress made to date and highlights the pitfalls. It postulates a series of scenarios for delivering zero carbon homes together with a toolbox of policy instruments for implementation.
Happy reading!