A reduction in the energy demand of buildings can make a major contribution to achieving national and international carbon reduction goals, in addition to addressing the interlinked issues of sustainable development, fuel poverty and fuel security. Despite improvements in thermal efficiency, the energy demand of buildings stubbornly remains unchanged, or is only declining slowly, due to the challenges posed by growing populations, the expectations of larger, more comfortable and better equipped living spaces, and an expanding commercial sector.

Building Futures offers an interdisciplinary approach to explore this lack of progress, combining technical and social insights into the challenges of designing, constructing and operating new low-energy buildings, as well as improving the existing, inefficient, building stock. The twin roles of energy efficiency, which is predominantly concerned with technological solutions, and energy conservation, which involves changing people’s behaviour, are both explored. The book includes a broad geographical range and scale of case studies from the UK, Europe and further afield, including Passivhaus in Germany and the UK, Dongtan Eco City in China and retrofit houses in Denmark.

This book is a valuable resource for students and academics of environmental science and energy-based subjects, as well as construction and building management professionals.

Jane Powell is a Senior Lecturer in the School of Environmental Sciences at the University of East Anglia. She teaches and has research interests in the energy efficiency of buildings and low-carbon energy, in addition to environmental evaluation methodologies such as lifecycle assessment.

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‘This book is a must read for anyone planning a career in the built environment. It accurately captures the complexities of energy demand through focusing on interdisciplinarity and astutely assesses the opportunities of smart energy in homes, retrofits and new builds. Importantly, the book puts people right at the centre of its thinking.’

*Philip Sellwood, Chief Executive, Energy Saving Trust*

‘We are on the threshold of a “next generation” of design thinking. This book explores some of the shortcomings in current approaches and provides blueprints for designing genuinely better buildings in which we can, over their and our lifetimes, successfully and comfortably survive in a warming and resource-challenged future.’

*Sue Roaf, Heriot-Watt University, Edinburgh*
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Foreword

Tackling the current, and unacceptable, levels of modern energy services deprivation (1.5 billion people without electricity and three billion without clean cooking) will have a transformative social impact through poverty alleviation and improved livelihoods, productivity, human health and energy security, together with environmental (e.g. indoor and outdoor air pollution, climate and ecosystem) co-benefits. That will, however, only be the case if there is a transition to a low-carbon economy and we decrease our reliance on fossil fuels, which is driving the single most serious environmental and development issue facing the world today – human-induced climate change.

There is no doubt that the composition of the atmosphere and the Earth’s climate have changed since the Industrial Revolution, predominantly because of human activities. The atmospheric concentration of carbon dioxide has increased by over 30 per cent since the pre-industrial era, primarily from the combustion of fossil fuels and deforestation, accompanied by an increase in global mean surface temperature of about 0.85°C. The IPCC Fifth Assessment Report projects that without additional actions to reduce greenhouse gas emissions the projected emissions growth is expected to result in global mean surface temperature increases relative to pre-industrial levels in 2100 from 2.5°C to 7.8°C when climate uncertainties are included. Even full implementation of the Cancun pledges will not set the world on a pathway to achieve the 2°C goal. The impacts of climate change are likely to be extensive and primarily negative, and to cut across many sectors. For example, throughout the world, biodiversity at the genetic, species and landscape level is being lost, and ecosystems and their services are being degraded. In addition, food and water security are being threatened, as is human health, in many parts of the world.

Global warming caused by human-induced carbon dioxide increases is essentially irreversible on timescales of at least 1,000 years, mainly because of the ocean’s storage of heat. Therefore, today’s decisions about anthropogenic carbon dioxide emissions will determine the climate of the coming millennium. Without strong action to reduce emissions over the course of this century, we are likely to increase the atmospheric concentration by at least 300 ppm, taking concentrations to 750 ppm CO₂e or higher by the end of this
century or the beginning of the next. The world’s current commitments to reduce emissions are consistent with at least a 3°C rise (50–50 chance) in temperature. Such a rise has not been seen on the planet for around three million years, much longer than Homo sapiens have existed. Human-induced carbon dioxide emissions pose a serious risk of a 5°C increase to an average temperature not seen on the planet for 30 million years.

The major fossil fuel sources of carbon dioxide emissions are from energy production and use, with the key sectors being transportation, buildings and industry. This book, Building Futures: Managing Energy in the Built Environment, is essential reading for those interested in reducing emissions from buildings in a cost-effective and socially acceptable manner. It points out that energy is essential for all societies in order to meet their need for food, shelter and industry, and that the issue of energy use is not solely associated with climate change, but also energy security, fuel poverty, pollution, resource limitations and poverty alleviation. Universal access to clean energy services is vital for the poor, and a transition to a low-carbon economy will require rapid technological evolution in efficient energy use, environmentally sound low-carbon renewable energy sources and carbon capture and storage, coupled with an appropriate policy framework (including putting a price on carbon) and changes in behaviour. The longer we wait to transition to a low-carbon economy, the more we are locked into a high-carbon energy system with consequent environmental damage to ecological and socioeconomic systems. Therefore, if the world is to have any chance of achieving the politically stated goal of limiting the increase in global mean surface temperature to no more than 2°C above pre-industrial levels (this would require a 50 per cent or greater reduction in global emissions by 2050), then energy demand in the building sector must decrease significantly in both existing and future buildings. This will be a major challenge for both developed and developing countries.

The book, which adopts an interdisciplinary approach to explore the key issues and solutions for reducing the energy demand of buildings in a warming world, discusses a wide range of issues, including approaches to reduce occupational energy use, energy embodied within buildings, the energy performance gap of buildings (i.e. the difference between the predicted and actual performance), approaches to retrofit existing buildings, energy efficiency building standards (specifically Passivhaus), building ventilation and building futures. Some of the key messages of the book include the following:

- Globally, energy demand continues to increase, with buildings currently being responsible for 34 per cent globally and 57 per cent in OECD countries.
- The number of households world-wide is predicted to grow by 67 per cent and the floor area of the service sector by almost 195 per cent by 2050.
- Addressing energy demand in the building environment is seen as critical by many countries trying to reduce their carbon emissions.
- Significant improvements in energy efficiency have driven down energy demand in all types of buildings, but this is counterbalanced by: demographic changes, such as increasing and ageing populations, leading to growing numbers of households; a desire for warmer and larger living and working spaces; and a greater number of appliances, particularly ICT equipment. In the service sector increases in energy demand are driven by more mechanical ventilation and air conditioning.
- The underlying reasons for energy use in buildings are complex and cross numerous disciplines, with no ‘magic bullet’ solutions. Even very technical aspects often have
social causes or consequences. Thus while substantial improvements to reduce energy consumption can be achieved with existing technologies, design strategies and technical innovations, they are insufficient alone to meet these challenges.

- To overcome the numerous barriers and market failures that undermine investment in energy efficiency in the built environment requires policy interventions; however, their effectiveness is highly dependent on how they are implemented and enforced.
- Given that 80 per cent of UK buildings in 2050 have already been built, it is imperative that the energy efficiency of the current stock is improved, while recognizing that the cost of retrofitting increases dramatically with the reduction in carbon emissions.
- Even newly constructed or retrofitted low-energy buildings often do not achieve the anticipated energy demand reductions.
- To reduce energy demand a broad interdisciplinary, systems-based approach is required that focuses not only on buildings during occupation but throughout their lifecycle, including the institutions that deliver them (planning, design, construction, policy).

The potential energy savings and consequent reduction in carbon dioxide emissions that can be achieved by the buildings sector are in line with the (UK) 80 per cent reductions that are required from the sector by 2050. As this book demonstrates, much of the technological knowledge is already available, but the application of that knowledge will not meet its target goals unless the users of those buildings are also given voice and the buildings are viewed as a socio-technological system. That is why I believe this book will be invaluable for all those involved in the building sector, from engineers to builders and occupiers.

Professor Sir Bob Watson CMG FRS
Monash Sustainability Institute, Monash University
& School of Environmental Sciences, University of East Anglia
February 2015

Professor Sir Bob Watson is Visiting Professor at Monash Sustainability Institute and Director of Strategic Development at the Tyndall Centre for Climate Change Research at the University of East Anglia. His many former roles include: DEFRA Chief Scientist; Chief Scientific Advisor and Director at the World Bank; Associate Director for Environment in the Office of Science and Technology Policy in the Executive Office of the President in the White House; and Director of the Science Division and Chief Scientist for the Office of Mission to Planet Earth at the National Aeronautics and Space Administration (NASA). He is also a Blue Planet Award Winner.
The built environment will form a key part of how we, as a society, plan to address key global challenges, such as climate change, fuel poverty and energy security. These challenges emphasise the urgency of calls to reduce the energy demand of our building stock. But how do we practically go about reducing demand? What are the main obstacles to or enablers of change? What are we to realistically expect if we continue to focus on the technological ‘solutions’ that currently dominate policy? How can we best measure and monitor progress and performance? How could building energy demand change in the future? And, ultimately, what does all this mean for our future aspirations of constructing a lower-energy building stock?

In exploring such questions, we adopt an interdisciplinary approach that predominantly uses technical issues as starting points, before utilising social science perspectives for additional insight. Interdisciplinarity is important because although many challenges to reducing energy demand appear to be technical, in reality they are more complex and require the input of less technical disciplines such as the social sciences. Using this approach can provide a clearer understanding about how exactly those technologies will be adopted and used in reality.

This desire to write an interdisciplinary book on the built environment caused us problems when liaising with various publishers. We discovered that the vast majority are ill-equipped to even review an interdisciplinary book proposal, as editorial departments tend to be organised along traditional disciplinary boundaries (e.g. engineering, sociology). It is thus unsurprising that there are so few books that adopt an interdisciplinary perspective – spanning both technical and social disciplines – as we do here. It is exactly for these reasons that we are grateful to Routledge, who were able to engage with such interdisciplinarity.

This book consists of eight chapters. The first two chapters – Energy in the built environment (Chapter 1) and Reducing energy demand (Chapter 2) set the scene and provide context and a solid rationale for the rest of the book. Specifically, the first chapter starts with a review of global energy demand and the challenges that demand is causing,
before focusing on how energy is used in buildings and what is driving changes in that demand. The second chapter introduces different strategies for lowering the energy demand of buildings, which assists in detailing some of the more technical concepts that other chapters build upon and essentially take for granted. The following chapters then explore in greater depth: how one takes into consideration the energy demand of buildings across their whole lifecycle, including that which is embodied into materials (Chapter 3); differences between the expected energy performance and what is actually achieved (Chapter 4); the need to retrofit our existing building stock (Chapter 5); the Passivhaus energy efficiency standard (Chapter 6); and the challenges of meeting the ventilation requirements of our building stock (Chapter 7). Chapter 8 reflects more broadly on the cross-cutting synergies and challenges from the previous chapters and looks at possible ways forward.

This book is intended for those from both interdisciplinary and single-discipline backgrounds, who have an interest in learning more about how energy is used at present and is likely to be used in the future, as part of designing, constructing, retrofitting and occupying the international building stock. The book is inspired by an array of disciplines, including architecture, building engineering, economics, environmental sciences, human geography, sociology and science and technology studies. Specifically, this book is targeted at undergraduate- and Masters-level students, while PhD students will hopefully find it provides useful background to their research. We also hope this book will provide insight for construction, architecture, planning and building management professionals, particularly through the inclusion of real-world examples, practical guidance and a jargon-free narrative.

The title of this book rather presumptuously refers to the ‘built environment’, but we actually write about ‘buildings’. In terms of energy and demand, buildings are the central component of the built environment, but we recognise the importance of considering how the future of our buildings is managed in the context of the wider built environment. While energy management is often used interchangeably with the targeting of energy savings, in this book we implicitly adopt a broader approach. Indeed, we emphasise how different ways (e.g. design, planning, construction, maintenance, occupation) of engaging with energy-demanding building technologies represent some form of energy management.

This book is also firmly about the ‘environment’. We are not engineers; we are qualified to write about how to construct a building. Rather, we are environmental scientists, for whom trying to understand and manage environmental impacts and challenges is central to our focus and beliefs. We were also, at different times, all environmental science students at the University of East Anglia, so are interdisciplinary to the core. Our joint experience of teaching an energy module from an interdisciplinary perspective, and trying to find an appropriate interdisciplinary textbook, inspired the writing of this book.

We hope this book will contribute to an improved understanding of the complexity of reducing energy demand in buildings and of showing that there are no easy answers or quick-fix solutions. Nevertheless, we hope a holistic, interdisciplinary approach to this problem will lead towards sustainable ways forward for society.

Jane Powell, Jennifer Monahan, Chris Foulds
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We also thank our colleagues at Routledge who patiently guided us first-time authors through the intricacies of publication.
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Acronyms and units

ach  air changes per hour
ASHP  air source heat pump
BEMS  building energy management systems
BIM  buildings information modelling
BPIE  Building Performance Institute Europe
BRE  Building Research Establishment
BREEAM  Building Research Establishment Environmental Assessment Methodology
BSI  Building Standard Institute
BSRIA  Building Services Research and Information Association
C  carbon
CAD  computer-aided design
CEN  Comité Européen de Normalisation
CFL  compact fluorescent light bulb
CHP  combined heat and power
CIBSE  Chartered Institute of Building Services Engineers
CfSH  Code for Sustainable Homes
CO₂  carbon dioxide
CO₂e  carbon dioxide equivalent
CoP  coefficient of performance
COPD  chronic obstructive pulmonary disease
DEC  Display Energy Certificate
DECC  (UK) Department for Energy and Climate Change
DOE  (US) Department of Energy
EC  European Commission
ECO  Energy Company Obligation
EIO  economic input–output (analysis)
EEA  European Economic Association
EIA  (US) Energy Information Administration
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1 Energy in the built environment

1.1 Introduction

Energy is essential for all societies in order to meet their needs for food, shelter, industry and commerce. Energy-dense fossil fuels have allowed most countries to develop in a way that would have amazed pre-industrial society. Escalating populations, with rising standards of living, drive an ever-increasing global demand for energy, resulting in the interlinked problems of climate change, pollution, limits to resources, fuel poverty and energy security. As energy resources become scarcer, their extraction will be more expensive and cause increased environmental damage, leading to higher prices and increased fuel poverty.

However, despite this need to curb our demand for energy, in the words of the International Energy Agency, ‘taking all new developments and policies into account, the world is still failing to put the global energy system onto a more sustainable path’ (IEA, 2012, p. 1). Not only are we failing to progress sufficiently towards our long-term carbon targets, but we are also failing to tackle the inequity in access to energy resources, the health issues associated with energy use and the limits to our energy resources.

Globally we mainly use energy for the residential sector (25 per cent), services (9 per cent), industry (31 per cent) and transport (31 per cent) (2012 figures) (Figure 1.1). In addition to the residential sector, the energy used by ‘services’, which includes commercial, retail, public services, leisure sector, hospitals and education sectors, is also almost entirely associated with buildings. World-wide, buildings are considered to have an energy demand of over one-third of global energy and half of global electricity demand (IEA, 2013). So, if we are to tackle our energy-related problems successfully, the built environment needs to be a major contributor to reducing energy demand and carbon emissions. Technically, this reduction is relatively straightforward for buildings, compared to the logistical problems posed by other sectors such as transport. However, improvements in the energy efficiency of buildings are undermined by various factors, such as population growth and increases in living standards. Indeed, the number of households world-wide is
predicted to grow by 67 per cent and the floor area of the service sector by almost 195 per cent by 2050 (from 2007) (OECD/IEA, 2011).

Significant progress has been made to improve the thermal envelope of buildings, but the actual energy demand has not declined as much as predicted. In addition to technical failings, this problem is also due to how our buildings are used, suggesting that a more holistic, interdisciplinary approach is needed to explore the technical, environmental and social challenges of designing and using low-energy buildings. We are unlikely to meet our energy and carbon targets unless an interdisciplinary approach is used to tackle this challenge. The need for such an approach has been echoed by the UK Royal Academy of Engineers (2010), which identified an urgent need for multidisciplinary research in building design, engineering, energy and carbon efficiency that would inform the construction industry of the potential of alternative initiatives.

This first chapter initially explores why energy demand is a problem, discussing climate change, fuel poverty and energy security. We then examine how much energy we use globally, in the EU and the UK, and then focus on different energy sectors (industry, commercial, residential and transport), identifying why buildings are particularly important. This will include why the amount and types of energy we use are important, and in particular the carbon consequences of the fuel used, especially the electricity fuel mix. Trends in energy demand will be examined, identifying the underlying demographic and sociotechnical drivers for changes in energy use in buildings. We then go on to discuss the challenges to reducing energy demand in buildings and explore examples of policy solutions that are being used to address these challenges.

1.2 Why is energy use a problem?

Energy, of course, is used by everyone, in all parts of the global economy, although its form varies considerably. The poorest people use ‘local fuels’ such as wood and manure to cook basic ingredients and to keep warm, while Western societies use energy, predominantly from fossil fuels, to extract resources and manufacture products, for transportation and to provide services (heat, cooling and hot water) at work and in our homes. But this increasing