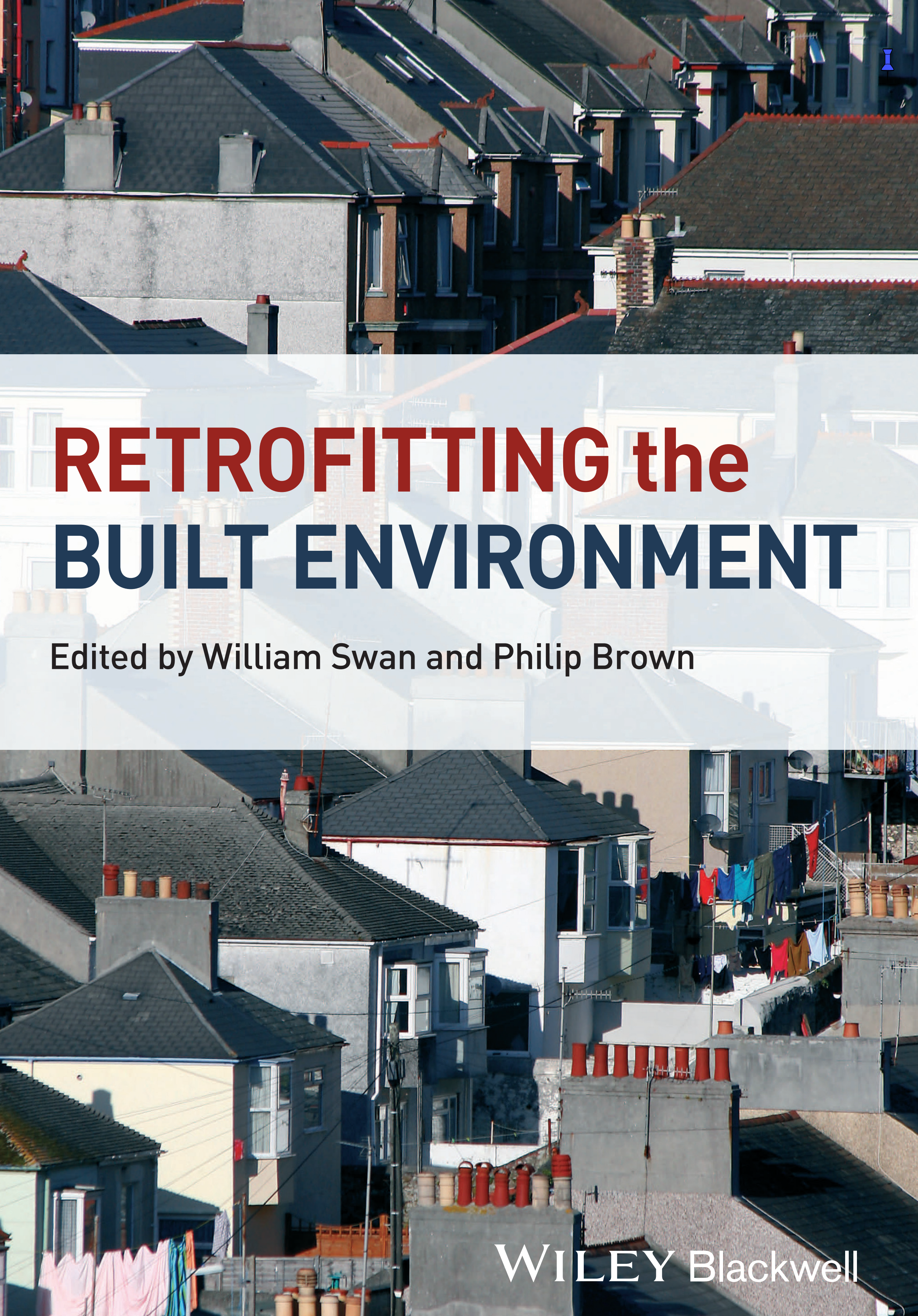

# RETROFITTING the BUILT ENVIRONMENT

Edited by William Swan and Philip Brown

WILEY Blackwell

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William Swan & Philip Brown
*University of Salford, UK*

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**Giovanni Dotelli** is Associate Professor of Materials Science at Politecnico di Milano, Italy, where he teaches courses on fundamentals of materials science and more advanced courses on materials for energy and environment, to electrical, environmental, chemical and materials engineers. He leads the Materials for Energy and Environment Laboratory (Mat4En2) at the Chemistry, Materials, and Chemical Engineering Department. His main research interests range from materials for renewable and alternative energy sources, in particular fuel cells, to hybrid materials for environmental applications and life cycle analysis of materials and industrial processes. He has led and contributed to several research projects on these topics, published numerous papers on peer-reviewed journals and contributed to many national and international conferences. He actively collaborates with many industries in the field of sustainability, product development and Green product design.

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**Patricia Gee** is President and owner of GreenRoots Strategies (GRS), a consulting practice specializing in stakeholder engagement and participatory programme design, environmental education and training, and Green sector economic development services. GRS has provided behaviour-based energy education and training services to residents and staff of over 10 000 social housing units across North America. Patricia has worked as staff and consultant to public housing authorities and resident councils and has directed publicly funded welfare-to-work initiatives that incorporated housing subsidies, work readiness training, remedial and continuing education and home ownership components. As Community Programs Manager with the NC Alternative Energy Corporation (now Advanced Energy), Patricia directed consumer research, design and demonstration of community-based sustainability initiatives and environmental social marketing strategies. She has worked as a non-profit executive director, teacher, certified mediator and trainer to design programmes that facilitate adoption of efficiency behaviours that endure over time. She received her BA from the University of North Carolina at Chapel Hill.

**Victoria Haines** is a Senior Lecturer and heads the User Centred Design Research Group at Loughborough Design School, Loughborough University. She is a Fellow of the Institute of Ergonomics and Human Factors and a Registered European Ergonomist. Her research focuses on consumer behaviour and user-centred design, exploring how people interact with their environment and the products and services they use, particularly in the area of energy efficiency and domestic buildings. She has worked extensively on multidisciplinary projects with commercial and industrial partners, acting as Co-Investigator on RCUK/E.ON funded projects CALEBRE (developing consumer appealing technologies for building retrofit) and CCC (Carbon, Control and Comfort in social housing), as well as the EPSRC DEFACTO project, focusing on domestic energy saving following refurbishment.

**Marianne Heaslip** is an architect at URBED (Urbanism Environment Design) Ltd in Manchester, UK. In recent years she has developed an expertise in low-energy building retrofit, through direct involvement in retrofit projects, strategic research and mapping of programme models, and evaluation of completed projects. She was a designer on 10 whole house retrofits as part of the TSB 'Retrofit for the Future' project, working on specification, supply chains and resident liaison in very low-energy retrofit. She is currently working with the Carbon Co-op in Manchester and community-led regeneration projects in Liverpool. She was a researcher and co-author of The Community Green Deal for SHAP (Sustainable Housing Action Partnership), which mapped out how low-energy refurbishment might be rolled out at a neighbourhood and regional scale. She also contributed to the Greater Manchester Domestic Retrofit Strategy.

**Mike Hodson** is Associate Director and Senior Research Fellow at the Centre for Sustainable Urban and Regional Futures (SURF), University of Salford, Manchester, UK. His research interests focus on urban and regional transitions to low-carbon economies and the lessons to be learned from such processes. Mike has published and presented widely on this agenda. He has done so for academic, practitioner and policy audiences, in the UK and internationally. Most recently Mike has written *Low Carbon*

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**Simon Marvin** is currently the Carillion Chair of Low Carbon Cities and Deputy Director of Durham Energy Institute in the Department of Geography at the University of Durham. Simon is an expert on the changing relations between cities, regions and infrastructure networks in a period of resource constraint, institutional restructuring and climate change. Simon's research has been funded by the ESRC, EPSRC, international research foundations, the European Commission, commercial funders and many public agencies. He is currently working with the UNEP as a lead author on a major new report on decoupling cities and resource use. His research is currently focused on two large programmes – the first looking at comparative urban responses to climate change and resource constraint by cities in Africa, China, Sweden and the UK, and the second funded by the EPSRC looking at whether and how UK cities develop the knowledge and capability to systemically re-engineer their built environment and urban infrastructure.

**Tim May** is Professor and Director of the Centre for Sustainable Urban and Regional Futures (SURF), University of Salford, Manchester, UK. His interests centre upon the relationship between knowledge, action, organizational strategy and working context, which he has developed in a variety of fields including: local government, probation and social services, universities, private businesses and urban and regional policy. Tim has written and edited 14 books that have been translated into 15 languages. He was also the series editor of *Issues in Society* – an international book series with Open University Press/McGraw-Hill in which 17 books were published (1998–2010). Among his more recent publications are a book on *Social Research and Reflexivity* (with Beth Perry, Sage Publications, 2011), a 4th edition of *Social Research: Issues, Methods and Process* (Open University Press/McGraw-Hill, 2011) and a special edition of the *Built Environment Journal* (with Beth Perry) on 'The roles of universities in building knowledge cities'.

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**Val Mitchell** is a Lecturer and member of the User Centred Design research group at Loughborough Design School. Val has over 20 years multidisciplinary research experience specialising in the development of User Centred Design (UCD) methodologies for eliciting user requirements for future technologies and services, in particular understanding user needs and requirements. She is currently a senior researcher on the EPSRC/E.On funded CALEBRE project, which is investigating user behaviours and comfort relating to the implementation of energy saving technologies within the home. She is Co-I on the EPSRC LEEDR project, which is seeking to reduce energy demand in homes through the innovative application of ICT, and also the EPSRC REFIT project, which is seeking to provide personalised, tailored retrofit advice to home owners.

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**Luke Smith** is an Architectural Technologist whose career to date has been dedicated to low carbon sustainable development and refurbishment of buildings. His experience includes working with the Energy Efficiency Partnership for Buildings, a not-for-profit membership organisation that facilitates closer working between industry, government and community organisations. He has also worked with the National Energy Foundation, the University of Salford and with Housing Associations and Local Authorities to advise on the conception and delivery of numerous domestic and non-domestic sustainable retrofit projects. Most recently he has contributed to a Built Environment Sustainable Energy Action Plan for the Liverpool City Region and led the development of a bespoke toolkit capable of systematically evaluating the opportunities and feasibility of reducing the demand for energy and water across a portfolio of existing assets. Luke is a BREEAM Accredited Professional, holds APMP status and is a qualified Domestic Energy Assessor. Prior to his work on retrofit Luke worked with the Vietnamese Green Building Council on the development and application of sustainable building metrics and benchmarks, Preston City Council and contributed to a number of international sustainable design competitions.

**Will Swan** is a Senior Lecturer in Buildings Retrofit based in the School of Built Environment in the University of Salford. He leads a number of projects in the field of sustainable retrofit looking at issues of the delivery of sustainable retrofit. He is particularly interested in issues of adoption, assessment of delivery of sustainable retrofit with regards to supply chains and process. Will chairs the Greater Manchester Retrofit Product and Process Innovation Group, sits on the National Refurbishment Centre and the Greater Manchester Buildings Group, dealing with buildings and energy use generally for buildings stock. Previously, he worked for the Centre of Construction Innovation where he advised on regional policy for sustainable buildings.

**Stephen Todd**, Senior Lecturer in Construction and Maintenance Technology, Building Pathology and Defects at the University of Salford, UK. Stephen has a background in practice before entering academia. He has worked on innovative European Commission funded low-energy housing research. He has also undertaken Stock Condition Surveys for Local Authorities and is a registered Energy Trainer, Code for Sustainable Homes Assessor and BRE Associate. He was also part of the team that developed the Warrington Energy House, which was a collaborative project between the University of Salford, Warrington Housing Association and Warrington Borough Council. For the past 28 years he has undertaken consultancy work in the building defects and energy conservation areas and has appeared as an expert witness where the quality of building work is under dispute. He also had a major input to the DETR Rebuilding Grant Project and was a member of the Welsh Pilot Scheme for Home Information Packs and Energy Performance Certification. He sits on Greater Manchester's Low Carbon Economic Area Group for Product and Process Innovation and previously on the Retrofit Standards Group. He also sits on an advisory panel for DCLG in respect of changes to the Building Regulations.

**Alexandra Willey** is a Special Projects Manager within the Property Investment team at Affinity Sutton, a national affordable housing provider to over 57 000 homes in the UK. After completing a Masters in town planning, she joined the organisation on the Graduate Management scheme in 2009, completing placements with Community Investment, Strategic Projects and Asset Management before being appointed as the FutureFit Project Manager in June 2010. FutureFit was Affinity Sutton's response to the challenge of Greening its homes and involved delivering various packages of retrofit and energy efficiency lifestyle advice to 150 homes nationwide. The award winning project looked at the practical implications of wide-scale retrofit and has provided a body of evidence to help prepare the industry for the Government's Green Deal. As Special Projects Manager, a post she has held since 2011, Alex is responsible for Affinity Sutton's approach to the retrofit agenda, including feeding into a number of industry groups and engaging with staff and residents around the forthcoming Green Deal.

# Foreword

*Kevin Anderson*

## Setting the scene for 2012

With early evidence that large-scale impacts of climate change are becoming discernable from the background of natural variability, there is increasing concern over the international community's abject failure to control emissions. The International Energy Agency's (IEA) chief executive (Maria van der Hoeven 2012) captures this pivotal moment in history when noting that 'The current state of affairs is unacceptable …. Energy-related $CO_2$ emissions are at historic highs, and under current policies, we estimate that energy use and $CO_2$ emissions [will] increase by a third by 2020, and almost double by 2050.' The IEA's chief economist (Fatih Birol; see Rose 2012) goes on to state that '[This] trend is perfectly in line with a temperature increase of 6 degrees Celsius, which would have devastating consequences for the planet.'

## Reality or rhetoric: Revealing the challenge of climate change

It is almost two decades since the international community committed to the 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (UN 1992). However, it was not until 2009 that the threshold between dangerous and acceptable levels of climate change was finally enshrined in an international agreement. The Copenhagen Accord (UN 2009), later reiterated in the Cancun Agreements, established a clear target against which to measure progress. The Accord, to which most nations are now signatories, requires that the global community 'hold the increase in global temperature below 2 degrees Celsius, and take action to meet this objective consistent with science and on the basis of equity'.

Against this backdrop of well-meaning but ultimately rhetorical commitments, emissions of carbon dioxide have continued to rise (IEA 2012), this despite several years of economic contraction in many industrialised nations. In 2009–2010, global carbon dioxide emissions rose markedly, up by almost 6%; in 2010–2011 they rose by a further 3%, with a similar rate of growth anticipated for this year.

Coinciding with this escalation in emissions, there is increasing recognition that climate change has little correlation with long-term end-point reduction targets, for example the UK's statutory requirement for an 80% reduction in emissions by 2050. By contrast, the rise in temperature is closely related to the continual build-up of long-lived greenhouse gases, particularly carbon dioxide, in the atmosphere. This characterisation of climate change as an issue of cumulative emissions and *carbon budgets*, has fundamental implications for the framing, chronology and urgency of policies for reducing emissions. Whilst 2050 targets lend themselves to gradual reductions dominated by the roll-out of low-carbon energy supply technologies, the science makes clear that in the absence of radical and immediate mitigation, such technologies will fail to deliver on the UK's international climate change commitments (Anderson *et al.* 2008).

The scale of the challenge, framed by scientifically informed carbon budgets as opposed to scientifically illiterate 2050 targets, has fundamental implications for mitigation policies, or, if neglected, the level of climate-related impacts and accompanying adaptation. This already testing transition from fiction to fact around climate change is made yet more difficult for the UK (and all Annex 1 nations) once the 'equity' dimension of the Copenhagen Accord is acknowledged (Anderson and Bows 2011).

The UK government, with guidance from the Committee on Climate Change (CCC), have established an overarching regime for UK mitigation policy premised on non-Annex 1 emissions peaking by around 2018. Whilst this may be a little later than is assumed for Annex 1 nations, it is nevertheless far removed from the spirit, if not the words, of the Copenhagen Accord, which explicitly recognises 'that the time frame for peaking will be longer in developing countries and … that social and economic development and poverty eradication are the first and overriding priorities'. If the UK were to take seriously the international commitments to which it is a signatory, the peak in emissions from non-Annex 1 nations would be post-2025, with the consequent rate of mitigation for the UK substantially increased.

Similarly, and again despite its explicit commitments, the UK frames national obligations in terms of a global carbon budget that, according to the CCC's own analysis, has a high probability (63%) of exceeding 2 °C. This not only contravenes the probabilities accompanying the Copenhagen Accord, but also those associated with the UK's own Low Carbon Transition Plan as well as various EU commitments.

Finally, the CCC and UK government's chosen carbon budget takes no account of global deforestation, presuming instead that any such emissions are solely the responsibility of nations where deforestation occurs. Given that the UK and most Annex 1 nations have already reaped the short-term rewards of their own national deforestation, this presumption is incompatible with the Accord's equity concerns (Anderson and Bows 2011).

Bringing together the science with a direct reading of the UK's international commitments transforms the climate challenge agenda from one of gradual mitigation and adaptation to 2 °C to one of urgent and deep reductions in emissions alongside adaptation to 4 °C (and higher) futures. As it stands the UK's current position, though politically palatable, is evidently and significantly in breach of international commitments as well as its own domestic obligations.

Consequently, whilst the UK asserts:

- its intention to make a fair contribution to avoiding dangerous anthropogenic interference with the climate system;
- that a 2 °C rise in global mean surface temperature is the appropriate delineation between acceptable and dangerous levels of climate change;

- that the chance of exceeding the 2 °C threshold should be kept to *exceptionally unlikely* to *very unlikely* (1% to 10%) (Intergovernmental Panel on Climate Change 2010);
- that national mitigation efforts should be derived on the *basis of equity*, by which non-Annex 1 nations are given considerable emissions space to further develop;

… the reality is that the UK position is premised on:

- a ~63% chance of exceeding 2 °C (contrasts with the below 10% chance to which it has committed);
- an almost complete disregard for issues of equity, with poorer nations:
  - expected to bear all of the responsibility for deforestation,
  - required to peak their emissions just a few years after nations such as the UK,
  - and be responsible for all emissions from manufactured goods consumed within the UK, but manufactured in poorer nations (i.e. maintain a 'producer'-based inventory of emissions).

## Retrofitting the future: Making the most of what we have

The scale of the mitigation challenge faced by the international community, even for an outside probability of staying below 2 °C, is unprecedented. However, for the wealthier parts of the world, not only are the necessary rates of mitigation beyond anything previously countenanced, they need to begin immediately if any emission space is to remain for poorer nations to develop. As a guide to the challenge, Annex 1 nations need to achieve an absolute reduction in emissions of around 40% by 2015, 70% by 2020 and over 90% by 2030 – and still emissions from non-Annex 1 nations would be required to peak by around 2025.

However, the challenge, particularly for the built environment and wider infrastructure, is more demanding still. Coincident with such deep mitigation is the need to ensure that communities are resilient to large and unpredictable changes in their local climate. The prospects of holding to a 2 °C future are slim; a 4 °C rise in the second half of the twenty-first century must be seriously considered (New *et al.* 2011). It is here that the built environment must endeavour to find the appropriate compromise. Houses must be designed not only to be low- or zero-carbon, but also to provide shelter in climatic futures likely to be very different from those currently experienced.

The UK is probably in a more fortunate position than many nations. Not only is it geographically insulated from some of the more extreme temperature impacts, the UK is a wealthy nation with a good science base that is beginning to provide some understanding of regional impacts. However, whilst the mitigation agenda is quantitatively clear, impacts and adaptation will never be subject to such certainty. Consequently, despite the benefits that accrue to the UK, the country's uncertain climatic prospects frame the future of the built environment as one of compromise and learning-by-doing rather than of optimisation.

With around 30% of the UK's carbon emissions arising from its 26 million domestic residences (EST undated) the built environment is a pivotal sector in terms of mitigation and adaptation. As in all sectors, to date the focus of attention has been typically on new technologies and new equipment as a path to a low-carbon and resilient future. However, such a vision is simply incompatible with the chronology of change necessary to deliver a 2°C or even 3°C future. Virtually all the properties in which we will be living in 2015 and 2020 exist today, as do many of those for 2030 and even 2050. Consequently, although attention is focused typically on new-build, the real substance of the challenge is in retrofitting. Transforming the existing housing stock into the low-carbon and climate-resilient bedrock of communities is itself a difficult task. However, for the UK not to renege on its 2 °C commitments, this transition must begin now and be achieved within the coming decade. Perhaps the sector's greatest challenge is that this can only succeed if genuine partnership is developed between civil engineers, architects, planners, house-builders and, of course, householders. Ultimately, this is as much a political and social as it is a technical challenge, and one that needs to be tackled immediately if futile rhetoric on mitigation is to be replaced with meaningful leadership on climate change.

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# 1 Retrofitting the built environment: An introduction

*Will Swan and Philip Brown*

Sustainable retrofit, or refurbishment, of buildings to improve their energy performance has emerged as the major issue on the demand side of energy use. While there was detailed thinking about how new buildings would perform in a zero carbon world, it took a few individuals to point out that even if we had all new zero carbon buildings, we would only make a very small dent on the emissions of the building stock as a whole (Ravetz 2008; Kelly 2009). We needed to address the existing stock and we were quick to seek out technological fixes to the problem of existing buildings; super-insulation, new forms of heating systems and self-learning controls all found their way into demonstration projects. However, it soon became apparent to both the academic community and practitioners that the problem of sustainably retrofitting people's homes and workplaces was more than just an engineering challenge. Evidence from research projects and studies by industry, particularly the social housing sector, started to show us that there was real complexity; there was a need to address not only the physical nature of the property but also to address issues about people, policy, regulation, building physics, market transformation, supply chains, processes and monitoring. Industry was developing skills to address these issues, while academia identified the problem as being socio-technical in nature (Trist and Bamforth 1951; Trist 1981). Socio-technical systems provide an analytical framework to understand the interplay between physical 'things', rules and people, where regulation, technology, contracts and the way people live all interact to drive the success or failure of a new idea. This is can be considered at the small scale or extended to consider national issues such as retrofit (Geels 2005).

How do we, as academics, go about addressing a problem like the sustainable retrofit of buildings? We are traditionally isolated within specific discipline silos and are often viewed as maintaining a healthy distance from industry. We bid competitively, we are sometimes slow to share data and we are rewarded for publishing in journals that have a 2-year peer review process and small, specialist readerships. However, we are confronted with a problem that is current, interdisciplinary and pressing. The data that are produced by research need to be available more quickly, whilst at the same time

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maintaining rigour in our collection and analysis of that data. Academics need to get involved, not only in an evaluative mode, critiquing governmental and industrial intellectual shortcomings, but getting genuinely engaged – getting our hands dirty and, to some extent, putting our money where our mouth is. While the description of academics in their 'ivory towers' is less true today than it ever has been, we are still left with institutional frameworks, both within individual universities and in wider national structures that are designed to serve a different model.

If the problem is as serious as identified by Kevin Anderson (see the Foreword in this volume), then we need an academic approach that is fit for purpose. As Oreszczyn and Lowe (2010) and Lomas (2010) identified, we need an engaged, action-oriented, interdisciplinary nationally co-ordinated approach. Industry and academia need to run alongside one another and learning needs to be more quickly shared and implemented.

It is from this perspective that Retrofit 2012 was developed. Retrofit 2012 was a conference held in Salford, United Kingdom, in January 2012 and brought together over 100 papers from across the disciplines. It represented a chance for behavioural scientists, building surveyors, energy modellers, social policy academics and a wide range of other disciplines to share ideas. We also opened up the floor to participants from industry to share their experiences, data and insights from the field. For three days the traditional barriers were to some degree broken down, as practitioners and academics from different disciplines all expressed their views with regard to their perspective on the retrofit challenge. What was apparent from the sessions was that the traditional barriers between practice and academia and the disciplines frustrated many people. They were interested in the problem and relevant solutions; they wanted to talk about practical issues, using academic tools to clarify the sustainable retrofit problem for a wider audience than just their specific discipline.

*Retrofitting the Built Environment* is an extension of this conference. Contained within is a mix of policy, technical and social science papers, presented by both academic and industry authors, giving a multiple perspective of the issue from both a UK and international perspective.

The book is divided into four sections: Understanding the problem, Policy and regulation, Implementing and evaluating retrofit and People and communities.

**Part 1** is concerned with understanding the nature of the problem, May, Hodson, Marvin and Perry provide a critical perspective on how retrofit needs to be conceptualised within the context of the city; providing a framework for action for achieving the successful retrofit of the built environment. Palmer, Cooper and Hughes consider a different perspective, concerning themselves with the development of the Great Britain Housing Fact File and the implications that this large-scale and open data resource has for our decision-making. Meanwhile, Swan considers what the socio-technical perspective means for innovation in the sustainable retrofit sector. Using examples from the UK social housing sector, he discusses an underlying structure and identifies how these factors have interplayed to shape, not only the types of technical solutions but also the nature of the innovation process that has been adopted in sustainable retrofit projects.

**Part 2** is concerned with the policy and regulatory context within which retrofit takes place. Morgan provides an analysis of the policy drivers required in order to stimulate a reduction in energy demand needed to meet targets. By drawing upon the situation in both the United States and Europe he outlines the steps that will be required in order to facilitate the acceptance of mandatory building standards. Todd focuses on the UK and provides an historical and contemporary analysis of the building regulations and their impact on thermal retrofit within the domestic context. Murphy provides an assessment of the instruments that dominate policy action to reduce energy consumed for space heating in the existing residential stock of several front-running European countries. Here she highlights the knowledge gap that pervades these countries in the retrofitting of the built environment and posits the reasons for why this continues.

**Part 3** is concerned with the experiences of undertaking retrofit and all chapters within this section are authored by experienced and highly regarded practitioners in their field. Baker, Smith and Swan highlight the need for effective tools that underpin effective retrofit regardless of the scale of the challenge. Drawing upon both small- and large-scale examples, they outline the models that need to be applied to deliver energy savings over the long term. Ruggieri, Dotelli, Melia and Sabbadini take a case study from Northern Italy to delineate the value of taking a life cycle perspective to analyse a building's economic and environment performance with respect to energy efficiency. Willey draws together the experience and data generated during a large-scale domestic retrofit by a social housing provider in the UK. By reviewing every aspect of the retrofit challenge from the perspective of a housing provider this chapter shows the complex canvas upon which sustainable retrofit in the UK has to be played out upon. Finally, Fitton addresses the importance of collecting evidence to support retrofit through the use of monitoring and testing, considering not only how to physically monitor a property but also considering the underlying reasons for undertaking monitoring.

**Part 4** deals with some of the issues at the very core of the retrofit challenge: people. Gee and Chiapetta draw on their work within Canada in multifamily dwellings to talk about how whole system retrofit can be performed with care and engagement of the households who live through this highly technical and often invasive process. Brown provides an overview as to the role played by individuals in energy conservation and draws upon psychological research to outline the findings of research and the implications this has for the retrofit challenge. Mallaband, Haines and Mitchell take a perspective grounded in design by looking at the experiences households have had with a range of home improvements in the past in order to help understand some of the potential pitfalls of new mass retrofit programmes as is currently taking place in various national contexts. Heaslip takes the concept of usability as her conceptual tool to analyse the significant issues raised for the retrofit process. This chapter highlights the technical 'solutions' that can also be part of the problem if there is disconnect between the needs of the users, installers and designers.

As organisers of Retrofit 2012 and now as editors of this text, we have thoroughly relished the opportunity and space we have had to engage across disciplines, sectors and issues. Although responses to the retrofit challenge require pressing action in compiling this text we are aware that although some issues have clarity others, some of which are discussed here, raise more questions still.

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# Part 1

## Understanding the problem

# 2 Achieving 'systemic' urban retrofit: A framework for action

*Tim May, Mike Hodson, Simon Marvin and Beth Perry*

## Introduction

This chapter sets out an extended conception of the term 'retrofit' from those that are commonly advanced. In doing so it aims to enrich dominant, but often narrowly conceived, approaches to retrofit that take a building level focus and draw largely on engineering and construction-based forms of knowledge. Our extended view moves beyond conventional approaches that see retrofit as a domain of repairing and maintaining buildings and networked infrastructures to understanding retrofit at the scale of the city. This is because cities are increasingly sites where a set of critical pressures around decarbonisation, economic activity, and the organization of networked infrastructures and the built environment coalesce and where the potential for innovative responses to these pressures exists.

Over the last decade there has been increasing recognition that the rapid development of global urbanism – with 50 per cent of the world's population now living in urban areas (UN 2006) – is reshaping the earth's ecology (Dalby 2007). Urban infrastructures, which act as huge and complex 'metalogistical' systems, interconnect cities into diverse food, water, waste, energy and mobility systems whose carbon emissions are producing anthropogenic climate-induced change (Luke 2003). Urban resource systems and critical infrastructures are reshaping the ecological context – climate, weather, resources – within which cities are attempting to secure their long-term social, economic and material reproduction (UNEP 2007). Cities are also contexts where responses to these pressures can be formulated. The challenge for cities is how they reshape their infrastructures, buildings resource use and behaviours, with what capacity, governance frameworks, knowledge and intelligence to develop systemic urban responses to climate change and resource constraint.

Addressing these issues requires that we understand what the nature of the pressures are that contemporary cities are faced with, what dominant urban strategic responses to these pressures look like, how they are constituted and with what consequences. It also means that we do not merely accept the transferability of these

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strategies from place to place. This necessitates that we detail alternative ways to constitute responses at an urban scale – responses that recognise the existing organisation of networked infrastructures, the built environment and the energy, water and waste resources that flow through and are produced by them – but also that envision the ways in which these should and can be reconfigured through processes of retrofit. This is an issue that goes beyond single buildings or neighbourhoods and that requires us to focus on the scale of the city and how buildings, networks and flows need to be reorganised. It also means that reorganisation through retrofit activity involves a wider constituency of social and institutional interests than is often the case. A broader organisation of capacity and capability is necessary for building new and effective forms of urban knowledge to inform the retrofitting of energy, water and waste 'systems' and the built environment as well as 'systems' *governing* the strategic interrelationships between these systems.

This is no small challenge in that it involves retrofitting to be understood at the scale of the city. This means that retrofitting is not seen solely in terms of repairing and maintaining buildings but as requiring the reconfiguration of energy, water and waste systems and the built environment through which those systems of production and consumption are mediated. The challenge is how such processes are governed at a city level. This is a fundamental issue given that systemic retrofit requires bringing together not just those working at the levels of buildings, pipes and cables but policymakers, utilities, business, communities, users and so on.

This chapter, therefore, develops three key contributions: (1) it extends conventional conceptions of retrofit to the scale of the city and, in doing so, encompasses a diverse range of social and institutional interests; (2) it develops a framework for action on systemic retrofit that is grounded in a rich programme of social research; and (3) it brings together understanding of what retrofit can be with how it can be achieved.

Following this section the chapter has a further four sections. In the next section we set out the critical pressures for systemic urban retrofit. In the third section we lay out the contours of response to pressures for systemic urban retrofit. In the fourth section we detail a framework for action to orientate systemic urban retrofit. Finally, we set out key conclusions.

## Critical pressures for systemic urban retrofit

Why are strategies of systemic urban retrofit increasingly necessary? The answer to this question lies in a series of 'new' socio-economic and political problems posed by, for example, climate change and resource 'constraint'. The growth of new diseases and constraints on water resources and questions around energy security are pushing issues of ecological security further up the agenda of national governments (Meadowcroft 2005; Barry and Eckersley 2005), albeit with varying degrees of actual effort and resource. The critical issue for national governments is to ensure that their populations have secure and continued access to the resources needed for economic and social reproduction within situations of resource scarcity.

These are increasingly becoming issues at an urban scale, where the extent to which particular urban coalitions are able to anticipate, shape and respond strategically to national priorities or merely absorb them and 'muddle through' in a piecemeal and reactive manner is a critical issue. This provides the wider context within which we need to understand the contemporary pressures facing cities. These can be understood in respect of six interrelated issues.

First, an era premised on attempts to maintain economic growth in a context of economic globalisation means that 'competition' between places is encouraged (Brenner 2004). Second, place-based competition is occurring whilst established energy, water, waste and food resources that underpin economic growth are increasingly constrained. Despite accounting for around half of the world's population, cities are estimated to be responsible for around 75 per cent of energy consumption and 80 per cent of greenhouse gas emissions (While 2008). Third, these challenges are emerging at a time where the majority of the world's population, for the first time in human history, now lives in cities. This is a trend that is predicted to increase to over 60 per cent by 2030 (UN 2006).

Fourth, we are confronted by ageing infrastructures. These trends towards encouraging urban economic growth in a context of constrained resources and climate change meet infrastructural systems and legacies that were frequently developed more than a century ago in many Western contexts (Hodson and Marvin 2013). Fifth, with the privatisation and liberalisation of many infrastructures and the opening up to competition of provision, a wide range of distributed stakeholders and social interests are now involved in the functioning of infrastructures. That, in turn, leads to our final issue: governance, coordination and control. The challenge for effective urban infrastructure provision is predicated on multiple factors, multiple actors and multiple levels that require coordination to inform effective control of infrastructure systems in the face of contemporary pressures (Bulkeley and Kern 2006).

Cities are positioned in various ways when it comes to strategic responses to these pressures. With their concentrations of population, they have been shown to disproportionately consume resources and contribute to the production of climate change. At the same time, they are also positioned as 'victims' of climate change through, for example, the susceptibility of many coastal and river-side cities to flooding and the health consequences of the urban heat island effect (see Roaf *et al.* 2005). Yet cities, with their concentrations of people, expertise, assets and resources, are also potential innovative contexts of response to the issues of resource constraint and climate change. What this leads to is the opportunity to intervene in urban infrastructure and the material city, not in a piecemeal, project-based manner but instead focusing upon a systemic, long-term, sustainable strategy that deals with these pressures. That, in turn, raises the issue of *how* the economic and ecological future of cities can be secured against a background of resource constraint and climate change.

## Systemic urban retrofit as response

With these pressures in mind, urban environments can best be understood as multi-faceted socio-technical systems (Hodson and Marvin 2010a; see also Hodson and

Marvin 2010b for a fuller discussion of this point). Cities become 'locked in' to particular patterns of energy and resource use – constrained by existing infrastructural investments, the material organisation of the built environment, sunk costs, institutional rigidities and vested interests. Understanding how to better re-engineer, or retrofit, our cities and urban infrastructure, to overcome lock-in and facilitate systems change, will be critical to achieving sustainable urban environments.

A conventional definition of urban retrofitting is installing or fitting a city, or an existing building, with devices or new systems not in existence or available at the time of development. This definition is largely derived from the conceptualisation of a city as a quasi-industrial system in which technological devices are refitted into buildings and infrastructures to update and improve efficiency and performance. Here, the continual repair, maintenance and updating of buildings and infrastructure encompasses a wide variety of unremarkable (usually invisible and hidden) activity undertaken by a diverse range of users and social interests.

However, this persistent background activity of repair, maintenance and updating (Graham and Thrift 2007) is now being re-shaped by the set of new pressures and challenges on cities set out above. Urban retrofit is becoming increasingly strategic and systemic in orientation rather than solely project and technologically product based.

## Conventional-style 'project' retrofit and its limits

Conventional models of partial and project-based retrofit simply do not match up to the demands of these new pressures.

There have always been processes of repair and maintenance of buildings and infrastructure. These may involve the use of newer and/or novel technologies but generally serve to maintain the 'status quo'. As such, these processes of renewal are often small-scale, building- or owner-specific activities, framed within a particular socio-economic context to ensure continued operation of buildings and infrastructure rather than transformation. Such activities are often invisible to policymakers and are consequently difficult to identify and measure. While decisions to repair and maintain are useful contexts for retrofitting activity, they cannot easily be linked together in bigger programmes of activity that can build economies of scope and scale at the metropolitan level. There is a need to make repair and maintenance more explicit and to provide a context for shaping investment decisions, enlarging the choice of technologies and incorporating other priorities into systemic retrofitting.

Many previous processes of infrastructure renewal – conversion to natural gas, upgrading of telephone systems, the roll-out of new metering technologies, for example – took place when utilities were integrated (either public and or private) monopolies and the huge cost of retrofitting on a systemic basis could be shared between many different users over extended investment periods. The current landscape of privatised and often liberalised infrastructure means that systemic processes of retrofitting are often much more complex and difficult to plan, manage and roll out, with users dealing with multiple utility companies and unbundled infrastructure that is highly organisationally segmented. There is, thus, the paradox of a societal and collective need for greater co-ordination and integration just when the operational context is highly fragmented and splintered.

At the same time, conventional processes of retrofit have involved a growth-oriented logic of infrastructural development, in which resource consumption and expansion was largely seen as desirable and progressive. The environmental costs and problems associated with growth were increasingly displaced elsewhere, as resources were imported and consumed and wastes were transferred outside cities. Yet the new logic – although still strongly growth oriented and maintenance based – actually requires responses that challenge the logic of continued consumption. For instance, it prioritises demand management and reduction and emphasises the need for new technologies that prioritise ecological aims such as carbon reduction – which then raises wider questions about the roles and responsibilities of cities within extended resource flows.

Conventional retrofit has often had a strong social policy dimension, such as improving the energy performance of low-income households and, in developing countries, upgrading infrastructure in squatter community sites and settlements. The most common logic has been retrofitting as part of social policy 'done' to low-income and poor households, who are often seen as compliant and unable to resist. The issue is how this context translates when dealing with other urban communities who may have quite different ideas about retrofit.

Conventional retrofit has largely been project or network based, completed to a specific timescale, within a well-bounded and understood context and with capacity coming and going along with projects. However, systemic retrofit, dealing with the whole city in an integrated and holistic way, requires a much longer-term approach, with constant rounds of retrofitting, learning and upgrading to meet increasingly higher targets. While old-style retrofit can provide us with some useful lessons, it simply does not measure up to the requirements of systemic and managed socio-technical change.

## Emerging styles of 'systemic and strategic' retrofit?

The new emerging styles of retrofit make many new demands on what have conventionally been understood as largely separate realms of urban policy and networked infrastructure policy frameworks. There are five features of the emerging responses that are of particular interest in characterising what is an increasingly systemic and strategic focus to retrofit.

First, while there is still a short-term concern with repair, maintenance and renewal of buildings and infrastructure, this has become overlain by an increasing strategic priority to address longer-term issues around responses to climate change, energy security and the development of infrastructural resilience and adoption. What this means is that short-term repairs to maintain the performance of buildings and infrastructure now also have to be seen as contexts for incorporating low-carbon technologies, decentralised systems and demand management to deal with new pressures and challenges. Rather than piecemeal or immediate repair, the new priority is more concerned with retrofit as part of a wider systemic response.

Second, linked to this more strategic turn is an increase in the priority given to security issues associated with retrofit. Emerging issues here concern the role that decentralised and renewable energy may play in ensuring security against terrorism or centralised network failures. Critically, the adaptation agenda is leading infrastructure providers to ask which elements and parts of networks should be protected and even 'armoured' against climate change implications (Hodson and Marvin 2010c).

Third, retrofitting is increasingly being conceptualised as being about projects *and* system change. For example, it is increasingly being framed within wider concepts and initiatives such as 'low-carbon' and 'post-peak oil' cities and relocalisation initiatives, which envision system change across buildings and infrastructure. In this sense, individual retrofit projects are no longer simply stand-alone and concerned with repair, but, in aspiration, are linked to wider priorities and concerns at a metropolitan scale. However, critically, the relationships between system-wide visions of social change and their implementation through projects then need to be effectively co-ordinated and managed.

Fourth, as part of this widening and refocusing on systemic change, the objectives and benefits of retrofit activity are also being substantially enlarged. Rather than focusing on projects per se, new responses are seeking to place them in a wider context – linking to employment, green jobs, piloting and developing new technologies and the development of low-carbon economic transitions (Hodson and Marvin 2013). The ability to develop and manage systemic retrofit is being seen as an opportunity for place-based economic development, often developing new economic trajectories as part of the competitive positioning between places.

Fifth, and in contrast to the old retrofit agenda, the challenge of co-ordinating multiple social interests and different forms of knowledge and expertise, as well as the fragmented institutional context for managing processes of social and technological change, are giving rise to experimental forms of governance. Cities are taking different routes in attempting to co-ordinate existing social interests, urban policy and infrastructure policy in order to develop systemic capacity. Within the United Kingdom (UK), in Greater Manchester, the Low Carbon Economic Area for the built environment is behind a 5-year 'retrofit' initiative – developed alongside new city-regional governance arrangements that operates in the public and private sectors addressing insulation, smart metering technologies and small-scale renewables in the built environment. This approach brings together the delivery of critical national priorities with the assumption of creating low-carbon economic opportunities. In Wales, The Heads of the Valleys programme has a claimed £140 m investment over the lifetime of the initiative, which encompasses hundreds of projects and entails the Welsh Assembly Government working in partnership with numerous local authorities and multiple agencies and organisations across the communities of Merthyr Tydfil, Blaenau Gwent, Torfaen, Caerphilly and Rhondda Cynon Taf. The programme will operate over a 15-year period to potentially create Europe's largest low-carbon zone, with 40 000 microgeneration units or their equivalent installed, 65 000 houses assessed for their energy efficiency, 39 000 energy reduction measures implemented and targets to reduce emissions of at least 139 200 tonnes $CO_2$ a year.

We can conceptualise these various approaches as multiple experiments that might potentially be upscaled from experiments to metropolitan system change. What we can see, then, is that the challenge of developing project and systemic capacity for managed socio-technical change is set within a context of fragmentation and infrastructural splintering. This new context has to be actively made and re-made – there are no off-the-shelf models that can be simply applied. The construction of a theoretically and empirically informed framework for change is necessary to address *how* strategic and systemic retrofit takes place: to orientate purpose, coordinated action and assessment of the effects of such action. It is to this issue that we now turn.

## Systemic urban retrofit: A framework for action

In seeking to develop such a framework, how is it possible to develop systemic approaches in existing cities, which recognize the relationships between populations and environments? After all, urban transitions do not start from a blank sheet but from existing systems of infrastructures that are organised and have been influenced in particular ways. It is important to recognize this and to ask how this can be built on and/or be adapted to address priorities and through shared vision on the future inter-relationships of urban infrastructures, the built environment and territorial priorities? Questions are not just about the technical but the wider framing of infrastructure through a variety of social interests: for example utilities, regulators, developers, residents, citizens, environmental groups and business.

Urban resources, along with recognition of connectivity, reliance and responsibility to surrounding territories and their own populations, are the key ingredients informing effective and legitimate city governance and the sustainability of their solutions to contemporary problems. Relational thinking of this type varies within and between cities and depends not just on the form of city and its regional governance but joined up national policies at different scales of action. If policy were to exhibit these properties we would then expect the following characteristics: forward looking, outward looking, innovative, flexible and creative, evidence-based, inclusive and with joined-up methods of working. That would be a framework in which people work, but local intelligence varies and with that the capacity to inform the understanding needed for a joined-up approach.

As noted, cities experience different pressures according to their geography, history, population characteristics, resources and degrees of political autonomy in relation to their national contexts, including the regulatory frameworks in which their infrastructures operate. Although these variations are a reality, expectations are being placed upon cities to respond to contemporary challenges in three particular ways.

First, there is the pressure for integrated coordination of planning and infrastructure to 'future proof' the urban environment. To achieve this necessitates effective consultations and communications between utilities, planners and communities of users in order to improve delivery of strategic aspirations. Second, there is the introduction of new standards for development projects, including water neutrality, decentralized energy and carbon reduction targets. Third, via national and international pressures, there is a need to develop low-carbon transitions not only within new build but also existing and often dated infrastructures.

As we have suggested, effective responses are socio-technical and require cities to bring together two disconnected issues: 'what' is to be done (knowledge, targets, technological options and costs) and 'how' it is to be achieved in practice (institutions, capacity, publics and forms of governance). At present, there is a significant gap between 'what' and 'how' manifest, for example in: fragmentation of technical knowledge between utilities, engineers and planners; an absence of governance frameworks for managing relations between multiple stakeholders and infrastructure providers; a gap in translation from project-based work into strategic and systemic transitions; and a lack of integration between spatial planning and organizations that provide utilities.

Territorial governance priorities increasingly require degrees of control and influence over energy, water, waste and transport regimes. In terms of purposive transitions through retrofit the issue this raises is the extent to which urban territorial governance priorities can effectively be co-ordinated and aligned with the priorities and social interests that manage infrastructure networks. Yet, how urban territorial priorities are able to manage urban infrastructures varies across different cities and national contexts. Therefore, how territorial priorities of an urban governance network – and the social interests that produce them – are able to actively manage change in the socio-technical organisation of infrastructure networks and the built environment is central.

To generate the understanding necessary to effectively seal the gap between the actual and potential in different places requires the following to be addressed: how are pressures experienced and perceived in a particular city and by whom and how does this translate into a shared understanding of an urban socio-technical transition? What are the current and historic organisation of infrastructure in relation to a city and the level of capacity and capability to develop and operationalise a shared understanding into action? To what extent does learning takes place within and about urban transition and how does this change practices? That requires the introduction of reflexive practices in which there is a willingness to admit to and learn from mistakes in particular contexts. Active intermediation is a key ingredient of this process (May with Perry 2011).

The above requires the development of the knowledge, capacity and capability for public agencies, the private sector and multiple users to systemically re-engineer their built environments and urban infrastructures. Bridging these gaps requires the development of new forms of organization and expertise in order to understand how the growth ambitions of cities and city-regions can be effectively managed against a context of carbon constraint, the security of energy and water resources and the impacts of climate change.

It is the world's largest and most powerful cities and metropolitan areas (London, New York, San Francisco, cities of the C40) that are developing a more strategic orientation towards questions about their future resource requirements (Hodson and

Marvin 2010c). The world's largest and most powerful cities are at the forefront of using the powers and resources that are available to them to develop strategic and systemic responses to the emerging set of pressures leading to differences between systemic and piecemeal responses.

What is of key concern is that the objectives of cities – economic growth targets, social inclusion and carbon emissions reduction – are becoming intertwined with socio-technical infrastructure systems that may, or may not, be organised on the scale of the city itself. These complex sets of pressures highlight the fact that it is no longer appropriate – if it ever were the case – to provide urban infrastructure on a piecemeal, project-based manner, but that rather a systemic, long-term strategy is required. Consequently, the critical challenge for all those concerned is how strategic and systemic approaches to future infrastructure provision and utilisation in existing cities and communities can be developed and organised.

Transitions in urban infrastructures and the material city start from actually existing interrelationships of systems of infrastructure, the built environment and governance that are organised in particular ways. It is important to acknowledge this and to ask: how can this be adapted to address priorities and shared visions on the future of urban infrastructures? The territorial interests of groups and organisations may sit outside formal governance frameworks of infrastructural provision. Therefore, the relationship between space and planning infrastructure is a core issue for cities, leading to questions concerning effective management and longer-term sustainability.

Given the existence of significant differences between cities, the following questions inform an assessment of the capacity and capability to fill a gap between aspirations and delivery. Are visions for the future of the city inclusive of different viewpoints and how do these translate into collective understandings of socio-technical transitions? Are the strengths and limitations of current infrastructure provision well understood among different providers in a way that informs coordinated actions? Where are the sources of knowledge generation about city transitions and future pressures and are those integrated in a way that ensures learning takes place for policy development and practice? What pressures are experienced in a particular city and do these take account of all issues needed to develop holistic and sustainable approaches? What are the capabilities to not only develop but also put into practice shared visions and joined-up practices within the city?

## The SURF-Arup Framework

To meet these issues, extensive work with stakeholders and a placement in the global engineering firm Arup has informed how we meet the gap between policy and practice in existing cities through the development of the SURF-Arup Framework (a full and detailed account of the Framework is set out in May *et al.* 2010). Effectively addressing this gap requires the following:

- The creation of joined-up capacities in cities, government and stakeholder organisations to deal with critical infrastructure.

- The production of 'enlarged' utility strategies in scope and scale to enable more efficient production and extend demand management and decentralized technologies.
- The movement from information to intelligence to understand and then integrate new developments.
- The exercise of implementation with a variety of partners who understand the implications for existing infrastructure.
- The development of social visions through inclusive participation that are aligned with existing levels of governance for strategic orientation.
- The ceasing of short-term consultancies and instead the development of long-term partnerships with those who have the capacity to understand joined-up working over time.
- The delivery of effective context-sensitive learning for innovative and transferable solutions.
- The establishment of strategic and systemic capabilities to manage social and technical change in a programmatic way.

It is not enough to talk about 'what' should be done. What is needed is a process for 'how' that is to be achieved where it is tailored to specific cities and their contexts. This is the primary purpose of the Framework as a blueprint for action. In deploying this, cities can ask themselves just how far they have come in developing a holistic framework for city-regional infrastructural development and the steps needed to develop and implement plans for its realisation. Each step requires the input of knowledge, an assessment of its value and the production of clear ways forward in order that different stakeholders remain co-ordinated through their inclusion in the process. It includes one stage (4) that is designed to continually feed intelligence back into the process. In this way it is up-to-date with the latest ideas and practices in order that its solutions are more effective and progress is understood by all partners in the process. The five stages of the Framework are as follows:

*STAGE 1: The context*. Here relevant knowledge is gathered and converted into intelligence so that an assessment can be made of the current level of spatial distribution of assets, quantity, quality, use, accessibility and connectivity.

*STAGE 2: The strategic landscape*. In this stage, understanding is developed of the extent to which strategic direction and implementation in infrastructure provision is joined up across the city and with its surrounding areas and transport links, as well as with economic, spatial, environmental and social priorities.

*STAGE 3: Develop capacity and capability*. Through a process of identification of where strengths and gaps in capacity and capability lie and where opportunities are created for improvements in planning and investments in critical infrastructure.

*STAGE 4: Preparing for the future*. This stage provides a dedicated resource that makes it possible to identify, anticipate, stimulate and disseminate potential changes, threats and opportunities in the development of critical infrastructure provision.

*STAGE 5: An action plan*. In this final stage an action plan is constructed, that draws upon results from stages 1 to 4, with clear time frames in the short, medium and longer term, for programme and policy interventions to achieve integrated strategic objectives that are understood across different sectors, groups and populations.

Having clear ways forward based on a common vision that involves different groups and sectors and the mobilisation and deployment of the right expertise is necessary for success. In implementation, it is important to have well-understood criteria for measuring success that are shared among different stakeholders. That is to say 'how we will know' when actions produced through the Framework have been achieved. With the above points in mind, the following five 'tests' are designed to inform those outcomes.

1. That well-co-ordinated and communicated understandings of the challenges that the city faces have been achieved. This requires the involvement of utility providers, municipal government, regulators, developers, business, citizens and 'users'. It is important not to omit marginalised social interests whose omission then leads to less effective and joined-up solutions. Pursued effectively, this will mean that different social interests have engaged, co-ordinated and aligned around a social vision of systemic and managed socio-technical change
2. That there is good evidence of having engaged with and learnt from different levels of governance. Multilevel governance arrangements and socio-technical systems involve institutions that operate across different scales of action (local, city, regional, national and international). This requires the construction of coalitions and the development of shared city visions for achieving effective outcomes and a good understanding of how regulatory regimes enable and constrain action in the city. Resulting from this will be that the city has focused on opportunities to learn from and shape developments for collective benefit.
3. Holistic and sustainable approaches, political ownership, vision will have been achieved, along with conditions for their realization. Building a capacity to inform actions and possessing the capability to act means investing in relationships between groups and sectors based upon an integration of knowledge from various sources. It requires investment in education/awareness/training of various work areas across sectors in terms of network, territorial and regulatory issues. Done well, this will mean that a working consensus is achieved, involving good communications and coordination, based on understanding what is to be achieved, how, with what resources and towards what ends.
4. A genuine desire exists to co-create solutions and implement solutions, be forward thinking and build partnerships where no one group is dominant. Dialogue is about trust and openness and a co-responsibility to put aspirations into action as a pre-condition for innovation. This will mean that commitment is in place and shared across the full range of activities to develop systemic change.

5. Different roles may be performed better at different scales of intervention. The territorial scale of intervention needs to be appropriate to the issue to be addressed. There should not be an excess of worrying about artificial boundaries, but a focus upon governance arrangements that provide an active intermediary role that works to bring a variety of different network, territorial and regulatory social interests together for mutual benefit. Addressed effectively, this will mean that active management of network and territorial interests is achieved and criteria for success are known and shared among different groups and sectors.

## Conclusions

In this chapter we have made three particular contributions to debates around retrofit. First, we have developed a wider conception of retrofit than that which is conventionally utilized, that is systemic in its scope and socio-technical in its constitution. Second, we have laid out a framework for orientating action towards systemic urban retrofit. Third, in doing this we have brought together understandings of what retrofit can be with how it can be achieved.

The existing constitution of capacity to engage in systemic urban retrofit is variable between different urban contexts. Not only does our Framework for action provide a basis for informing action but it also requires those actions to inform revisions of the Framework over time. Our call, therefore, is not only for action on systemic urban retrofit informed by the Framework but also for learning from those actions to be incorporated into adapted versions of the framework.

We have outlined a process that develops shared understanding, shared priorities and understanding of the reasons for conflicting priorities. In particular, this necessitates a genuine desire to co-create solutions, produce forward thinking and build partnerships where no one group is dominant and where dialogue is about trust and openness rather than just a seat at the table.

Because of the importance of context for effective solutions, the focus of our recommendation is upon 'how' to provide ways forward. This requires moving away from techno-fixes and the politics of world city exemplars. Our suggestions are a challenge to business as usual because our current and future circumstances call for radical changes in how we organise our cities and the services upon which we all rely.

Overall, the shift required is from a project focus to more strategic and systemic transitions encompassing an enlarged notion of retrofit, wider sets of social and societal interests, the need for systemic change and the capacity to provide this in particular contexts. The shift is from seeing the city as a passive site for the implementation of new technologies to instead seeing it as a context for innovation, experimentation, the production of new technologies, the testing of them in niches and socio-technical experiments, and the search for upscaling and scale/scope economies. All of this is underpinned by the need for social and technical change and an increasing recognition of the need for behavioural change rather than just technology implementation.

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# 3 Openness in household energy use: The new Housing Energy Fact File

*Jason Palmer, Ian Cooper and Martin Hughes*

## Introduction

Here we discuss the *Housing Energy Fact File* (HEFF) (Palmer and Cooper 2011), first published in 2011 by the Department of Energy and Climate Change (DECC). The Fact File aims to draw together, in a single publication, most of the important data about energy use in homes in Great Britain since 1970. In its new and extended formats, it is intended for broad readership, not just policy-makers and researchers but interested members of the public as well. The information presented covers trends in energy use since 1970, as well as data on carbon emissions and energy generation trends, the housing stock, households and bills, energy use in homes and what shapes it, and renewables and microgeneration. The Fact File is published as a report, and is also accompanied by a spreadsheet that contains all of the tables and graphs described in the report.

The team who have produced the Fact File for DECC have tried explicitly to open up for public scrutiny the document itself, the data on which it is based and the model used for interrogating the data, and to make them available for third party use. This supports the Department's policy statement on Transparency and Freedom of Information that commits it to being 'an open and transparent government department which aims to ensure that its data is as accessible as possible' (DECC 2010b). As a result, there is now a considerable suite of related documents and supporting tools that interested parties can access in order to see for themselves the basis for the facts that are reported. These documents and tools can be used both to scrutinize the information presented in the Fact File – which therefore no longer needs to be taken on trust – and to enable interested parties to run their own analyses of the available data.

The latest figures in tables and graphs in the Fact File were generated using the Cambridge Housing Model (CHM), which was developed by Cambridge Architectural Research specifically for DECC to help inform its policy decisions on energy and housing (CARL *et al.* 2011). The model is publicly available to allow individuals to

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interrogate the data in a transparent way and is supported by an accompanying guide that explains how the model has been developed in detail (Hughes 2011). Those who are more interested in the outcomes from using the model are directed to a companion volume, *Energy Consumption in the United Kingdom* (ECUK) (DECC 2011). This publication looks beyond housing to the wider trends in energy consumption in the United Kingdom, using data that have been published annually since the late 1990s. Statistics are brought together here from a variety of sources to provide a comprehensive review of energy consumption and changes in efficiency, intensity and output since the 1970s, with a particular focus on trends since 1990. Taken together, the Fact File and ECUK allow policy makers and others to understand the most significant historic trends in household energy use – to help plan for the future and to develop policies that take us towards national targets for greenhouse gas emissions while ensuring we have enough energy to meet our needs for energy services.

## The Fact File's evidence base

The Cambridge Housing Model (CHM) is a domestic energy model for Great Britain and the United Kingdom, used to generate estimates of energy use for DECC which are reported both in the HEFF and in the domestic data tables in the associated EUCK. This use of the CHM replaces the previous use of the Building Research Establishment Housing Model for Energy Studies (BREHOMES) for these purposes.

The primary source of input data for the CHM is the English Housing Survey (CLG 2011). This survey records information about both the people using homes (e.g. their ages, employment status, banded incomes) and the dwellings they live in (e.g. type of heating system, presence and thickness of loft, wall and floor insulation, presence of double or single glazing, construction materials, low-energy or other lights, dwelling dimensions, presence of some renewable energy systems).

In 2009, the EHS dataset provided information on 16 150 representative English dwellings. Each of these cases represents a quantity of dwellings. These cases are weighted so that their sum is equal to the total number of dwellings in England (22.3 million in 2009). The model reads in the EHS dwelling for each case and performs building physic calculations to estimate energy consumption and associated $CO_2$ emissions, by use and by fuel type. When both of the latter are multiplied by the associated weightings and then summed across all cases, total values for the housing stock in England are generated. These then need to be scaled up, using appropriate England to Great Britain, or Great Britain to United Kingdom, scaling factors, to create the energy use and $CO_2$ emissions in Great Britain and the United Kingdom, respectively.

The CHM has been further updated to include data from the Scottish House Condition Survey (SCHS) in order to produce a more accurate picture of Great Britain homes. In 2008, the SCHS provided data on just under 9400 dwellings. To achieve this update, the input data from the SCHS was processed to match the form of the EHS data.

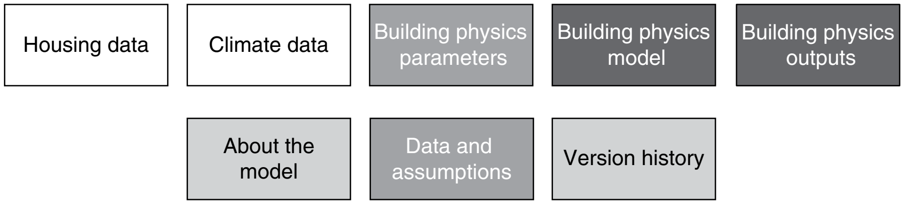


**Figure 3.1** Elements of the Cambridge Housing Model.

## The model underpinning the Fact File

The CHM was built in Microsoft Excel in order to make it accessible to those who are not experienced modellers. Its calculations are principally performed directly within screen-based worksheets, as shown in Figure 3.1.

To assist users, we have used coloured shading of cells within the model to signify inputs, calculations, assumptions and outputs. This is for guidance only since, on occasion, the distinction between these can be blurred. For example, some of the assumptions are implicit in building physics parameters, so they are recorded in the 'B Physics Parameters' worksheet rather than the 'Data and Assumptions' worksheet.

Each representative dwelling type is fed into the Housing Data worksheet. The calculations used in the CHM are principally based on the Standard Assessment Procedure (SAP) 2009 worksheet (DECC 2010a), which is the current Building Regulations method for assessing the energy use of new dwellings. As the latest interpretation of the Building Research Establishment Domestic Energy Model (BREDEM) (Anderson *et al.* 2002), it is the most widely tested and widely used framework for assessing energy use in UK homes.

However, the SAP/BREMEM methodology was devised to provide a standardized approach for calculating the energy performance of specific dwellings in order to check for compliance with Part L of the Building Regulations. It was not designed for estimating actual energy consumption across the whole housing stock and it specifically excluded 'unregulated energy' (cooking and appliances energy use). We modified SAP 2009 to include these uses of energy.

Data from the EHS and SHCS, such as dwelling dimension data, window dimensions, building materials and insulation thicknesses, is 'cleaned' and processed by running it through a converter. The cleaning process removes any obviously inconsistent values from the datasets (e.g. floor area data where raw EHS data records a ground floor area of 50 $m^2$, a second floor area of 50 $m^2$ but zero floor area for the first floor). In order to generate the required input 'housing data', some data need to be interpreted, some combined and some default assumptions need to be made. Detailed advice on how to convert data for use in the model is available in *Converting English Housing Survey Data for Use in Energy Models* (CARL and UCL 2012). Once these 'housing data' have been generated, it they can be input directly into the Housing Data Sheet. Appropriate 'climate data' can also be entered. The Building Physics

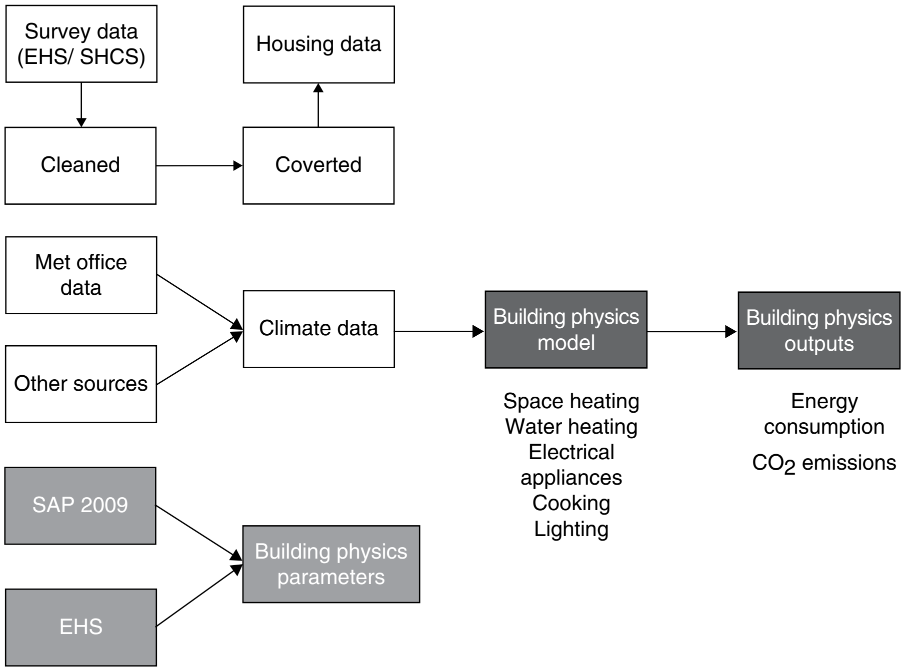


**Figure 3.2** Overview of the Cambridge Housing Model.

Parameters Sheet contains a large number of variables and related assumptions primarily taken from or based on SAP 2009 (e.g. about how to derive U-values from insulation thicknesses and materials, and thermal mass parameters).

The Building Physics Model then uses the information from the Housing Data, Climate Data and Building Physics Parameters to perform the model calculations – principally based on the SAP 2009 worksheet calculations. The model can either be run for a single case or for all the cases listed in the Housing Data and the results are displayed in the Building Physics Outputs, as shown in Figure 3.2.

## Building accountability and consensus

Much of the process by which previous editions of the Fact File (Shorrock and Utley 2008) were generated in the past remained shrouded in mystery. With the HEFF we have sought to make the workings, and the underlying assumptions, of the CHM as open to scrutiny as possible. This allows third parties to understand more about the uncertainty in the work, and where necessary to challenge us if they have access to better sources of data.

As part of this process, we have employed stakeholder engagement techniques to bring a wide range of expertise and opinion to bear on the work done under our DECC contract. Two expert panels, one made up of domestic energy modellers and the other of policy makers, along with a steering committee drawn from government administrations, academia and the private sector, have been used to guide:

- the development and application of the model
- the writing and revision of the Fact File and
- improvement of other supporting documents and tools.

Drafts of the model, the Fact File, tools and the supporting documentation have been circulated to these participants for scrutiny, particularly, for instance, where assumptions underpinning SAP 2009 have been challenged or where there is only a limited evidence base, such as assumptions about internal temperatures in housing during the heating season. The guiding aim here has been both to make our decision-making more transparent and accountable and to build as large a consensus as possible about how to act for the best where doubts or limited information prevail. This approach has helped us meet our aspiration to open up energy consumption in the domestic sector to a wider public audience and to more informed critical comment and scrutiny.

## Summary points from the Fact File

$CO_2$ emissions

Great Britain's Housing Energy Fact File 2011 showed that the domestic sector's carbon dioxide emissions from housing has fallen since 1970, although they have remained broadly stable since 1995. This was despite increases in the number of homes and changing expectations about energy use in the home. There are many more British homes today than there were in 1970: towards 26 million now, compared to just over 18 million at the start of the period. Inevitably, this puts upward pressure on carbon emissions.

Added to this, significant changes in heating systems, comfort expectations, insulation and use of appliances have transformed carbon emissions from housing. The rise of central heating, from near-zero to 97% of homes pushed up $CO_2$ emissions from heating. Central heating also brought with it the expectation of heating in all rooms of the home, and typically heating that came on before householders got up in the morning and before they got home from work. Inevitably, both led to increased energy use for heating. So too for electrical appliances – greater ownership and use of dozens of household appliances we all take for granted today led to increased use of electricity to power them.

However, recently more efficient condensing boilers, better controls and dramatically better insulation helped to contain the rise. More efficient appliances also push down household $CO_2$ emissions, but probably less than the spectacularly more efficient electricity generation (in terms of $kgCO_2/kWh$) since the 1980s.

Overall there was a broad downward trend in $CO_2$ emissions from housing (see Figure 3.3). However, the trajectory was not straight – cold, prolonged winters led to

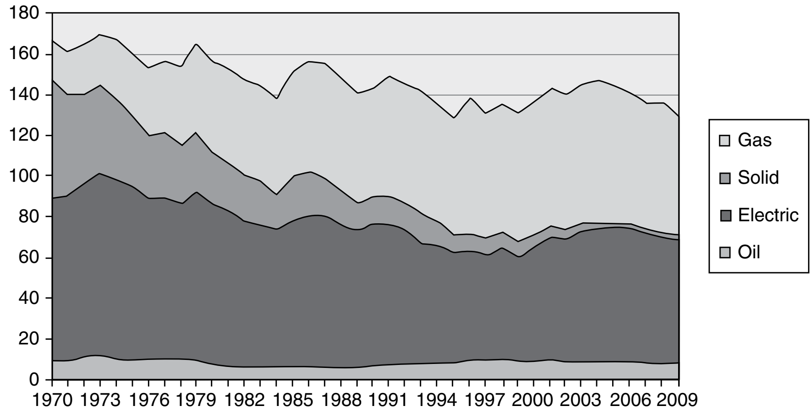


**Figure 3.3** Trends in $CO_2$ emissions from Housing Energy 1970–2009.

higher $CO_2$ emissions, so upward spikes in the graph coincide with cold winters and downward spikes with mild ones. Gas use more than trebled from 1970 to 2009, while solid fuel use fell away from more than a third of housing $CO_2$ in 1970 to less than 2% today. Carbon emissions from electricity, meanwhile, fell by nearly a quarter since 1970.

However, electricity's share of total household $CO_2$ emissions remained fairly stable, at between two-fifths and half of carbon emissions from housing (see Figure 3.3). Increased consumption in kW h was broadly offset by switching from coal to (more carbon-efficient) gas and nuclear electricity.

## Energy prices

As to the cost of energy in the home, we found that the cost per unit of electricity, solid fuel and oil have all increased in real terms, while gas costs per unit fell by 11% over the last 40 years. Unsurprisingly, rising costs for electricity hit poorer households with electric heating the hardest.

The real price of electricity increased by over a quarter from 1970 to 2009 and the rise after 2003 was much steeper: a jump of two-thirds in only six years (see Figure 3.4). This is significant because electricity is three or four times more expensive per kW h than other forms of energy. The prices of gas and solid fuels have tended to be more stable.

Heating oil closed the period about 40% more expensive in real terms than it was in 1970. However, the most volatile time for oil costs was in the 1970s and 1980s, when the price increased by more than 150%, and then slipped back to the same cost in real terms. Gas prices were remarkably stable in real terms throughout the four decades in the graph.

The price of solid fuels, including coal, coke and breeze, rose gradually during the period, finishing nearly 90% more expensive in real terms. (This is probably less significant than price changes for electricity and gas because far fewer homes now use solid fuel heating.)

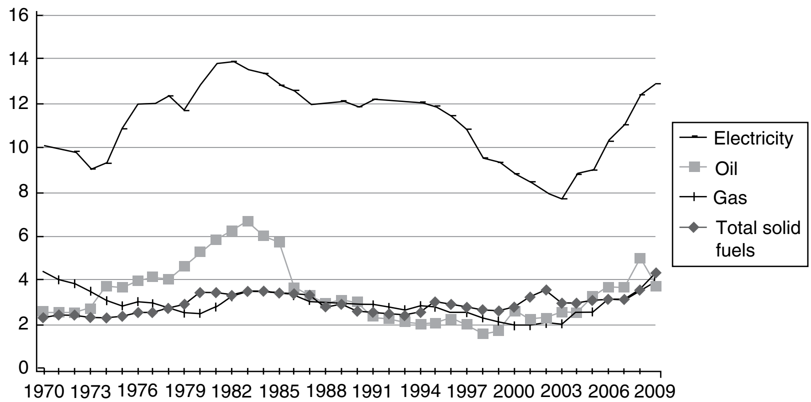


**Figure 3.4** Price of energy in pence per kW h 1970–2009.

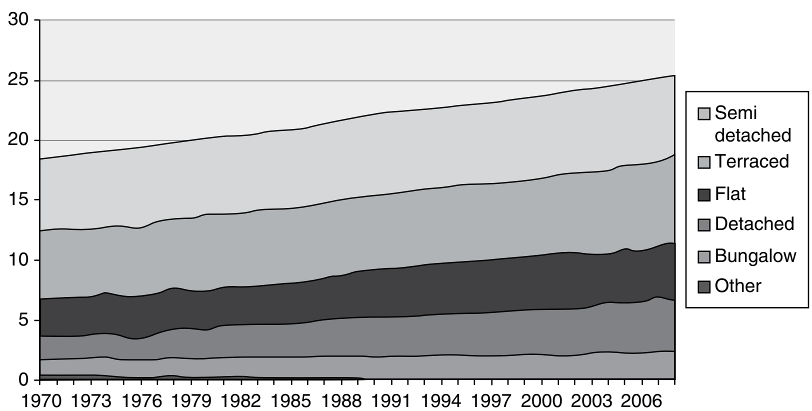


**Figure 3.5** Trends in house types 1970–2009.

Overall these changes mean that there has been only a small change in the cost of energy in real terms over the last 40 years, although there have been short periods of steep rises and falls. Solid fuels have become more expensive (which may have accelerated the shift away from coal heating). Given how incomes have risen over the period, we now spend a much smaller fraction of our income on energy, which does nothing to curtail our use of energy in the home.

## Housing stock

Over the last 40 years the change in the housing stock was quite pronounced (see Figure 3.5). While semi-detached and terraced houses have always been the most common house types (each representing just under a third of the housing stock

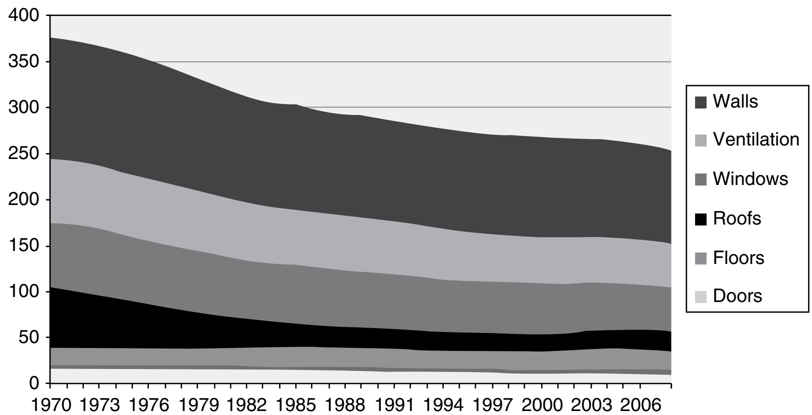


**Figure 3.6** Average heat loss per dwelling.

throughout the period), flats and detached houses have become more common. Flats are now 19% of the housing stock and detached houses are 17%.

This is significant in energy terms because heating energy is related to external wall area and window area. Flats tend to have less external wall area compared to their floor area (so have less heat loss in winter), while detached houses typically have more external wall and more windows than equivalent homes of other types. However, the heating energy effects of proportionately more flats and detached houses probably offset each other. A bias towards higher glazing ratios (larger windows compared to walls) in many modern flats may undermine some of the benefit of lower wall to floor ratios.

Some house types also tend to be larger (e.g. detached houses) or smaller (e.g. flats) than an average home. Since heating energy is correlated to floor area, this means that the doubling in the number of detached homes would increase heating energy unless other factors affecting heating changed.

## Heat loss

Given that space heating is the largest slice of energy use in Britain's homes, it is worth looking carefully at overall heat loss. During the heating season, this has fallen significantly in the last four decades, partly because of the fabric improvements, such as insulation and double-glazing, which are discussed in more detail below.

In 1970, the overall rate of heat loss from a home was, on average, 376 W/°C. This is linked to the difference between internal and external temperature, called the 'temperature difference'. This measure of heat loss says that for an average home, if it is 1 °C cooler outside than inside, you need 376 W of heating to maintain a stable temperature. The measure is affected by insulation and ventilation losses. The heat loss figure for 2008 in Figure 3.6, 254 W/°C, implies that for a typical cold winter's day

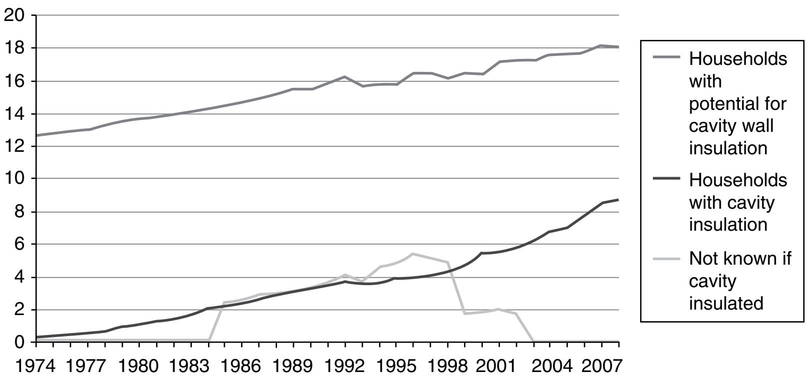


**Figure 3.7** Cavity wall insulation installations.

with an external temperature of 0 °C and an internal temperature of 20 °C, an average house would need 5 kW of heat to maintain a stable temperature. This is equivalent to five small electric fan heaters.

Data for Figure 3.6 was modelled, rather than based on observation or surveys. This means it is subject to uncertainty, which we discuss below. On average, the rate of heat loss reduced after 1970 for all elements that make up the external envelope of a home – walls, windows, roof and doors – bar one, the floor. It also reduced the ventilation through those elements. The reduction was most pronounced for roofs – a 70% decrease in heat loss. This reflects the dramatic improvement in loft insulation in new and existing homes. Windows, doors and ventilation saw similar reductions of about 30%. According to these figures, heat loss through floors appeared to increase by 14%, but this may be due to changes in data collection, or to more accurate judgements about whether floors lack insulation.

So there were significant improvements over the four decades per average dwelling (i.e. the average across dwelling types, weighted according to the actual number of dwellings in each type). Overall, however, the total heat loss for the stock as a whole (i.e. average heat loss × number of homes) only reduced by about 4% from 1970 to 2008, largely because many more homes were added to the stock.

## Insulation

Now that most homes have been brought up to adequate standards of loft insulation, cavity wall insulation is one of the biggest opportunities for improving energy efficiency in homes. There was a stark increase in cavity wall insulation in Britain's housing stock up to 2008, outlined in Figure 3.7. In 1974, two-thirds of the housing stock was capable of having cavity wall insulation but it had been installed in less than 2% of these homes. By 2008, the proportion of the stock capable of having this form of insulation had grown a little to 70% and over a third, 34%, had it. This was a 17-fold increase.

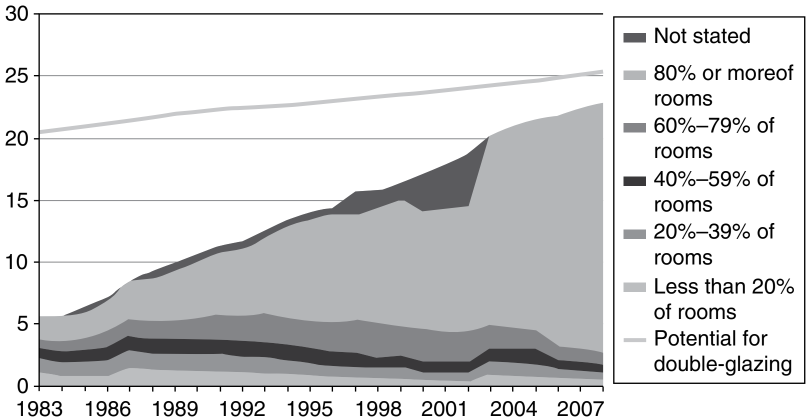


**Figure 3.8** Installed double-glazing.

Double-glazing

The last four decades saw significant increases in the number of homes with double-glazing, as shown in Figure 3.8. After 1970, the proportion of homes with some level of double-glazing grew nearly 12-fold, from just under 8% to 90% in 2008. Since 1983 (the first time figures on the amount of double-glazing present became available), the proportion of homes with 80% or more of their rooms double-glazed has increased almost nine-fold, from 9% to 80% in 2008.

Some form of whole-house double-glazing is becoming a near universal standard (where 'double-glazing' refers to sealed units rather than windows with secondary glazing). Homes built now must have double-glazing to meet the Building Regulations. Since 2002, most existing homes where windows are replaced also need to be double-glazed.

## Uncertainty analysis

All but the simplest models are subject to uncertainty and the Cambridge Housing Model is no exception. The building physics calculations are complex; we use EHS data on a sample of representative dwellings to represent the English housing stock and regional climate data to represent climatic variations across the country. The EHS data is typically not in a form suitable for direct input into the model and must therefore be manipulated prior to use. We have minimal information on occupant behaviour and all stages in the modelling process are subject to inaccuracies such as mis-measurement or error – from the EHS survey and the SAP worksheet calculations to our interpretation and implementation of those calculations. For this reason we need to understand better the issues within both the data and the model.

To understand fully the issues of uncertainty, we first consider a simple 'one at a time analysis' to assess the sensitivity of total domestic energy estimates to variations in individual model parameters. This is followed by considering the possible sources of uncertainty in our modelling process. Finally, we undertake a Monte Carlo uncertainty analysis to consider the potential impact of such uncertainty on our estimates for total domestic energy consumption.

The baseline CHM estimates total domestic energy use for England in 2009 as 445.3 TW h – this is a single point estimate with no consideration of uncertainty. The actual measured value is 417.6 TW h, based on the pro rata scaling of the Digest of UK Energy Statistics ('DUKES') figure for the UK (DECC 2011), so the model overestimates by 6.6%. The DUKES data provide a comprehensive picture of energy production and use over the last five years. It is one of the most significant statistical publications about energy, and it includes tables, charts and commentary, with separate sections on coal, petroleum, gas, electricity, renewables and combined heat and power. Much of the household energy data comes from annual submissions about sales from the energy companies. However, it should be recognised that the 'measured' figure is itself subject to uncertainty, in terms of both how the DUKES data are assembled and how we scale from UK to England using household estimates (CLG November 2010).

Sensitivity analysis is a systematic method for changing parameters in a model in order to assess the impacts of those changes and a number of sensitivity analysis methods are available (Saltelli and Annoni 2010). Here we adopt a one-at-a-time approach, which involves changing input parameters individually and assessing the effect on outputs, with changes to parameters applied within a limited range of uncertainties (e.g. increasing the floor area by 1% and seeing what effect this has on the estimate of total energy use). This is a simple approach that can be employed quickly and easily to a large number of model parameters. Such an approach allows you to determine the relative significance of parameters and is useful for identifying which model parameters the outputs are particularly sensitive to change (Lomas and Eppel 1992).

Table 3.1 shows the results of applying a one-at-a-time approach to the parameters in the CHM for the top 15 parameters. The parameters are sorted into descending order in terms of the absolute value of their 'normalised sensitivity parameter'. A normalised sensitivity figure of, say, –0.66 for heating system efficiency means that a 1% increase in the efficiency of the heating systems in all dwellings results in a 0.66% fall in the estimate of total domestic energy consumption in England in 2009. The original baseline value shown for each parameter is a weighted average across all English dwellings. Our sensitivity analysis covers input housing data, input climate data, assumed behavioural data (internal demand temperature and heating regimes) and a large number of default SAP parameters; in total we have conducted the analysis on 102 parameters.

Our one-at-a-time sensitivity analysis indicates that the internal demand temperature is by far the most significant parameter in the modelling process, followed by main heating system efficiency, external temperature, floor area, storey height and heating regimes. These are all inputs to the CHM, as opposed to SAP constants or values. This tells us that the main sources of uncertainty in modelling come from the limited empirical data about demand temperature and boiler efficiencies.

**Table 3.1** Results of local sensitivity analysis for the 15 most sensitive parameters in the Cambridge Housing Model (base case total energy consumption for England is 445.3 TW h/year).

| Input parameter | Initial set value $x_i$ | Normalised sensitivity coefficient $S_i$ |
|---|---|---|
| 1. Internal demand temperature (°C) | 19.0 | 1.54 |
| 2. Main heating system efficiency (%) | 80.5 | –0.66 |
| 3. External temperature (°C) | 7.5 | –0.59 |
| 4. Total floor area ($m^2$) | 96.4 | 0.53 |
| 5. Storey height (m) | 2.5 | 0.46 |
| 6. Daily heating hours (h) | 11.0 | 0.27 |
| 7. DHW system efficiency (%) | 76.6 | –0.19 |
| 8. Wall U-value ($W/m^2 K$) | 1.2 | 0.18 |
| 9. Effective air change rate (ach) | 1.0 | 0.18 |
| 10. Wind factor parameter | 4.0 | –0.17 |
| 11. Wind speed (m/s) | 4.8 | 0.17 |
| 12. Infiltration rate (ach) | 0.8 | 0.17 |
| 13. Appliances energy: TFAxN coefficient | 0.47 | 0.17 |
| 14. Shelter factor | 0.9 | 0.16 |
| 15. Main heating responsiveness | 0.9 | –0.15 |

The one-at-a-time sensitivity analysis is informative, but such an approach does not capture the overall uncertainty in our estimates for total domestic energy consumption. It does not account for uncertainty in multiple parameters or distinguish between well-known parameters and parameters where there is a much weaker evidence base. Understanding the impact of uncertainty on model outputs involves estimating the nature of the uncertainty in the modelling process and combining the effects of these uncertainties simultaneously. The starting point for this analysis is an assessment of the uncertainty in the modelling process. Figure 3.9 gives an overview of the known sources of uncertainty.

These sources of uncertainty are described in more detail elsewhere, along with a more thorough description of our uncertainty work (Hughes *et al*. 2013). We defined simple levels of uncertainty for each input into the Model and carried out Monte Carlo simulation based on random sampling. The Monte Carlo approach involves repeated running of the model with different values for the uncertain parameters in each simulation run. In each run the values for the uncertain parameters are randomly selected based on the probability distribution that describes each parameter's uncertainty. The output of a run is a single-point estimate of total domestic energy, but the repeated running of the model using random sampling generates multiple single-point estimates that form a distribution of total domestic energy values due to the uncertainty in the input parameters.

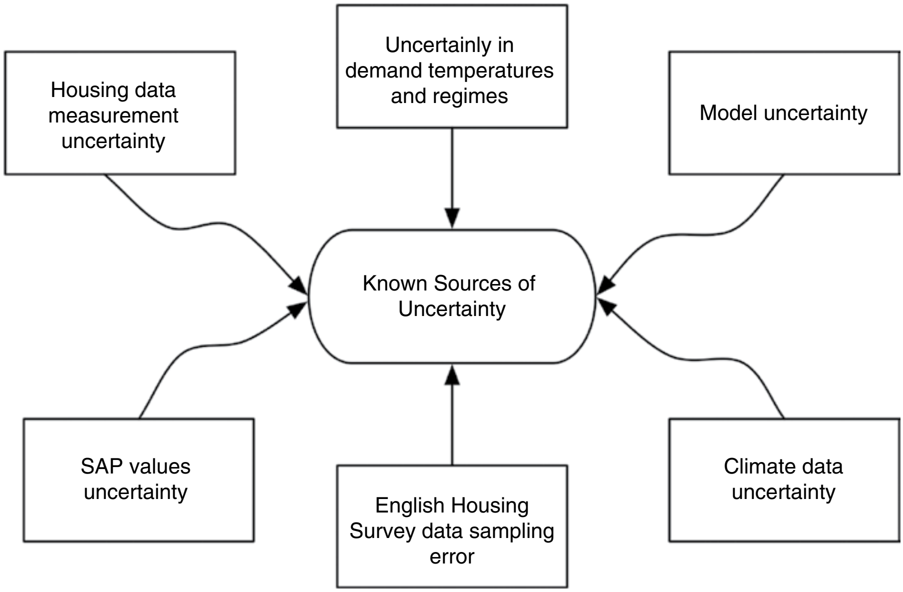


**Figure 3.9** Overview of the categories of known sources of uncertainty present in modeling.

The outputs from our uncertainty analysis are distributions of total English domestic energy consumption. Figure 3.10 shows the distribution for our estimates of total energy for England in 2009. These results are based on a sample of 2000 runs. Analysis of the convergence of the 2.5%, 50% and 97.5% confidence intervals confirmed that 2000 sample runs were more than adequate to achieve convergence (to within 0.5%).

Figure 3.10 shows that there is a wide range in possible estimates of total energy use when all parameters are systematically varied between upper and lower limits. The range of values shown here is based on a limited assessment of uncertainty in the modelling process. The difference between our mean value from the Monte Carlo simulations and the 'measured' total energy use in 2009 is 11%. This gives an indication of further uncertainty in the modelling process. People using the modelled data should be aware of this model overestimate of 11%, in addition to the uncertainty shown in the graph. All modelled data in the Fact File is adjusted to align with DUKES, which reduces the uncertainty in reported figures.

## Conclusions

We have tried to make our work for DECC on household energy use as transparent and accessible as possible to third parties. We believe this is in the interests of both policy makers and the research community. Policy makers benefit from increased scrutiny of work carried out for them by outside contractors and by allowing the

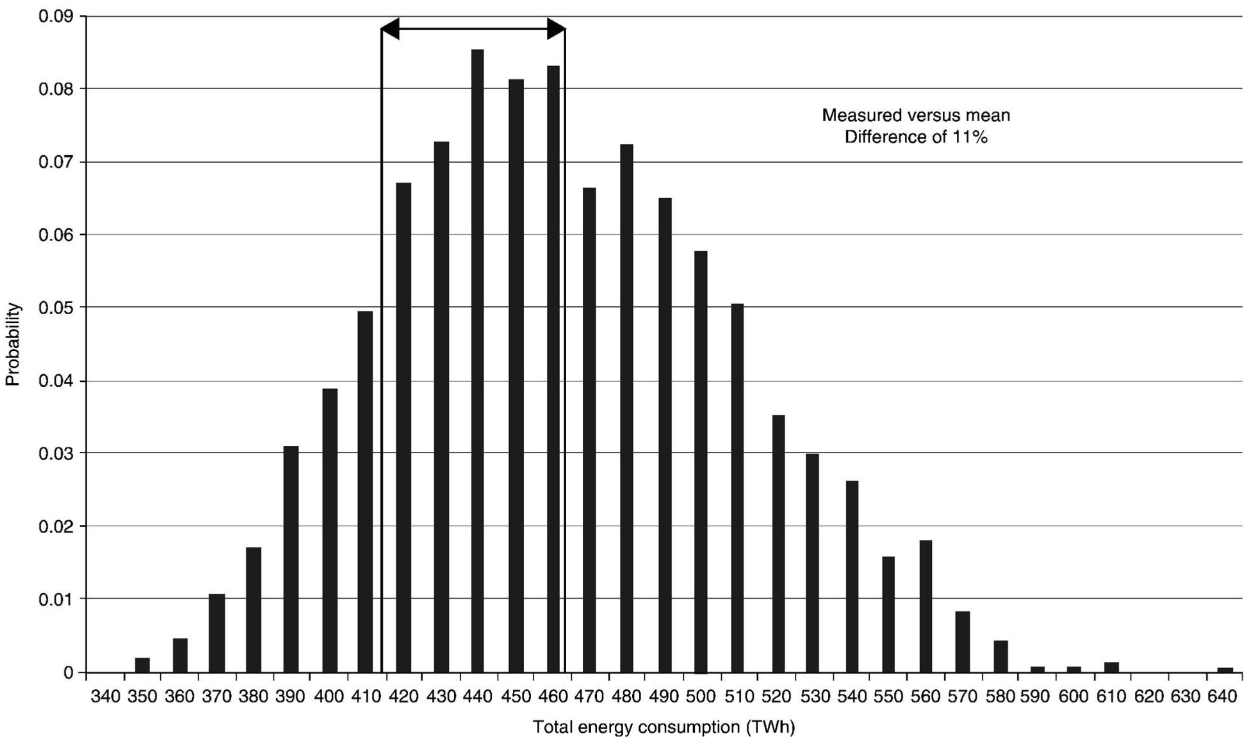


**Figure 3.10** Modelled estimates of total English domestic energy consumption (TW h) in 2009 using the CHM. The 'measured' value from DUKES is 417.6 TW h, while the mean of our Monte Carlo analysis is 463.1 TW h.

research community to undertake work that is not possible within government – building on government-funded data and tools.

The research community benefits from getting access to data that would be hugely expensive to collect from scratch and from using the same model as the government uses to understand household energy use. Researchers also benefit by having access to consistent, clearly described assumptions and methods for modelling. This allows much more effective collaborations and comparisons between work carried out in different organizations.

We all benefit by avoiding inefficient duplication of work – both modelling and data collection. Instead, we can collectively focus resources where there is most potential to increase our understanding – for example understanding more about uncertainty in modelling, part of which is presented here.

## Acknowledgements

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# 4 Retrofit innovation in the UK social housing sector: A socio-technical perspective

*Will Swan*

## Introduction

Sustainable retrofit of the existing housing stock is a vital component in addressing energy policy issues for the UK domestic sector (Roberts 2008; Kelly 2009; Mansfield 2009). While new build, particularly in the social housing sector, has been subject to increasingly stringent regulation, through the Building Regulations (ODPM 2006) and the Code for Sustainable Homes (CLG 2009), there is recognition that this will mean change for only a small part of the current housing stock, having only a minimal effect on the overall energy use and related emissions of the domestic sector. The existing UK housing stock is replaced at less than 1% per annum (Boardman 2007; Ravetz 2008; HM Government 2010a), so in order to reduce energy consumption and the associated carbon dioxide emissions, the current wisdom is that the existing stock must be brought up to higher energy performance standards (Kelly 2009; Mansfield 2009).

Retrofitting the existing housing stock has been viewed as a large-scale and complex engineering problem (Kelly 2009). However, to appreciate the nature of the problem fully we have to define it better. Retrofit is a response to energy policy (DTI 2006, 2007) requirements to reduce carbon dioxide emissions, address fuel poverty and improve UK energy security. The retrofit concept involves making physical improvements to homes, such as improved insulation or heating systems, to make them more energy efficient. When this simple idea is attempted in practice, this engineering problem becomes more complex than the simple application of fabric and systems solutions. Homeowners are resistant to the adoption of new technologies for a variety of reasons, financial models to support delivery seem complex, methods to identify potential upgrades are not fully developed and warranty and regulatory issues create difficulties. For example, the recent 'rent-a-roof' model for the installation of photovoltaic cells seen in the UK is a prime example of the complexity in the domestic energy sector (Brignall 2012). What appeared to be a relatively simple business model, where a resident has free electricity in return for the use of their roof

*Retrofitting the Built Environment*, First Edition. Edited by William Swan and Philip Brown.

to allow a company to collect the feed-in tariff, has led to unforeseen complications. Some of the individuals who have rented their roofs in this way have struggled to re-mortgage, due to the 'leasing' of their roof space being viewed as a problem by some mortgage providers. A narrow engineering perspective of how we approach the sustainable retrofit of our properties means that there are unforeseen outcomes and unintended consequences.

Two successive UK Governments have identified social housing as a test-bed for the development of the sustainable retrofit market (HM Government 2010). The sustainable retrofit market can be viewed as emerging, and so specific activity by Government may be required to effectively upscale the market (van Sandick and Oostra 2010) to a point where it may be acceptable to owner-occupiers or private landlords, who make up the larger proportion of the housing market. Social housing has the benefit of retrofit decisions being made by property professionals, who may have a more detailed understanding of their properties, more effectively project manage and have an existing programme of maintenance and refurbishment for their properties (Jenkins 2010). In 2011, the University of Salford, in partnership with Finnish research organization VTT, undertook a study of retrofit innovation in social housing. This study took a wider view of innovation, considering not only technical solutions but also the process, finance and behavioural innovations that might be needed to drive successful implementation. Here we consider how this innovation interacted with the different elements of the socio-technical regime and how teams managed this complexity. The study indicates that retrofit covers many issues from the regulatory and policy domains, through technical and informational issues, to "people" issues, each driving what might be initially viewed as a technical problem (Geels 2005). When we innovate in the field of retrofit, we need to embrace this complexity if we are going to succeed.

## Innovation and retrofit

When we consider retrofit in terms of innovation we are often drawn to the technological perspective. The pure 'engineering' view, where new physical products are brought to bear to solve the problem, can give a very narrow perspective of how innovation works within the sector. Fundamentally, innovation is about change. Van der Ven identified innovation as:

> … the development and implementation of new ideas by people who over time engage in transactions with others within an institutional order (Van de Ven *et al.* 1986, p. 590).

Much of the innovation literature does focus around the appearance of new technologies, albeit this is often used as a starting point for a wider analysis, such as new paradigms of science and technology on a large scale (Kuhn 1970), or new products and services (Henderson and Clark 1990). Sexton and Barrett (2003) extended the definition of innovation beyond something new, stating that the innovation should also improve overall performance. This pragmatic approach considers that not only something new is happening, but also that it is adopted (Edwards *et al.* 2004) and generates an improvement for the organization or, in the case of the retrofit, the household.

Gann (2003) takes a more expansive stance when considering innovation, which in the context of the retrofit problem, could be considered to be more appropriate:

> But innovation is not solely about competition, market development and economic growth. Issues of customer choice, social and environmental sustainability and quality of life are equally important. This is particularly the case in the production and use of the built environment, which provides much of the fixed capital infrastructure required by modern society (Gann 2003, p. 553).

Gann's view is more in line with what was observed in the study of retrofit innovation within the social housing sector, where wider social objectives such as the reduction of carbon emissions or fuel poverty are core drivers for innovation.

Innovation is a socio-technical concept and the literature does recognize that organizational contexts (Lesseure *et al.* 2004), regulatory frameworks (Gann 1998) and multiple stakeholders (Afuah and Bharam 1995) all combine to drive and influence innovation in specific contexts. In the next section we investigate a socio-technical framework that helps us map the factors we need to consider when innovating within the domestic energy regime.

## Innovation and socio-technical systems

How does a new product come to be adopted? The issue of adoption is a complex one and often not driven solely by the performance or quality of a product (Afuah and Bharam 1995), but by a wide number of different factors. Here we outline a socio-technical framework that provides a context for understanding innovations within the UK retrofit sector.

Socio-technical systems were identified by the Tavistock group, emerging as an analytical response to production problems within the mining industry (Trist and Bamforth 1951; Trist 1981). At the core of the approach is the proposition that many systems are a combination of both physical and non-physical constructions and the human context (Geels 2005) and that change was dependent on the complex interactions between these elements. Socio-technical analysis can be considered at different levels of scale, from small work groups (Trist and Bamforth 1951) right up to large-scale national systems (Geels 2005; Geels and Schot 2007; Verbong and Geels 2007). Geels defines socio-technical systems as displaying the following characteristics:

> At the level of societal functions, a range of elements are linked together to achieve functionality, for example, technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and productions systems (Geels 2005, p. 5).

Geels (2005) identifies three levels that interact when considering innovation in a socio-technical context, as shown in Figure 4.1. The first is the landscape, which includes factors outside the system that have a driving influence. In the case of retrofit

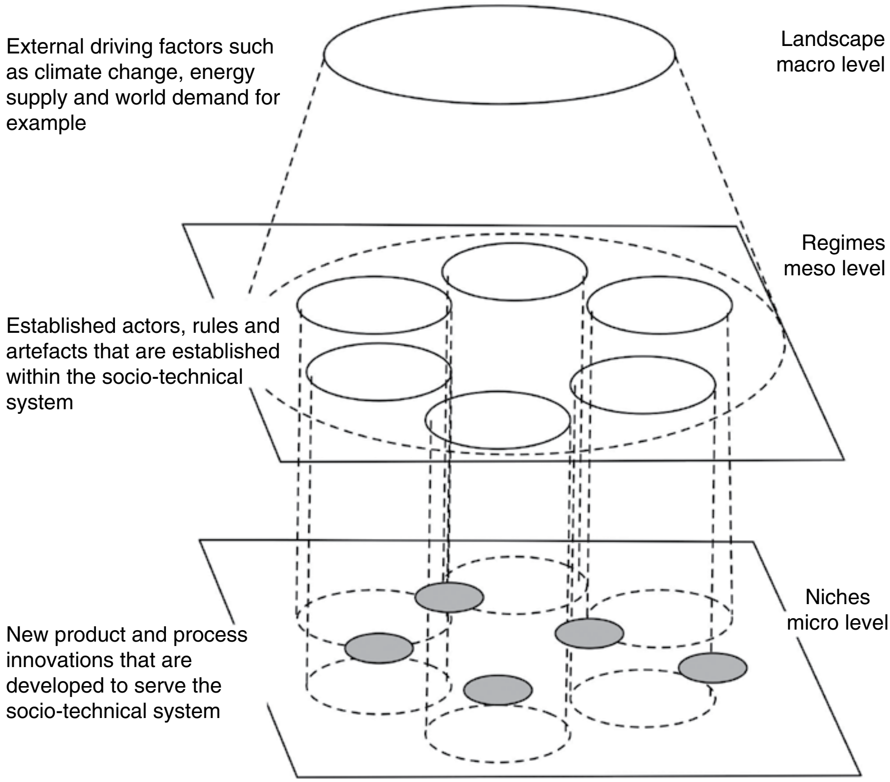


**Figure 4.1** Three levels of socio-technical systems (adapted from Geels 2005).

innovations these factors might be issues such as climate change or declining energy reserves. The second layer is the socio-technical regime; this is the structure of artefacts, actors and rules that link together to form the system. The final layer is that of niche innovations. These innovations are developed at the micro level and then must be adopted into the regime if they are to be widely used. The regime may appropriate the new innovation, as it fits easily within the existing regime, or the regime may adapt to accommodate the new innovation, with structures changing to reflect the innovation's new place in the regime. Alternatively, the innovation might be rejected by the regime and fail entirely. This view links closely with the concept of disruption from innovation theory (Henderson and Clark 1990).

The model is not without critics (Genus and Coles 2008; Smith and Stirling 2008); issues regarding the robustness of the data collection, the role of the researcher in making decisions, particularly where systems and regime boundaries are drawn, and the historical nature of the approach are all criticised. However, Genus and Coles do recognise:

> … it appears as if the potential contribution of the MLP (Multi Level Perspective)/ transitions framework could be limited to offering a heuristic device that can be used to organise data about long-term, complex and competitive technological trajectories … (Genus and Coles 2008, p. 1442).

It is this application of the Geels model we are considering, using the structure of people and organisations (actors), rules and things (artefacts) that link together in different ways and understanding how they interact with each other. Here the model is used to described the structure of the retrofit problem and, using examples from case studies, attempt to understand the nature of innovation within this context. The situation is pressing for industry and the UK Government, particularly in the context of the emerging Green Deal, and the ability to express even part of the associated complexity can provide a structured framework for us to consider innovation issues.

## What does the domestic energy regime look like?

Figure 4.2 shows us a simplified model of the socio-technical regime for domestic energy. Any innovation will have to be appropriated into, or accommodated by, this framework if it is to be adopted. For example, a new approach to electrical microgeneration will have to be able to physically connect to the energy infrastructure, but it will also have to be legal to do so within the current rules. Softer issues, such as its usability, will be important, while subsidies may be put in place to improve its take-up.

This model is adapted from the Geels examples for shipping, aviation and rail. Within the model there are three different types of elements to consider: actors, or stakeholders, such as skilled workers or residents, who have a decision-making and action taking role within the framework, rules both formal and informal, such as policy frameworks or regulations, that govern the way decisions are made and actions undertaken, and artefacts, the physical components of the system. These are described in more detail below.

### Artefacts

In many ways the easiest element of a socio-technical system to engage with is the physical artefact. Figure 4.3 outlines the kinds of physical products that may be applied to a property to improve its energy performance. Fabric improvements, heating and electrical systems, renewable energy and controls all have a role to play in reducing the energy use and carbon emissions from homes. They also connect with other physical artefacts within the system, such as the existing building and the energy grid.

When we consider ‘innovation’ within the retrofit sector, it is clear that the physical artefact is where many groups feel that innovation occurs. Better performing insulation, new controls or heating systems can all be seen to drive the performance of a building, but the socio-technical concept tells us the model is more complex than this. A well-designed intuitive heating control system may not be adopted if it cannot link with products, meet regulations and be appropriately priced.

### Actors within the domestic energy regime

Each regime has a number of actors that work within the wider structure. These different actors all have a role to play in either encouraging or blocking the passage of niche innovations into the socio-technical regime. They can be the creators of new

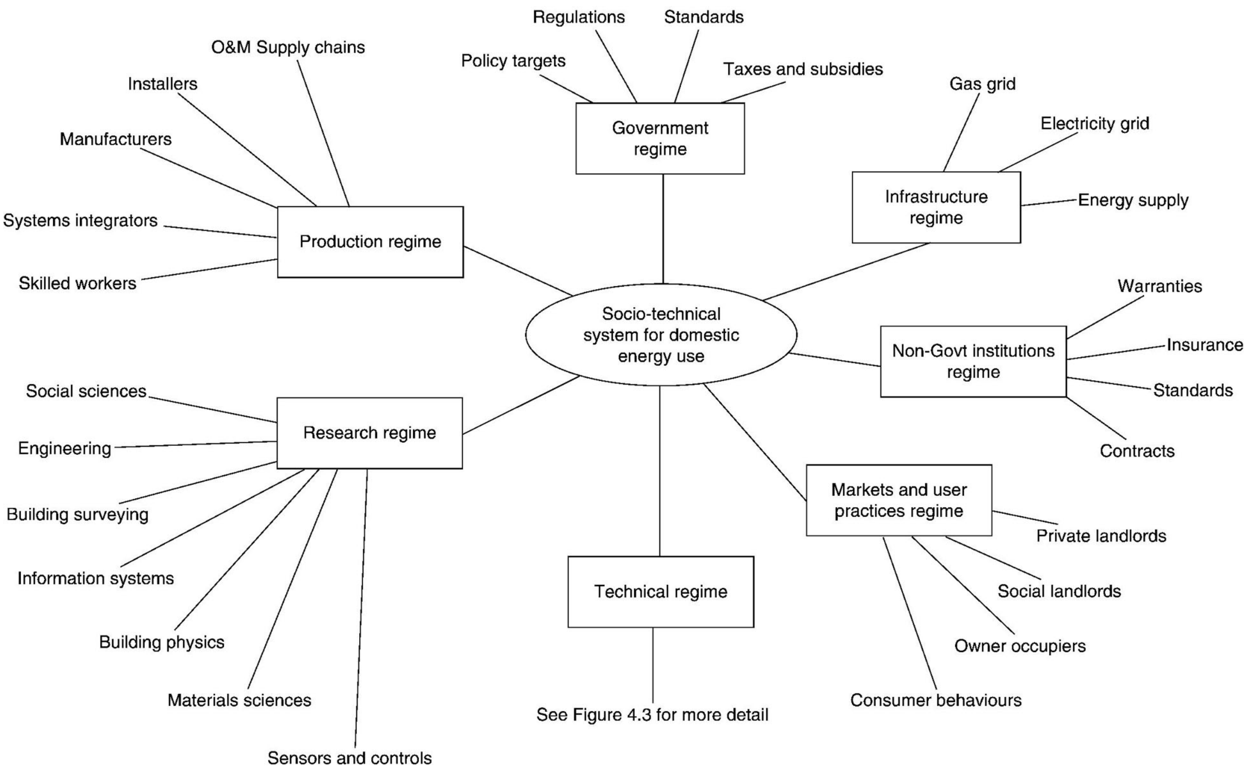


**Figure 4.2** Socio-technical regime for a domestic energy system (adapted from Geels 2005).

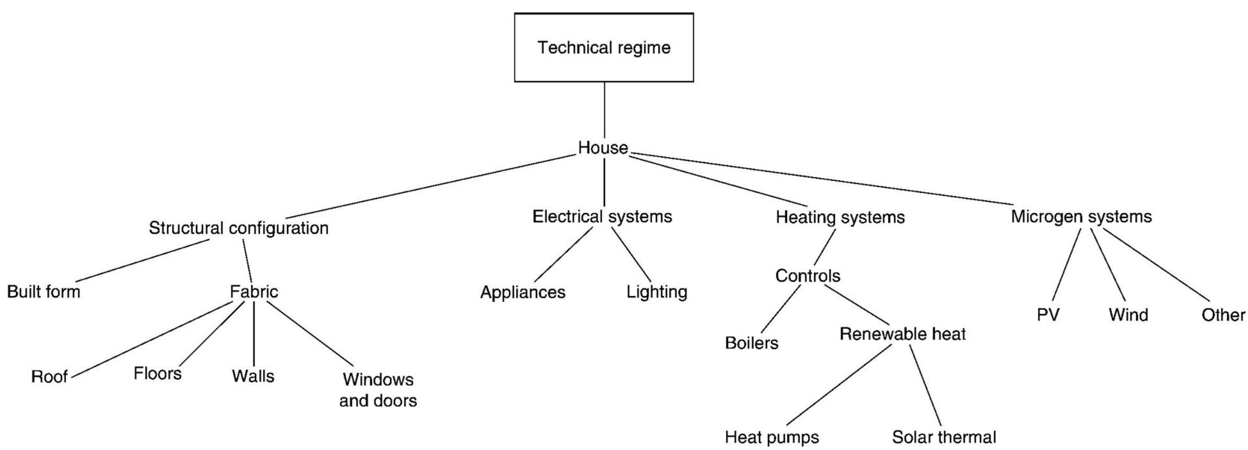


**Figure 4.3** Retrofit product hierarchy.

**Table 4.1** Actors within the domestic energy regime.

| Regime | Actors | Key Functions |
|---|---|---|
| Government | • Department of Energy and Climate Change<br>• Communities and Local Government<br>• Local Government<br>• Planning<br>• Building Control<br>• Regulators | The development of policy and appropriate legislation and regulation. Processes to ensure the application and enforcement of regulation. Tax and subsidy frameworks |
| Infrastructure | • Energy supply companies<br>• Infrastructure companies | Provision of effective infrastructure and energy supply |
| Non-governmental institutions | • Insurance companies<br>• Valuation companies<br>• Certification bodies<br>• Professional bodies<br>• Warranty providers<br>• Finance companies<br>• Energy advisory services | Development of frameworks to provide insurance and legal cover, protection of standards, consumer advice and financial models |
| Markets and user practices | • Owner occupiers<br>• House builders<br>• Social landlords<br>• Private landlords<br>• Residents | Various markets for products and services to provide energy-efficient new and existing homes |
| Technical regime | • Equipment manufacturers<br>• Materials manufacturers | Development of physical products and materials to be applied to new and existing homes |
| Knowledge regime | • Universities<br>• Other research bodies<br>• Consultants<br>• Manufacturers<br>• Training providers | Development of knowledge with regards to the whole socio-technical regime |
| Production regime | • Contractors<br>• Installers<br>• Manufacturers<br>• Resellers | Delivery of products as applied into new and existing homes |

products, such as manufacturers, or policy makers and regulators that will determine the rules that govern adoption of new technology through models such as the Building Regulations or the Green Deal. Table 4.1 identifies the major actors that can be considered to have influence on the domestic energy regime. They are mapped on to each of the generic sub-regimes as identified by Geels.

Rules within the domestic energy regime

Geels (2005) identifies three different types of rules: regulative, normative and cognitive. Regulative covers formal rules such as sanctions, standards or incentives and have an important role to play in this domain. Normative rules are concerned with shared values and norms between different stakeholder groups. Cognitive rules are the models for action, or the *way things are done*, that determine behaviours, such as bodies of knowledge, heuristics and models of effective action.

This socio-technical perspective forms the theoretical basis for the ApRemodel study of retrofit innovation in the social housing sector (Swan *et al.* 2012). The study looked at 18 different case studies and identified 41 individual innovations. Here the case studies are used to understand some of the main innovation issues for the social housing sector in terms of retrofit. The innovations ranged from technology demonstrators to large-scale retrofit programmes. An innovation was identified as being a product or process that was new to the UK retrofit industry, rather than using an organizational boundary as a determining factor. So while an activity may have been innovative for an organization, if it was an established practice elsewhere it was not included. The full list of innovation case studies is shown in Table 4.2.

**Table 4.2** List of case studies.

| Case title | Description |
|---|---|
| EcoPod at Chartist House | The EcoPod was an off-site manufactured heating system incorporating gas boilers and solar thermal. This was also supported by a Building Management System. Resident engagement was also well supported through both the design of the installation process and relationship management |
| WHISCERS | WHISCERS is a scanning system design to support the off-site manufacture of internal wall insulation with precision cutting, reducing the amount of time required to install, and reducing wast. |
| Sheffield Road Biomass, Barnsley | Barnsley has had a long commitment to the use of biomass. While biomass itself is not innovative, Barnsley Council has built an integrated infrastructure to support the local production and delivery of biomass fuel |
| Gentoo, Pay as You Save | The pilot Pay as You Save Programme, conducted by Gentoo, served as a forerunner for the Green Deal, using energy savings gained by retrofit to finance the capital costs of the improvement programme |
| South Wight Housing Association, Chale | A retrofit programme, which incorporated long-term monitoring activity, was supported through the development of community champions, local residents who were trained to support the rest of the community through the retrofit process |
| WattBox | This technology was applied in a number of the Retrofit for the Future projects funded by the Technology Strategy Board. It is a self-learning heating and hot water control supported by sensors, designed to support users meet their needs in the most energy-efficient way |

**Table 4.2** (*Continued*)

| Case title | Description |
|---|---|
| Worthing Homes, Relish | Worthing Homes conducted a range of interventions to evaluate both behavioural and technical interventions. This looked to build an approach that would maximise the widerretrofit programme |
| Salix Homes, Salford Barracks | The Salford Barracks project was an early example of the use of the CESP funding to undertake large-scale retrofit. This also included engagement and post-installation evaluation with residents and the use of the Social Return on Investment Model to evaluate the outcomes of the project |
| Affinity Sutton, FutureFit | FutureFit is an integrated model of retrofit delivery for 102 properties, ranging from the definition of retrofit packages with various cost brackets, resident performance monitoring |
| City South Manchester, Hulme Tower Blocks | Hulme Tower Blocks were externally clad, with innovations in the development of the supply chain and engagement of residents. |
| Southern Housing Group, Green Doctor | The Green Doctor Initiative was concerned with training residents to act as community advisors to support individuals in their energy use, providing a mixture of advice and basic retrofit measures |
| Octavia Housing, Passiv Haus | Early example of the application of the PassivHaus approach as applied to retrofit |
| EnerPHit | EnerPHit is an emerging retrofit standard that connects with PassivHaus principles. This is an early example of the pilot project delivered through the TSB Retrofit for the Future Programme |
| Fusion21, Retrofit Frameworks | Fusion21 is a social enterprise that is developing a holistic delivery model addressing technical, commercial and social aspects of the retrofit delivery process. It uses the procurement framework as a vehicle to deliver jobs and skills to local residents |
| Urbed, Rotherham Retrofit | This multihouse retrofit project was delivered as part of the TSB Retrofit for the Future Programme to demonstrate large carbon savings for a lower cost, driven by a fabric first approach |
| Islington Art Engagement | A series of arts projects used to promote and engage residents with the retrofit concept and process |
| Urbed, Carbon Co-operative | Based on the Community Green Deal Report, this model is designed to create a social enterprise that will be able to channel funds, such as the Feed-in Tariff and Renewable Heat Incentive, to support neighbourhood retrofit driven by local residents |
| Salix, Regents Park Estate | This project looked at innovative ways of trying to engage mixed tenure in the neighbourhood level retrofit to drive economies of scale and avoid the issue of 'pepper-potting' of properties, which can reduce both efficiency and effectiveness of retrofit. |

## What is the nature of innovation in the UK social housing sector?

When considering the case studies two major issues were highlighted with regards to the nature of the innovations observed. The first factor was that many of the innovations could be described as incremental. Incremental innovation means that an existing product or process is slightly changed and does not overturn existing rules or structures (Henderson and Clark 1990). They were often minor developments or adaptations of existing processes, technologies or standards that had previously existed. Of the 41 identified innovations, 35 were categorized as incremental. Examples of this include adapting building surveying approaches and tools for retrofit, as in FutureFit and Fusion21, or modifying resident engagement techniques to fit the new context, as in EcoPod and the Islington Art Project. This was often driven by the tool in question not being sufficient for the retrofit approach. FutureFit and Fusion21 both adapted the modelling tool, the Reduced Data Standard Assessment Procedure (RdSAP), in order to make it fit their approach. However, as RdSAP is an industry standard approach, neither felt it was appropriate to take an entirely new approach. It is a regulative rule that many people understand and use to evaluate the energy performance of their properties, forming the basis for the Energy Performance Certificate used in the UK.

The second issue is that of complexity. The case studies that were concerned with delivering whole retrofit projects were often composed of a number of innovations covering different elements of the retrofit process from surveying and modelling of buildings (Fusion21, FutureFit, Urbed Community Green Deal (Urbed 2010), Relish), procurement and delivery processes (FutureFit, Urbed Community Green Deal, Salford Barracks), resident engagement (Fusion21, Relish, FutureFit, Urbed Community Green Deal) and finance (FutureFit, Urbed Community Green Deal, Gentoo Pay as You Save). The delivery of physical retrofit required a range of innovations to ensure effective implementation. The research team were interested as to whether new innovations were developed as barriers became apparent, creating a responsive or 'situational' innovation as is often found in the construction industry (Slaughter 1993), where project teams innovate around problems as they arise, rather than a more structured process, as might be seen in traditional product development. The case studies revealed that the sustainable retrofit of domestic properties is being viewed in a systemic way by early adopters. Projects such as EcoPod, Community Green Deal and Fusion21 underline the application of this systemic thinking, which is required to ensure the delivery of a built environment with improved energy efficiency. This means that technological choices have been considered in their wider context. The successful application of a technical innovation was often driven by the innovation being supported by a range of other innovative activities that were designed to address potential barriers to the innovation's implementation.

The issues of incremental innovation and the need to respond to complexity may be related problems. The low risk incremental approach is potentially a response to this complexity. There are so many issues to be addressed by the delivery teams, such as resident in-use issues or existing standards for definition and installation of retrofit, that radical solutions might have presented too much risk of non-adoption. The innovations that were used were often merely 'tweaks' of existing approaches to support the practical delivery of retrofit, often applied in groups of innovations. This could be because the teams were innovative and saw multiple opportunities to innovate, but also it could be considered that the new nature of the problem required additional innovations to make the proposed approach work in an effective way. These planned, multifaceted responses undertaken in many of the cases shows that industry recognises the socio-technical nature of the problem, even if they would not describe it as such.

## Resident focused approach

In the majority of the case studies, the residents were placed very much at the centre of the process. Social housing accounts for 16% of the UK housing stock (CLG 2011) with private rented accounting for 18% and owner occupiers 66%. Social housing residents represent a less complex group in terms of adoption, as key knowledge and access to finance barriers are addressed by the landlord. However, residents still have the capability to refuse to have the changes made to their homes and so must be handled carefully if a retrofit project is to be a success. There are two identified areas where innovations are required to address residents: the risk of non-adoption and the risk of incorrect use of installed technology. Even for innovations that are ostensibly technical, resident factors often drove the innovation's development. For example, the WattBox control system was designed to enable residents more simply to control their energy use, while the WHISCERS scanning tool, where rooms were scanned and measured using a laser and internal insulation cut-off site, was developed to reduce resident disruption during the installation of internal wall insulation, another major barrier to the non-adoption of many retrofit technologies.

Adoption risk is a major problem for sustainable retrofit. In many of the cases the upgrades were provided for free and residents met even this offer with refusals. Much of the engagement, in many of the cases, was adapted from the approaches used in Decent Homes, a major upgrade programme undertaken for social housing, which focused on housing quality generally. This included the use of established techniques such as, resident liaison officers, open days where people could see and use the technology, and the use of resident champions. Both Fusion21 and FutureFit identified that there were high costs associated with engagement that were often not considered within wider project costs.

Advice after the installation phase was also a large part of the retrofit programme case studies, such as Relish, FutureFit and Fusion21. Resident champions were used to support residents in the use of their technology after installation, as in the Green Doctor Initiative of Southern Housing. The EcoPod approach, while using advice and support similar to the other cases, also highlighted an interesting issue with regards to people's perception of change. The residents had their gas boilers removed and a large system of gas boilers and solar thermal panels was placed on the roof. The residents were then provided heat through a heat exchanger and hot water on demand from the tanks on the roof. What was interesting was that the heat exchanger looked very much like the boiler they were used to. The thermostat also worked in exactly the same way as their previous system. The residents indicated that this was an important part in making the transition from one system to another easier.

EcoPod also shows a good example of a normative, or value-based, rule that residents within the upgraded tower block seemed to share. The existing gas fires were to be removed as part of the upgrade, but many of the residents used the fires not only for heating but felt that they served as an aesthetic focal point for the room. This led to the replacement of the fires with electric fires. This idea of a fire as something other than a heating source was shared by many individuals within the housing complex and shows an interesting example of a value-based norm that can impact the adoption of technology. It is not driven by performance, but by social rules regarding how people view their homes and the way they use them.

## Technical innovations

Many of the cases were only considered in the context of their non-technical elements, partially driven by the intentional bias within the ApRemodel study. During the wider case study analysis, where over 30 cases were considered from the submissions, what was clear is that technical innovation was incremental in nature. There were examples of better insulation materials, controls or more efficient systems, but none of these can be described as radical innovations. The use of laser mapping technologies for the off-site cutting of insulation in the WHISCERS project brought scanning and computer numerically controlled off-site cutting to construction, while the EcoPod combined a number of existing technologies into a new engineering solution, a form of architectural innovation (Henderson and Clark 1990). The WattBox was a development of control systems, using heuristics to support people in the effective management of their heating and hot water.

## Understanding the process

The analysis of the case studies identified three areas where process innovations were applied: selecting retrofit options, understanding and managing delivery, and financing the retrofit solutions.

Determining the options that can be applied for upgrades formed a part of a number of the case studies. Fusion21, FutureFit and Urbed Community Green Deal all outlined approaches that were incremental advances from the models that currently exist. The development of these types of model is seen to underpin the assessment stage of the forthcoming Green Deal. All of the approaches used within the cases followed a type of Green Deal Assessment model, where RdSAP or a variant is used as a basis, but they extended the approach to include locational or planning factors and reduced the number of assumptions made by the model. These created new variants that the teams used to assess their properties in an effort to scope the types of retrofit options that would be achievable. The need to innovate around this process appeared to be twofold. The first was that the current approach, where RdSAP is used with recommendations selected from Appendix T as in the standard Energy Performance Certificate, was not considered robust enough to deliver detailed options. The second issue is that the tools represented an attempt to capture cognitive rules as to what types of improvements would be appropriate for what types of properties and households. This creates the potential for replicability and early options appraisal to be undertaken using embedded rules, rather than relying on varying understanding of the retrofit problem.

Refurbishment is in many ways more complex than new build. Sustainable refurbishment will include a number of different trades and creates potential for clashes (Egbu 1997). Urbed outlined a delivery process within their community Green Deal model, while EcoPod looked to create a resident-centred process that specifically managed risk associated with residents during the delivery process. WHISCERS, the scanning tool, looked to apply off-site principles to the installation of internal wall insulation. A number of the case respondents recognized that more work was needed to effectively understand refurbishment processes and where principles such as lean, off-site manufacture and supply chain management might be brought to bear, indicating a potential research area for the sector.

Financial models are an issue of growing importance for retrofit. Unlike Decent Homes, where the funding was provided from Government, the upgrade of the housing stock for energy efficiency is taking place within a different economic context. The lack of capital has led to approaches such as the rent-a-roof schemes, seen as a response to subsidies provided through the Feed-in Tariff. Two of the case studies focused very much on the innovative financial models required to fund any sustainable retrofit. The Gentoo Pay as You Save (PAYS) pilot was one of the projects that were developed to test the principles of the forthcoming Green Deal. The concept was to use the energy savings derived from the implementation of a sustainable retrofit as a revenue stream to fund the capital works. The implementation of the PAYS model required changes to tenancy agreements to allow payments to be made. The Green Deal's passage through the UK parliament, particularly the level of consultation, shows the wide variety of stakeholders and rules that must be engaged with when financial innovation is attempted.

## Conclusions

The understanding of innovation in the sustainable retrofit market is dominated by two key factors. First, innovation is often in groups, or networks of innovations. The physical upgrade works are often accompanied by behavioural, energy modelling or financial innovations. The second is that the innovations are mainly incremental in nature. The issues of incremental innovation and the need to respond to complexity are related problems. The low-risk incremental approach is a response to this complexity. There are so many issues to be addressed, such as resident in-use issues or existing standards for definition and installation of retrofit, that radical solutions might have presented too much risk of non-adoption. The innovations that were used were often merely 'tweaks' of existing approaches, to support the practical delivery of retrofit, and often applied in groups of innovations. This could be because the teams were innovative and saw multiple opportunities to innovate, but also it could be considered that the new nature of the problem required additional innovations to make the proposed approach work in an effective way. These planned, multifaceted responses undertaken in many of the cases shows that industry recognises the socio-technical nature of the problem.

Socio-technical systems show us the level of complexity within the domestic energy system (Lomas 2010; Oreszczyn and Lowe 2010). Each layer of rules and actors means that any niche innovation that tries to enter the market must address multiple contextual factors. An incremental improvement on the way that things are currently done is more easily accommodated into this schema of rules, actors and artefacts, carrying less risk of failure. Rules and regulations do not need to be changed, supply chains easily understand the products or approaches in terms of installation and maintenance, and users can more easily engage with slight improvements of familiar products. The risks of incremental innovation are low and this has resonance with a construction industry skilled at managing risk. Radical innovations may fight against entrenched regulation, stakeholder inertia and an unwillingness of installer or user markets to accept, but to be successful must bring major benefits for actors to make them shift from often entrenched positions. The sheer extent and complexity of the socio-technical regime for domestic energy use makes it a less likely candidate for radical innovation. This is further compounded by the recent turbulence in the regulative environment. Changes in the grant regimes from the Carbon Emissions Reduction Target and Communities Energy Savings Programme to the forthcoming Green Deal and Energy Company Obligation have been in the pipeline for some time. Changes to subsidies through the Feed-in Tariff and delays in the introduction of the Renewable Heat Incentive mean that the socio-technical regime is uncertain in some regulative aspects, which can have a powerful effect in shaping innovation (Gann 2003). This is the paradox of the socio-technical regime for the domestic energy system, a complex mélange of inertia and uncertainty, representing a risky combination for potential innovators.

This begs the question as to whether we will see the kind of radical innovation that may be required to reduce carbon emissions to virtually zero for the housing stock by 2050 or whether it will be a series of incremental wins, running through basic measures to renewables. It may be that we have a dominant approach to thinking about reducing energy use in the housing stock, where many elements of the socio-technical regime, particularly around technology, industry practice and market attitudes, has had a long time to consolidate itself. If this is the case then only an approach that generates substantial benefit will cause a change in attitudes among stakeholders and lead to a long-lasting change in the way we consume energy in our homes. This benefit may be driven by the benefit delivered by the individual innovation or it may be that energy costs and climate issues become so pressing that we are compelled to change.

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# Part 2

## Policy and regulation

# 5 A roadmap to significant reductions in energy use for existing buildings: The long view

*Stephen Morgan*

## Introduction

Most energy efficiency programmes and policies addressing existing buildings on both sides of the Atlantic have failed to meet the goals of policymakers with even modest greenhouse gas and/or energy reduction goals being met. In the United States, ratepayer funded utility programmes routinely fail to keep up with annual growth in electricity sales (Lemoine and Prindle 2009). European programmes, characterized by high energy prices, mandatory benchmarking without performance requirements and white tags have failed to achieve deep penetration. The success of mandatory new building standards on both continents in meeting 25–40% reductions in energy use inspires greater interest in a similar building code policy for existing buildings.

Indeed, Australia and Denmark moved in that direction by adopting mandatory building energy ratings more than a decade ago. In Australia a study undertaken by the Australian Capital Territory, which has a 10-year disclosure policy for rating homes and commercial buildings, reveals that higher ratings earned 3% price premiums at the time of sale per star improvement in the rating on a six-point scale (Department of Environment, Water, Heritage and the Arts 2008). Commercial buildings enjoyed comparable results. Denmark's residential labelling requirement, in place since l996, has not seen significant results in real estate appreciation, in large part due to ineffective compliance and low awareness (Kjaerbye, 2008). Mandatory building labelling is gaining momentum in the US, as city governments in New York, Washington, DC, and San Francisco have large commercial building labelling requirements pending or in place. In the UK, the Government's unveiling of Display Energy Certificates (businesses) and Energy Performance Certificates (homes) are widely adopted, showing that mandatory existing building standards can be politically feasible. Given that energy efficiency greenhouse gas reduction potentials over the next 30 years reside primarily (60–75%) in existing buildings on both continents, policymakers cannot ignore this powerful lever to address the issue.

*Retrofitting the Built Environment*, First Edition. Edited by William Swan and Philip Brown.

Yet there are strong entrenched interests opposed to mandatory existing building standards. Owners, realtors and lenders lead the professions mobilised to undermine policy proposals for mandatory standards. For each of these interests, the strong perception is one of costly regulatory burdens imposed without offsetting benefits. Even local governments bristle at the concept of overburdened building inspectors taking on yet another unfunded mandate. Without strong, indisputable evidence that energy efficiency investments are sound, savings are measurable and sustained, and real estate appreciation is attainable, the political support for mandatory existing building standards will remain weak.

If the emerging mandatory commercial building labelling and disclosure programmes are to be successful in triggering significant energy efficiency investments, and if residential building labelling and disclosure programmes can be mandated, we must first develop an understanding of what comprises successful energy efficiency programmes. It is noteworthy that today the only US 'marketplace' for an energy efficiency services industry is in the so-called 'MUSH' sector, municipalities (and other government buildings), universities, schools and hospitals. These are the most regulated of building owners, reliant primarily upon taxpayer funding and lacking the resources to invest in energy-related capital improvements. Ten to fifteen regional and national companies, known as energy services companies, provide a one-stop service, identifying cost-effective energy efficiency measures, securing third party financing, hiring and overseeing installation contractors, guaranteeing savings, monitoring long-term utility costs and providing annual training for maintenance staff to assure the persistence of savings. Energy performance contracting statues passed by state governments enable this industry to thrive and it is now approaching $8 billion dollars in annual revenues (Goldman 2010). In the UK, energy performance contracting is only just now entering the MUSH sector. The absence of a tax-exempt financing opportunity and some poorly executed contracts a decade or more ago have stymied this approach. In the past two years a few new initiatives – such as that undertaken by the London Regional Authority and buttressed by access to low-cost government-provided financing – have successfully reintroduced energy performance in 86 buildings to date (Strand 2012).

Outside of the MUSH sector and public housing, energy performance contracting is rare and there is no effective energy efficiency services marketplace; the US lacks a significant one-stop contracting, comprehensive retrofit industry or readily accessible financing. Nor are there demonstrated savings results across residential neighbourhoods or commercial districts or even for specific building types. The oft-mentioned barriers in small and large residential and commercial buildings are too difficult to surmount – lack of knowledge, absence of accessible financing, shortage of documented results, split incentives and the hassle of arranging for multiple contractors. We have in the US instead a patchwork of utility and government-funded programmes, focused primarily on specific measures, end users and geographies with high electricity costs and progressive state governments. Comprehensive building treatments for all cost-effective measures, regardless of fuel type, does not happen outside of a few US Department of Energy pilot programmes.

This paper sets forth a theoretical framework or roadmap for how we get from today's multiplicity of largely ineffectual policies and programmes in the US to a set of conditions preparing us for a political climate in which mandatory standards for existing buildings can be effective, create a fully functioning energy services marketplace and trigger energy efficiency investments an order of magnitude greater than what we are experiencing today. The author believes that the basic principles of market formation embraced in this thesis will have major applications not only in Europe but in the United States as well.

It will take perhaps a decade to mobilize the political will to mandate existing building standards, arguably the only feasible way to achieve energy savings in the 25–40% range across the buildings sector within the next 25–30 years. However, the ambitious goals set by our national, state and local governments to reduce energy usage and greenhouse gases cannot be met with a gradual, incremental approach to prompting energy efficiency investments and the consensus required for mandatory existing building standards will not develop. Instead an aggressive and intelligent path might follow a trajectory as follows, working from 2020 backwards to the present:

- building benchmarking, labelling and disclosure, moving from voluntary to mandatory;
- incentive programmes characterized by one-stop contracting, on-bill and property assessed financing, utility incentives based on savings performance, documented savings, strong quality assurance measures, delivered by competent organizations with a singular focus;
- unprecedented marketing, featuring innovative social marketing efforts;
- workforce training investments;
- appropriate timing for each of these developments.

We are looking to generate hypotheses and be forward-looking, drawing from research over the past half-decade. More prominently, the conclusions drawn from the author's observations over the past 30 years implementing and evaluating energy efficiency programmes across the US inform the judgements that form the basis of this effort. Examining the results of energy efficiency programmes underway for the past two decades by three Californian utilities and those operating for the past decade by the New York State Energy Research and Development Authority have been most helpful. Most recently, a US Department of Energy (DOE) stimulus programme initiated in 2009, the $420 million competitive Better Buildings programme, funding 25 pilot programmes by local governments and non-profit organizations, designed to achieve comprehensive building retrofits, inspires this inquiry.

## The building blocks of a successful energy efficient future in buildings

The progression backwards from existing building standards, accomplished by some combination of prescriptive equipment measures and consumption per square foot metrics, must be deliberate, aggressive and adaptive. As new technologies and methodologies are introduced to lower the cost and/or simplify the tasks associated with reaching each milestone along the path to major energy efficient (EE) investments, policymakers must be flexible in adapting programmes, regulations and incentives appropriately. Indeed, any existing building standard should be phased in, starting with large buildings and moving to smaller ones. As is the case with fuel economy standards for vehicles and appliance standards, they should be made more stringent over time.

Before describing each building block used to achieve a private sector marketplace in energy efficiency, the reader may find it helpful to understand some key diffferences underlying the various building market sub-sectors as they affect the motivations and capabilities to undertake energy efficiency investments. Building size and ownership are the two major distinctions of note in this realm. Large buildings (50 000 $ft^2$ or more) comprise more than two-thirds of building energy use in North American and most European countries. Large residential (multifamily) and commercial buildings present challenges and opportunities that warrant customised responses from programme design and marketing professionals. Ownership is the first complication: buildings with a single owner and with occupants working for the owner's firm or organisation are the easiest to serve because the split incentive problem does not exist. Unfortunately, most large buildings have many tenants and complex ownerships, so designing energy efficiency programmes that benefit both tenants and owners is a requirement for successful retrofits. Therefore understanding that the vast majority of owners require quick 2–3 year paybacks and require many months of property manager and owner deliberations is also essential. On the other hand, large buildings can attract large investments, more readily available financing and sophisticated energy engineering, and design/build contractors to serve them. The marketing strategy focuses on a few key decision makers, extending from the CEO and CFO to the key property manager.

Small residential buildings – typically one to four family homes – and small commercial buildings – typically retail stores and strip malls – also vary by ownership and tenancy. The owner-occupier and tenants with long-term leases are the best candidates for significant investments. Small buildings are more difficult to reach, requiring mass marketing techniques, and have less knowledge about what to do, who can do it and who can advise them. The myriad technologies invite multiple contractors for comprehensive retrofits, rendering the 'hassle factor' a more difficult barrier than it is for larger, more sophisticated building owners. The absence of available cash or financing options handicaps the small building owner to a greater degree than that facing the large building owner.

## Building benchmarking, labelling and disclosure

There are two ways to effectively label buildings associated with disclosures: (1) triggered disclosures at the time of sale and (2) scheduled disclosure, within a specified time frame. The first is common with single family homes, the second with large commercial buildings. For both the label should be simple, understandable and straightforward, and it should be repeated or renewed every 3–5 years. To impact home buyers, renters or building investors, the label or energy performance scoring should be prominent and visible. For home buyers, that is the offer sheet from the seller; for the commercial building, it should be comparable to an elevator inspection rating or a restaurant cleanliness rating, prominently displayed in the building lobby. The labelling methodology itself must be credible, reliable and delivered by a third party. These issues are being tested as the UK is in its fifth year of implementation for Display Energy Certificates (DEC) for businesses and Energy Performance Certificates (EPC) for homes. DEC certifications are mandatory for public buildings, but not for private ones, and do not apply for commercial buildings less than 1000 $m^2$. Other members of the EU have similar policies in place.

Beyond the passage of the labelling and disclosure requirements, a government can be most helpful by researching the impact of building labels on rents, vacancy rates and building sale prices. In many areas of the US, mandatory labelling will only gain traction when voluntary labelling has been adopted first. Pilot programmes with voluntary labelling should focus on high adoption rates in concentrated geographic areas, such as a neighbourhood or commercial business district.

The US Environmental Protection Agency (EPA) has pioneered a commercial buildings energy rating system, known as the Energy Portfolio Standard. Customized by building type, the standard can be self-scored and meets the standards of simplicity, clarity and ease of application. It is also not notably precise, but it is a forward step for a voluntary standard. Peer pressure among buildings in similar geographic regions and building types is triggering energy efficiency investments that probably would not have happened in the absence of the EPA programme. However, widespread adoption of voluntary standards is a necessary precursor to a mandatory existing buildings standard.

## Carrots: Incentive programmes integrated with one-stop contracting and on-bill financing

For twenty years and longer, utilities and state governments have offered residential and commercial incentive programmes for energy efficiency to their customers. While they have varied considerably and have been limited by utility avoiding cost tests (the cost of building a new power plant), until recently they have not been notably successful in generating significant customer participation or utility fuel reductions. Far less than 1% in both categories is typical. More recently, programme budgets, marketing sophistication and customer ease of access have improved in some parts of the country. In 2009, the US DOE made a significant investment in this area, committing $420 million to 25 local governments and non-profit agencies to create, or build upon, energy efficiency programmes committed to comprehensive retrofits of buildings. The programme, a stimulus effort known as Better Buildings, is the most ambitious attempt to inspire a major push forward in the theory and practice of energy efficiency targeted solely to the existing buildings market. The programme will continue through the autumn of 2013.

Investigation of best practices in this programme, and in a few of the best utility managed programmes around the country that have preceded Better Buildings, suggest the recommendations for well-designed incentive programmes. The best of these programmes are characterised by 15–25% grant incentives against total project cost and a significant rebate to bring down the cost of initial building assessments; multiple points of entry for the customer to access the programme; one-stop contracting to ease customer hassles in moving from the assessment to installation stage; a quality assurance programme to inspect the work of contractors by a third party; on-bill financing provided by the local utility; the opportunity to address all utilities, including electricity, gas, oil, steam and water; and a sophisticated, targeted marketing strategy. The programmes also require a minimum of 15% savings achieved, in contrast to many of the utility programmes targeting a single measure, such as lighting.

The on-bill financing is a critical element; participation rates and investment levels can double or triple with accessible, affordable financing associated with monthly utility bills or quarterly property tax bills. While residential property tax assessments are temporarily not feasible in the US, commercial property tax assessments that include energy financing and stay with the property at the time of sale are currently being demonstrated. Utility on-bill financing exists today in a few areas and should expand rapidly within the next two years. The Green Deal commitment by the UK to offer customers on-bill financing in the autumn of 2012, if implemented and marketed aggressively, could constitute a major step forward for Europe. Yet the Green Investment Bank, created by the government, and its private sector counterpart, the Green Deal Finance Company, have not yet come to terms to create a viable financing offering for homes and businesses. The absence of sufficient carrots in the level of government support, sophisticated marketing strategy and identification of credible, trusted third party delivery organisations is one reason for the delay in organising a viable financing programme.

In the US, perhaps the best example of a programme that has put together most of the elements described above is the City of Austin's energy efficiency programme. Benefiting from a platform that is the City's publicly owned electric utility, the City has financial incentives for all building types, secured in the wake of an energy audit and escalating in value as the comprehensiveness of the retrofit expands. The City has one of the nation's few on-bill financing programmes for both commercial and residential customers. It also has a mandatory audit and disclosure ordinance, triggered by all building sales. It is on track to reach a goal of 1500 MW in electric efficiency from the residential and commercial sectors by 2020 (Austin Energy 2011). Programmes initiated by new, non-profit organisations in Charlottesville, Virginia, and Cincinnati, Ohio, are borrowing many of the concepts pioneered in Austin. All three are Better Buildings Network grant recipients from the US DOE.

## Innovative marketing

The marketing strategy deserves special mention. In the light of recent research detailing the difficulty of selling social marketing programmes, and with the benefit of applying the principles learned from successful efforts in recycling and public health campaigns, the marketing effort has to inform customers, motivate their follow-through after assessment recommendations are presented, generate a sense of commitment, provide utility savings feedback, reward investments, reconnect with customers to provide second and third opportunities to take additional actions and leverage existing customers to motivate their neighbours (Lovelock and Weinberg 1989; Kotler and Lee 2008; McKenzie-Mohr 2011).

Among their findings number these on messaging (Mckenzie-Mohr 2011):

- Make use of focus groups before launching an outreach programme to understand these issues and conduct follow-up surveys to assess the quality of your programmes and services. Across the board, saving money is a much more attractive message than reducing GHG or other environmental impacts, and specific steps or programmes are more motivating than providing general information.
- In the residential sector, competition or 'keeping up with your neighbours' is effective.
- In the commercial sector, testimonials from similar building owners are very motivating.
- Larger customers require more direct and customised outreach strategies.

Customising messages to particular building types – restaurants or grocery stores, for example – coupled with testimonials from early adopters is important. Branding is important, as are multiple delivery methods for the messaging: the Internet, TV, radio newspapers (especially free media), door-to-door canvasses from volunteers recruited by community partner organisations, trade allies, bill stuffers in utility mailings and posters. The more the marketing effort resembles a sustained political campaign in its intensity, ingenuity and use of diverse distribution channels, the more successful it can be. Offering promotional 'sales' where higher incentives are available for brief periods and group discounts for enrolling neighbours in the programme are common place.

On-line applications are routine and a sophisticated information technology platform to record the job process, utility data, contractor actions, installed measures and monitored savings is vital. For the first time ever on a sizable scale, we can look forward to the prospect of widely documented and reported savings from retrofits available to customers and the general public. The absence of documented savings, arrayed against investment costs, has been a major barrier to investments in buildings to date. The credibility and local nature of programme management organisations add to the effectiveness of the marketing campaign. Figure 5.1 highlights some of the key strategies available.

## Workforce training

Energy efficiency programmes cannot assume that creating demand will automatically generate supply to match. Too many start-up programmes have struggled because the contractor community did not have the requisite skills to deliver the

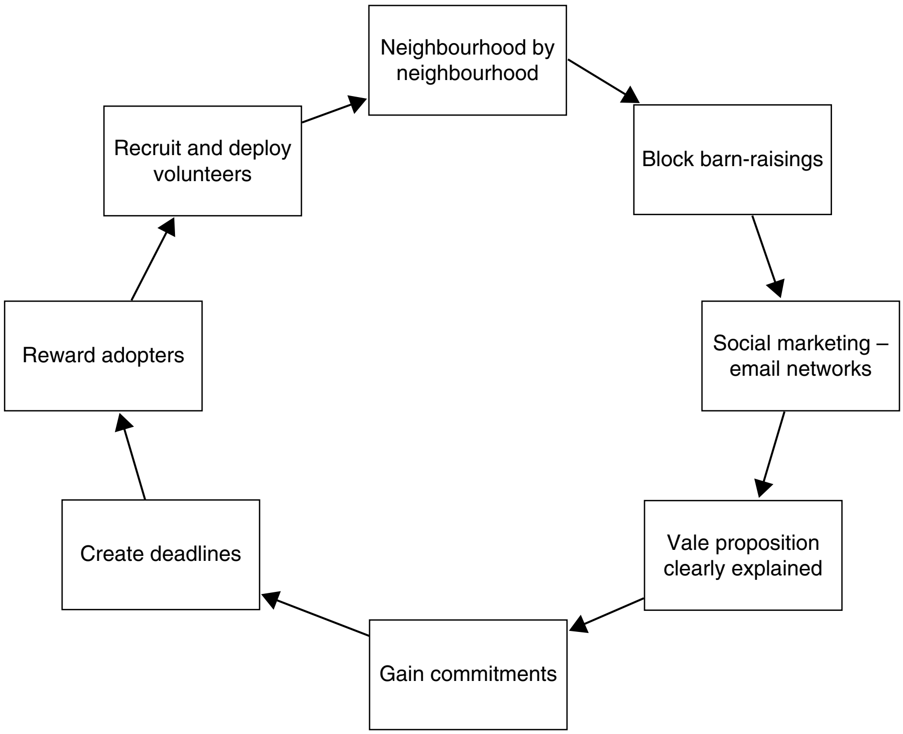


**Figure 5.1** Marketing campaign strategy.

comprehensive retrofits recommended in diagnostic assessments. To succeed in their own missions – and to deliver measurable value to their communities and the local political leadership – programme managers of EE programmes must allocate some resources to the whole process of:

- Recruiting workers with aptitudes for this work, paying attention to affirmative action and equal opportunity in employment and promotion.
- Ensuring training and certification matched to the real and continuing job market.
- Placing graduates appropriately, ensuring on-the-job training and career advancement opportunities.
- Soliciting feedback from trainees, employers and trainers to improve the process.

In the US residential sector today, very few residential contractors possess both air sealing and insulation skills; fewer still can also serve as general contractors to arrange for HVAC installations. Likewise, too few HVAC design and installation companies understand how to do air sealing well. In the commercial sector, most energy service firms have strong lighting design and installation expertise. Outside the performance contracting marketplace, however, few are proficient at HVAC, controls and lighting. Without better skills, a capacity to manage a broader range of measures and project management experience, the workforce will not meet the challenge implicit in comprehensive building retrofits.

Labour unions, community colleges and other workforce training institutions must also overcome their too common mismatch of training emphases with the available demand in a community. Too frequently, training has emphasised solar installers to the detriment of air sealing, assessment skills and other skills more commonly required in the emerging energy efficient marketplace. Accurately gauging the number of jobs required in each skill category is another problem that adequate market characterisation can solve.

Certifications and placement must be carefully calibrated to teach appropriate skills well, provide affordable courses and facilitate the placement of graduates in situations where they can thrive. Training institutions should re-certify and incrementally add to the depth of the curriculum. Facility managers are a particularly important constituency to service. The solicitation of feedback from facility managers, students, employers and other training institutions can improve both the curriculum and the experience for new hires. In the short run, government and utilities must be in the business of subsidising both training institutions and their students to move the workforce forward at an accelerated pace.

## Independent programme management organisations with credibility, strong missions and focus

It matters a great deal what kind of organisational entity manages an energy efficiency programme. In the US, utilities whose chief mission is selling electricity or gas encounter difficulties in effectively managing programmes to 'unsell' their product. They also face considerable scepticism in convincing their customers to commit themselves to their programmes. In the UK, customer distrust of utilities and their marketing messages is no less widespread. While regulatory decisons and state laws to decouple utility commodity sales from profits on energy efficiency investments have mitigated these issues in a few regions of the US, the problems are still widespread. Two of the most successful energy efficiency programmes in the US are managed by non-utility third parties: a non-profit agency, Vermont Energy Investment Corporation, in Vermont; and a state energy office, the New York Energy Research and Demonstration Authority, in New York. In both states the regulators and state legislatures have funnelled ratepayer contributions for energy efficiency to these third party programme managers. The UK's Green Deal utilises the utilities for the on-bill financing component and £1.3 billion per year in programme support for fuel poverty and carbon reduction, but does not rely upon them for marketing or programme delivery functions.

The ongoing Better Buildings programme has funded 25 new community-based programmes, most of whose grantees are local governments. Those local governments that have outsourced their programme management, marketing and other key functions to third parties have performed significantly better than those that kept these functions within City Hall. Government procurement, hiring and invoicing requirements can delay essential programme elements for months or longer. Just as damaging to programme execution is the difficulty of local governments in focusing their staff and other resources on the mission of planning and delivering energy efficiency programmes geared to building owners. The Specific Better Building Network programme launches in Charlotte, Atlanta, New Orleans and Charleston, for example, have been slowed by the bureaucratic difficulties in bringing focus and deliberate speed to the details and roll-out of marketing, quality assurance and other key elements.

Overcoming the barriers to building owner acceptance and participation in energy efficiency programmes is an inordinately challenging undertaking. Any organisation that assumes this challenge cannot be distracted by serving other masters or by pursuing other goals. Skilful, dedicated programme managers are required. Enjoying the respect of key stakeholders is necessary to the success of the programme management organisation. The implementing organisation must have flexibility in its hiring, procurement and other management functions.

Several non-profit organisations with singular missions to provide energy efficiency programmes to existing building owners have done particularly well in the Better Buildings programme. Their strong missions, absence of bureaucratic rules undermining flexibility, local credibility, marketing expertise, laser-like focus and community partnerships go some way to explaining their success. While this is not the only model for successful programme management, it is one worthy of further study and replication.

## Appropriate timing

Workforce development and incentive programmes can take place now and so too can voluntary benchmarking. Documenting energy savings and demonstrating how to enlist building owner participation, small and large, are the near-term challenges. Once we have learned how to cost-effectively attract customer participation in comprehensive retrofit programmes, we can anticipate a tipping point in participation rates. Unfortunately that day is not yet on the horizon.

Mandatory benchmarking, labelling and disclosure programmes will trigger the reaching of that tipping point. The emerging mandatory benchmarking programmes in California, New York City and Washington, DC, may pioneer a path for the rest of the US. Realistically, we are 2–4 years distant from widespread adoption of mandatory benchmarking and disclosure. In some parts of the nation, we may be a decade away.

When mandatory benchmarking and disclosure are in place, we can anticipate another 4–6 years of experience before the real estate professionals, lenders, building owners and elected officials will seriously consider mandatory existing standards. It will take a decade or more to sweep the country, unless a federal mandate is put into place. A climatic disaster widely attributed to global warming may accelerate this schedule, but neither planning for nor advocating such a disaster is wise public policy.

## Conclusion and further research

Once energy efficiency practitioners and researchers accept the premise that – outside of the institutional and government sectors – there is no private sector energy efficiency marketplace, they can understand the depth of the challenge in motivating building owners to invest in comprehensive energy retrofits. More than 90% of the US experience to date has been rate payer funded, utility administered programmes focused primarily on electricity measures, most commonly one or two at a time. The concept of fuel-blind (and water) comprehensive retrofits based upon the building owner's economic perspective is quite novel. The absence of documentary evidence testifying to the economic impact of energy efficiency retrofits is a large impediment to owner commitment. So too is the absence of a workforce infrastructure capable of providing expert, one-stop contracting for measures encompassing multiple fuels and multiple end uses. Finally, the paucity of affordable, accessible financing opportunities stymies even motivated owners without the cash on hand to finance retrofits.

This paper posits a pathway to mandatory existing building standards, the only compelling vehicle to assuring significant owner investments in energy efficiency measures. The ongoing US DOE Better Building programme is the first large-scale experiment in facilitating comprehensive building retrofits. It is too early to evaluate its results. In two years, DOE will have completed several evaluations. Meanwhile, the research opportunities to evaluate the near-term policy and programmatic elements articulated in this paper – incentive programmes, accessible financing, marketing strategies, strong quality assurance components, intelligent workforce development activities, mission-driven programme management organisations, documented cost and savings results – together and individually merit careful and thorough research efforts.

Likewise, the early ventures in local mandatory benchmarking and disclosure for commercial buildings deserve similar scrutiny from the research community. Can we demonstrate that comprehensive retrofits result in higher real estate values, lower vacancy rates, higher rents and reasonable returns on investments? These and similar economic evaluations await the documentation of investment costs and savings in measures spanning several end uses: space conditioning, water, lighting, appliances, hot water and plug loads.

It is also quite possible that there may be alternative pathways to achieving the 25–40% energy reductions in existing building use necessary to attain the mid-century greenhouse gas levels climate scientists state are required to stabilise our planet. Emerging and new technologies may provide a huge boost in that direction; alternative policies may also contribute significantly. It is abundantly clear that we must move beyond our present energy efficiency programmatic efforts that contribute less than 1% savings results to programmes and polices that contribute close to an order of magnitude improvements. That the UK's Green Deal has committed to on-bill financing for its utility customers could be a significant trigger to EE investments. We eagerly anticipate this initiative and these broader efforts: the next few years should signal the best paths to pursue.

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# 6 Thermal retrofit and building regulations for dwellings in the UK

*Stephen Todd*

## Introduction

Approximately two-thirds of homes standing in 2050 will have been built before 2005 (Department for Communities and Local Government 2006a) prior to the introduction of more stringent building regulations with regards to energy performance (Part L) in 2006. Therefore it is imperative that housing standards and regulation reflect the need to effectively upgrade the existing stock. This accounts for a major part of the stock, as the replacement rate of the housing stock in the UK is currently less than 1% per year (Department for Communities and Local Government 2006a). When combined with some 7 million hard to treat homes (Department for Communities and Local Government 2006a) within this stock, mainly made up of solid wall properties, we can see the extent of the challenge we face.

Research undertaken in Greater Manchester by the Low Carbon Economic Area (LCEA) Housing Retrofit Group (Rock *et al.* 2011) identified upgrade measures for housing in Greater Manchester. One of the outputs of this work was the development of three sustainable retrofit packages defined by the improvement in energy performance they brought about; Basic, Intermediate and Major Standards measures were identified and their impact on SAP/EPC/kg $CO_2$ levels calculated using the Standard Assessment Procedure (SAP), the recognised energy modelling approach in the UK. The packages were broken down into sub-group elements to help users decide where their property is in relation to the works being recommended. It has also helped users to identify whether the investment will be cost-effective in the long term and help to reduce the user's potential future energy costs. This study, which was based on the existing property types within Greater Manchester, identified that the major part of any retrofit strategy will be focused on the fabric of the property. A strategy of upgrading should endorse the 'Fabric First' methodology (Heaslip 2012), which aims to improve insulation, glazing and airtightness of dwellings. All these types of upgrade measures will have to comply with the requirements of the Building Regulations Part L1B (HM Government 2010a, 2010b). The Building

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Regulations are in place 'to ensure that buildings are safe, healthy, accessible and sustainable for current and future generations'.

Given the nature of the challenge we need to consider how the regulations will help shape our response to the sustainable retrofit problem. Here we consider the current regulations, their application and potential future developments that will be applied in the sustainable retrofit market in the UK.

## The UK Building Regulations

The UK Building Regulations exist principally to ensure the health, safety, welfare and convenience of people in and around buildings, together with the water and energy efficiency of buildings. Building regulations have developed from the thirteenth century, where issues of fire safety meant individual cities set regulations, culminating in the London Building Act of 1667, passed as a response to the Great Fire of London. Public health issues of the Victorian era extended powers to local authorities to create building by-laws. In 1966 the first set of national standard Building Regulations came into force in England and Wales, although these excluded London (Manco 2009).

They currently are comprised of 14 sections, each accompanied by an 'approved document', which outlines the required standards under the regulations. In 2006 the UK Government reviewed and updated Part L of the Building Regulations, 'Conservation of fuel and power', in order to make buildings more energy efficient and tackle climate change. In terms of housing, Part L1A (ODPM 2000) covers new buildings and Part L1B (ODPM 2000) covers existing homes. These regulations set out mandatory and optional minimum standards to which all building works must comply, with the latest revision introducing some new requirements.

If a fabric intervention covers more than 25% of the wall area, then Building Regulations will apply. Improvement works affected by building regulation control include replacement windows, external doors with more than 50% glazing, installation of central heating boilers and/or wood burning stoves, and the installation of renewable technologies. Building regulation requirements are broken down into two parts, *procedural* and *substantive*. The procedural requirements, which address the way work is done, would be to either use accredited contractors registered on a nationally recognised 'Competent Persons Scheme' – thus allowing them to self-certify that their works comply - or to seek approval directly from a building control body. The *substantive* element, identifying what is to be done, means ensuring that the treatment works meet the functional requirements of Part L of the Building Regulations, details of which are outlined in the supporting guidance that is Approved Document L1B, which are outlined below. In addition, planning permission may also be required, particularly for measures that would involve changes to the external appearance of the property. For example, character properties or properties in conservation areas may be difficult to apply retrofit upgrades that substantively change the aesthetics of the property.

Approved Document L1B came into force in October of 2010 and is closely linked to the SAP 2009 methodology. The requirements in the Approved Document vary and depend on the type of work that is undertaken to the existing dwelling. The Approved Document gives guidance on compliance where the following occurs:

- the construction of an extension;
- a material change of use or a change to the building's energy status, including such work as loft and garage conversion;
- the provision or extension of a controlled fitting service or controlled fitting;
- the replacement or renovation of a thermal element.

This guidance takes the form of advice with regards to common building types and details for existing buildings.

## Standard Assessment Procedure (SAP 2009)

The Standard Assessment Procedure (SAP) is the recognised energy model for domestic buildings in the UK. It is used alongside Reduced Data SAP, which is used to generate Energy Performance Certificates (EPC). The 2009 edition of the Standard Assessment Procedure (SAP 2009) (HM Government 2009) was introduced as the national calculation methodology on 1 October 2010 and is used for compliance with Building Regulations in England and Wales. This model is based on BREDEM (Building Research Establishment Domestic Energy Model) and is an update to the 2005 version (Anderson *et al.* 1985). The model takes a variety of data points concerning the dimensions, fabric and systems of the building to identify energy use, carbon emissions and a number of other energy use factors.

The most significant change is that energy demand for heating, hot water and lighting is now calculated on a monthly basis that achieves greater overall accuracy. The effect of these changes will be to increase the calculated energy consumption in respect of heating. The data used in the hot water calculation has also changed. New dwellings will be designed to consume not more than 125 litres per person per day and this includes all water usage. This is in effect a 5% reduction as compared with SAP 2005 with inherent lower energy consumption for water heating. The fuel prices and carbon emission factors changed in SAP 2009. The $CO_2$ emission factors are used to calculate the environmental impact (EI) and the new emission factors take into account the 'carbon' used to create the fuel. For example, wood pellets (manufactured) have a higher emissions factor than wood logs. There are different boiler efficiencies for winter and summer months; this takes into account the lower efficiency of boilers in the summer when the load is reduced as they are providing hot water only. For example, a boiler with an annual efficiency of 90% has a summer efficiency of 80.8% and a winter efficiency of 90.9%.

Another major change in SAP 2009 is the way that party walls are dealt with. In SAP 2005, heat loss through party walls is assumed to be zero. In SAP 2009, the U-value of a cavity party wall will be set to between 0.0 and 0.5 $W/m^2K$, depending

**Table 6.1** U-values for party walls.

| **Party wall construction** | **U-value (W/m² K)** |
|---|---|
| Solid | 0.0 |
| Unfilled cavity with no effective edge sealing | 0.5 |
| Unfilled cavity with effective edge sealing around all exposed edges and in line with insulation layers in abutting elements | 0.2 |
| Fully filled cavity with effective edge sealing around all exposed edges and in line with insulation layers in abutting elements | 0.0 |

upon the specification. Wingfield *et al.* (2007) demonstrated that air movement within the cavity leads to a substantial amount of heat loss – more so than a similar area of external wall. U-values for cavity party walls were estimated at between 0.50 and 0.63 as compared to the external wall U-value of 0.23 and the floor U-value of 0.17. The U-values, which measure the heat transfer properties of a building element, assumed by SAP 2009, are therefore taken as 0.50 for an unfilled, unsealed cavity, 0.20 for a sealed unfilled cavity and 0.0 for a fully filled and sealed cavity, as summarised in Table 6.1. A higher U-value indicates a less thermally efficient building element.

SAP 2009 can be used where greater design flexibility is required, such as in the design of extensions. The carbon dioxide emission rate from the dwelling with its proposed extension should be no greater than that for the dwelling plus a notional extension built to the standards for new and improved thermal elements.

## Compliance with the Building Regulations

Energy performance relating to works and extensions in existing buildings is based on a revised elemental approach in which insulation and efficiency thresholds are set for individual parts of the building envelope and services (Todd 2006). There are requirements for standards to be achieved for 'thermal elements' (walls, floors and roofs), 'controlled fittings' (windows, doors and similar fittings) and 'controlled services' (heating, hot water, ventilation systems and lighting). Regulations apply whether as part of an extension, dividing a house into flats, replacing windows, extending a heating system, applying render to a gable wall or changing a building's energy status. The changes in required performance for existing buildings as compared to 2006 are shown in Tables 6.2 and 6.3. Thermal elements have to be thermally improved if renovation is done to:

> … 50% or more of the surface of an individual element or 25% or more of the building element unless the work will reduce the space by more than 5%.

The new or replacement building fabric should be constructed so that there are no reasonably avoidable thermal bridges in the insulation layers caused by gaps within the various elements, at the joints between elements, e.g. wall and floor junctions, and

**Table 6.2** Performance of retained thermal elements (U-value W/m$^2$K).

| Element | 2006 | 2010 | Improvement (%) |
|---|---|---|---|
| Wall | 0.35 | 0.30 | 14 |
| Pitched roof (insulated at ceiling level) | 0.16 | 0.16 | No change |
| Pitched roof (insulated at rafter level) | 0.20 | 0.18 | 10 |
| Flat roof | 0.25 | 0.18 | 28 |
| Floors | 0.25 | 0.25 | No change |

**Table 6.3** Performance of new thermal elements (U-value W/m$^2$K).

| Element | 2006 | 2010 | Improvement (%) |
|---|---|---|---|
| Wall | 0.30 | 0.28 | 7 |
| Pitched roof (insulated at ceiling level) | 0.16 | 0.16 | No change |
| Pitched roof (insulated at rafter level) | 0.20 | 0.18 | 10 |
| Flat roof | 0.2 | 0.18 | 10 |
| Floors | 0.22 | 0.22 | No change |
| Swimming pool basin | N/A | 0.25 | N/A |

at the edges of elements such as those around window and door openings. Thermal bridges, or cold bridges, are where these gaps cause heat to be conducted through a path of least resistance through a more thermally conductive material. Reasonable provision should also be made to reduce unwanted air leakage through the newly constructed thermal elements. A suitable approach to showing that the requirement has been achieved would be to adopt Accredited Construction Details. These are design drawings that show how a particular element can be constructed to ensure compliance with the Building Regulations.

### Conservatories and porches

The exemption from the energy efficiency requirements for conservatories and porches has been clarified and is contrary to the initial proposals. This means that a conservatory will be exempt from the energy efficiency requirements only where:

- it is at ground level;
- it does not exceed 30 m$^2$ in floor area;
- the walls, windows and doors separating the conservatory or porch from the building to which it is attached have not been removed or, if removed, have been replaced by a wall window or door that meets the current requirements for energy efficiency for walls, windows and doors; and

- the fixed heating system of the building to which the conservatory or porch is attached has not been extended into the conservatory or porch. This is the only significant difference to the previous 2006 Regulations, where conservatories only had to have 'independent temperature and on/off controls for any heating system'.

Where a conservatory or porch is not exempt, Approved Document L1B states that any walls, doors and windows that may separate the conservatory from the main building should be insulated and draught proofed to at least the same extent as the rest of the existing dwelling. The opaque roofs, walls and floors of the conservatory should have U-values no worse than those contained in Table 6.2.

### Windows and doors

The guidance on new or replacement windows in existing dwellings has been expanded. The minimum performance standards for windows and doors, measured by U-values, have been raised (Table 6.3). The British Fenestration Ratings Council (BFRC) first launched the Window Energy Rating (WER), which can be used as an alternative to the U-value (Table 6.4). The WER applied to the whole window including the frame and glass. It is defined by a formula that takes into account the available solar heat gains (window g-value) and subtracts the thermal losses that are dependent on the window U-value and the air leakage. The calculation below shows the elements that make up the assessment of a window's performance:

$$\mathrm{WER} = 196.7 \times ((1-f) \times g_{glass} - 68.5 \times (U + (0.0165 \times AL))$$

where
$f$ = frame factor (% of the window obscured by the frame and gaskets)
$g_{glass}$ = normal total solar energy transmittance of the glass determined by BSEN 410[4]
$U$ = whole window U-value
$AL$ = air leakage through the window in $m^3/h.m^2$ at 50 Pa pressure difference

Where windows, roof windows, rooflights or glazed doors have to be to a bespoke design (e.g. to match existing retained windows or in a building in a conservation area), a Window Energy Rating or composite U-value may not be available, and it may be unreasonable to expect the necessary calculations to be done for a one-off

**Table 6.4** Standards for controlled fittings.

| Fitting | 2006 Standard | 2010 Standard |
|---|---|---|
| Window, roof window and rooflight | WER Band D<br>OR<br>U-value = 1.8 W/m$^2$ K | WER Band C or better<br>OR<br>U-value = 1.6 W/m$^2$ K |
| Doors with more than 50% of their internal face area glazed | U-value = 2.2 W/m$^2$ K | U-value = 1.8 W/m$^2$ K |
| Other doors | U-value = 3.0 W/m$^2$ K | U-value = 1.8 W/m$^2$ K |

unit. Only in such exceptional circumstances (and having agreed it with the relevant Building Control Body and/or Competent Person) may the alternative standard of a centre-pane U-value be accepted.

### Renovation of thermal elements

Where an existing building element is to become part of the thermal envelope, reasonable provision has to be made to upgrade the element if the U-value is worse than the 2010 threshold values, which indicate a minimum thermal performance, shown in Table 6.5. The Regulations state that 'Reasonable provision would be to upgrade those thermal elements whose U-value is worse than the threshold given in Table 6.6 to achieve the required U-values provided that this is technically, functionally and economically feasible.' The guidance on the renovation of thermal elements in the Approved Documents has been clarified and expanded in relation to what constitutes 'renovation' and the extent of work on individual thermal elements that are captured

**Table 6.5** Renovation of a thermal element.

| | 2006 Standard U-value ($W/m^2K$) | | 2010 Standard U-value ($W/m^2K$) | |
|---|---|---|---|---|
| **Element** | **Threshold** | **Improved** | **Threshold** | **Improved** |
| Wall (cavity insulation) | 0.70 | 0.55 | 0.70 | 0.55 |
| Wall (external or internal insulation) | 0.70 | 0.35 | 0.70 | 0.30 |
| Floors | 0.70 | 0.25 | 0.70 | 0.25 |
| Pitched roof (insulation at ceiling level) | 0.35 | 0.16 | 0.35 | 0.16 |
| Pitched roof (insulation at rafter level) | 0.35 | 0.20 | 0.35 | 0.18 |
| Flat roof with integral insulation | 0.35 | 0.25 | 0.35 | 0.18 |

**Table 6.6** Rating bands and the WER.

| Rating band | Window Energy Rating (WER) | | |
|---|---|---|---|
| Band A | | WER | ≥ 0 |
| Band B | 0 > | WER | ≥ –10 |
| Band C | –10 > | WER | ≥ –20 |
| Band D | –20 > | WER | ≥ –30 |
| Band E | –30 > | WER | ≥ –50 |
| Band F | –50 > | WER | ≥ –70 |
| Band G | –70 > | WER | |

by the requirement. Schedule 4 of the Regulations has been amended with the effect that where the installation of insulation in a roof or loft space is the only work being carried out there is no requirement to notify building control.

The retained thermal elements include where an existing thermal element is part of a building subject to material change of use and where it is to become part of the thermal envelope where previously it was not, such as a garage conversion where the space is to be heated. Walls that had a U-value of 0.7 $W/m^2K$ or worse and which have insulation applied internally or externally need to achieve a U-value of 0.3 $W/m^2K$ rather than the previous standard of 0.35 $W/m^2K$. The test stated for economic feasibility is that the insulation should have a payback of 15 years or less. Simple payback is calculated by dividing the marginal additional cost of implementing an energy efficiency measure by the value of the annual saving achieved by that measure. The performance standard should not generally be worse than 0.7 $W/m^2K$.

The areas that are to be renovated are also important. For example, if an external wall of a living room is being re-plastered and the area is more than 50% of the area of the external walls in the room then all the walls are to be upgraded. If the wall was being rendered externally and the area is more than 50% of that elevation then the whole elevation would need to be upgraded.

The overriding conditions where the requirements of Part L1B may not have to be met are therefore:

- the insulation should be cost effective;
- measures that might compromise the design, e.g. making the floor area too small or the floor uneven;
- preservation of listed buildings of historic interest.

If achievement of the target U-value set out in Table 6.5 is not technically or functionally feasible or would not achieve a simple payback of 15 years or less, the element should be upgraded to the best standard possible given the constraints.

## Historic buildings

The guidance given by English Heritage (2011) should be taken into account in determining appropriate energy performance standards for building work in historic buildings. English Heritage state that:

> For historic buildings and those of traditional construction an appropriate balance needs to be achieved between building conservation and energy conservation if lasting damage is to be avoided both to the building's character and significance and its fabric. For example, it would be neither sustainable nor cost effective to replace a 200-year-old window that is capable of repair and upgrading with a new double-glazed alternative, and even less so if the new window were to have an anticipated life of only 20–30 years, as some do. Depending on the circumstances a good case might be made for well-designed and carefully installed draught-proofing or secondary glazing.

In each case the appropriate balance should be discussed early in the design process by consultation between the local authority's Building Control Officer or Approved Inspector and the Conservation Officer.

The guidance has been amended on exemptions for buildings in cases where compliance would unacceptably alter the character or appearance of a building including:

- Listed buildings
- Buildings in heritage and conservation areas
- Scheduled ancient monuments
- Buildings of architectural and historic interest
- Buildings of traditional construction with permeable fabric (hygroscopic).

Building Regulation 21(3) states that listed buildings are exempt from the energy efficiency requirements of the Building Regulations 'where compliance with the energy efficiency requirements would unacceptably alter their character or appearance'. The intention of this part of the regulations is to exempt works to improve energy efficiency that would not receive listed building consent. All buildings in conservation areas are exempt from the energy efficiency requirements of the Building Regulations 'where compliance with the energy efficiency requirements would unacceptably alter the character or appearance' of the building in the conservation area, whether or not it is listed. This is different from the requirements of planning law regarding conservation areas, which requires consideration only of the impact of proposed development on the character and appearance of the area. Until the 2006 revisions, scheduled monuments were completely exempt from the Building Regulations. The revised Building Regulation 21(3) now states that they are exempt from the energy efficiency requirements of the Building Regulations where compliance would unacceptably alter their character or appearance. Consent from the Secretary of State on the advice of English Heritage is required for most works that involve alterations or additions to scheduled monuments, including those designed to improve their energy efficiency. In practice the vast majority of scheduled monuments do not have complete walls and roofs and do not use energy for heating and cooling. However, many of them are lit at night and therefore present opportunities to reduce energy consumption through the use of more efficient lighting systems. New extensions to historic buildings or dwellings would, however, have to comply with the requirements of Part L1B of the Regulations.

## Consequential improvements

Regulation 28 of the Building Regulations may require additional work to be undertaken to make existing buildings more energy efficient where certain types of building work are proposed. This applies in existing buildings with a total useful floor area of over 1000 $m^2$ where the proposed work consists of:

- an extension;
- the initial provision of any fixed building service or an increase in the installed capacity.

Consequential improvements should only be carried out to the extent where they are technically, functionally and economically feasible. It should, however, be noted that there are relatively only a few dwellings that meet the floor area criterion.

Where a large amount of design flexibility is required, reasonable provision would be to use SAP 2009 to demonstrate that the calculated carbon dioxide emission rate from the dwelling with its proposed extension is no greater than for the dwelling plus a notional extension complying with the U-value standards and the opening areas referred to above with the door area set equal to the door area of the proposed extension, and the remainder of the openings being classified as windows. If, as part of achieving this, upgrades are proposed to the existing dwelling, such upgrades should be implemented to a standard that is no worse than the target U-value for improving retained thermal elements as set out Table 6.6.

## Future changes to building regulations

The 2012 Consultation on Changes to the Building Regulations Part L, Department for Communities and Local Government (2006b) includes proposals for tighter performance standards for works to existing buildings. The paper also contains proposals to introduce, on a phased basis, requirements for additional energy efficiency improvements to be carried out when other specified works (e.g. extensions) are planned and Green Deal (see below) finance is available as an option to meet the upfront costs.

The proposed changes Regulation 28 'Consequential improvements to energy performance' are planned to be updated to:

- Apply upon extension or increase in habitable area to all existing dwellings with effect from October 2012. The increases in habitable areas include, for example, loft and garage conversions. The 1000 $m^2$ threshold from the 2012 Regulations is to be removed.
- Apply upon boiler replacement and replacement of windows (50% of the windows in a single elevation/dwelling) in all existing dwellings with effect from April 2014.

Other proposed changes include:

- Non-exempt conservatories are to be classed as extensions and must meet the energy efficiency requirements including consequential improvement as appropriate.

Consequential improvements should only be carried out to the extent that they are technically and economically feasible. Where it can be demonstrated that Green Deal finance has been sought but cannot be obtained on the grounds of cost effectiveness, consequential improvements are not required.

**Table 6.7** Standards for controlled fittings.

| Fitting | 2010 Standard | 2012 Standard |
|---|---|---|
| Window, roof window and rooflight | WER Band C or better<br>OR<br>U-value = 1.6 $W/m^2 K$ | WER Band B or better<br>OR<br>U-value = 1.4 $W/m^2 K$ |
| Doors with more than 50% of their internal face area glazed | U-value = 1.8 $W/m^2 K$ | U-value = 1.4 $W/m^2 K$<br>OR<br>Doorset Energy Rating (DSER) Band D or better |
| Other doors | U-value = 1.8 $W/m^2 K$ | U-value = 1.4 $W/m^2 K$<br>OR<br>DSER Band D or better |

**Table 6.8** Performance of new thermal elements (U-value in $W/m^2 K$).

| Element | 2010 | 2012 | Improvement (%) |
|---|---|---|---|
| Wall | 0.28 | 0.20 | 28.6 |
| Pitched roof (insulated at ceiling level) | 0.16 | 0.15 | 6.3 |
| Pitched roof (insulated at rafter level) | 0.18 | 0.15 | 16.7 |
| Flat roof | 0.18 | 0.15 | 16.7 |
| Floors | 0.22 | 0.17 | 22.7 |
| Swimming pool basin | 0.25 | 0.25 | No change |

Where the trigger is the provision or replacement of a boiler or replacement of 50% of the windows in a single elevation/dwelling, reasonable provision for a consequential improvement would be to implement some of the following basic energy efficiency measures:

- If the thickness of the loft insulation is less than 150 mm upgrade to 250 mm.
- Fill any unfilled cavity walls that are suitable for filling.
- Upgrade any hot water cylinder.
- Draftproof any single-glazed windows.

It is expected that SAP 2012 will be the preferred calculation methodology and can be used to offer designers flexibility in much the same way as is currently available. The standards and level of improvement for controlled fittings and new elements are shown in Tables 6.7 and 6.8 respectively. The Government's preferred option is to phase in the consequential improvement requirements from October 2012, which will be at the same time as the launch of the Green Deal and can help with the costs of improving a dwelling's energy efficiency.

## The Energy Act 2011

A major emerging piece of UK legislation that impacts existing buildings is the Green Deal (Department for Energy and Climate Change), the provisions of which are included in the Energy Act 2011. The Government's Green Deal scheme aims to enable households to install home energy measures that are in part funded by a loan attached to the property rather than the household and repaid from savings in energy bills. The scheme has been driven by the need for a national comprehensive retrofit programme and carbon emission targets set for 2020 and 2050. In addition to its core aims, the Green Deal provides the potential to unlock not only a huge economic opportunity but also social benefits through warmer homes and mitigation of rising fuel costs; it also raises the prospect of local action where residents act together to bring about improvements to their homes and communities. Under the current proposals for the Green Deal, the Government has set certain criteria that must be met in order for the finance to be made available, which protects the resident from committing themselves to undertaking uneconomic measures within their homes.

The first is called the 'Golden Rule', which states that the measures recommended must produce sufficient savings on the annual energy bill to pay back the initial cost of carrying out the works. If the measures are installed the Green Deal Loan, which is given by a Green Deal Provider who manages the contract with the homeowner, will be attached to the property and paid back through payments of the electricity bill. This means that, should the occupants move, the new occupants will be liable for the payments. The measures recommended should be identified by an accredited Domestic Energy Assessor (DEA) who has undertaken an Energy Performance Certificate on the property or be based on the recommendations contained within an existing Energy Performance Certificate, which has been lodged by a DEA (National Energy Services Ltd 2012). Only accredited Green Deal Installers will be allowed to undertake the recommended measures, or installations, for the funds to be released under the Green Deal offer. It should be noted that properties should have the basic energy efficiency measures undertaken prior to implementing the high tech solutions for maximising energy income.

As well as the Green Deal a new Energy Company Obligation (ECO) fund is under development, which will be a replacement to the existing Carbon Emissions Reduction Target (CERT) and Community Energy Saving Programme (CESP) funds. The ECO will be divided into two parts, one that will be used to address carbon savings and one that addresses issues of Fuel Poverty or Affordable Warmth and will be targeted at vulnerable households. The ECO has been designed to work in concert with the Green Deal, bringing some measures such as external wall insulation into retrofit packages where they may not have been financially feasible without it.

The Energy Act 2011 also enables the Government to regulate to help ensure the take-up of cost-effective energy efficiency improvements in the private rented sector. From April 2016, domestic landlords should not be able to unreasonably refuse requests from their tenants for consent to energy efficiency improvements, where financial support is available, such as the Green Deal and/or the Energy Company Obligation (ECO); from April 2018, all private rented properties (domestic and non-domestic) should be brought up to a minimum energy efficiency standard rating, likely to be set at EPC rating 'E', and there is therefore a risk that some upgrade measures will not be economically viable. This requirement would be subject to there being no upfront financial cost to landlords. It is also likely that proposed changes in SAP will cause the energy ratings of existing buildings to be downgraded. There is also a range of other retrofit funding available for renewable technologies such as the Feed-in Tariff (FiT) and Renewable Heat Incentive (RHI). The expected launch date for the Green Deal and ECO was October 2012.

## Conclusions

The UK is currently engaged in a major effort to improve the energy conservation potential of its existing housing stock. The main regulatory framework that controls this retrofit area is the Building Regulations Part L1B and substantial changes have been made to this document to control work in this area. Of course not all work requires Building Regulation approval and other procedures are currently under development including the Green Deal, which could help to fund these improvements. We have also considered how compliance with the Building Regulations can be achieved. It is important to consider energy conservation in any major upgrading to a dwelling and we should be aiming for the optimal level of thermal upgrading.

One of the main proposals in the 2013 Regulations is the improved requirement for consequential improvements and the close association with the Green Deal. It is unlikely that the full retrofit potential of all properties will be achieved but it is imperative that an incremental 'whole house' approach is adopted to enable the most efficient and cost-effective measures to be applied systematically. It is also recognised that some of the targets used will make use of developing technologies, which could lead to some of the performance being achieved more economically, particularly in the renewables and insulation technology areas.

The regulatory framework provides a direction for the transformation of our existing building stock. However, this framework requires political will and, ultimately, enforcement to ensure that the desired outcomes of the regulations are carried through. The recent political wrangling around the 'conservatory tax', as the issue of consequential improvements was described by politicians and the media, indicates that the way people improve their homes and the demands placed on them by regulation is a major political issue. While professionals may see the logic of the development and application of regulations, homeowners may have a different view about any regulatory requirements that control how they improve their homes.

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# 7 Retrofitting existing dwellings: Lessons from the policy instruments of front-runners

*Lorraine Murphy*

## Introduction

Existing buildings are responsible for almost 50% of total final energy consumption and 25% of $CO_2$ emissions (IEA 2007, p. 4). Existing dwellings, constructed before or during the introduction of modest energy standards in building regulations, hold significant potential to reduce energy use. To meet national and international climate change obligations improved energy efficiency and reduction in greenhouse gas emissions are required by all sectors. Not only has the housing sector a key role to play in terms of share of consumption but energy efficiency can be improved and greenhouse gas emissions reduced in this sector more cost-effectively than in any other, often using existing technologies and practices, like boiler replacement and insulation (Ürge-Vorsatz *et al.* 2007; McKinsey & Company 2009).

Even if touted as the most cost-effective means of meeting climate change targets, and with added benefits of reduced household energy bills and improved comfort, the challenge of exploiting the potential of existing dwellings is immense. For example, meeting 2020 climate change targets in Germany will require the retrofit of approximately 20 million dwellings (KfW 2010). A similar mammoth effort is required in the UK with retrofit of 7 million dwellings, 25% of the housing stock, needed to meet 2020 targets (Jha 2009). Policy instruments steer action towards overcoming barriers and achieving the potential energy performance improvement of the building stock. However, with few descriptions of these instruments, particularly in terms of their performance, knowledge about what these instruments are and how and why they work is lacking.

In response to this knowledge gap a comparative study of the instruments that dominate action towards existing dwellings in several front-runner countries, Denmark, Germany and the UK, was conducted. The research objectives are to: (1) identify and characterise instruments considered as successful and (2) identify if and how the complexities of designing instruments for existing dwellings are managed. Documentary

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research was conducted to meet the first objective. To meet the second objective, a conceptual framework developed from the literature was used to assess instruments.

Aspects of traditional assessments, namely effectiveness and efficiency, were included if data were available. However, a fundamental goal is to deepen understanding of the content and scope of instruments used for driving retrofit activity in existing dwellings. This responds to a gap in our understanding: 'the purpose of almost all evaluations [i]s to measure the energy savings and cost . . . . As a result, there has been almost no discussion in the global literature on energy efficiency about general principles . . .' (Fairey and Goldstein 2006, pp. 8–64).

## Approach

Comparative study and data collection

Comparing the instruments used in different countries forms an evidence-based means of developing ideas of which instruments can work most effectively for existing dwellings. Front-runner countries were considered to offer the most fruitful evidence base and are defined as countries that set regulatory trends in policy fields (Jänicke 2005, p. 130). As well as front-runner status, countries were further isolated on the basis of broadly shared economic, social and environmental objectives. Denmark, Germany and the UK were chosen for the analysis. All case countries experience a moderate climate; therefore thermal envelope and microgeneration technology requirements and opportunities are assumed to be similar. The scale of renovation challenges are identified as largely comparable as 50–70% of dwellings in all of the countries pre-date 1970 when energy standards start to become more prevalent in building regulations (Itard and Meijer 2008, p. 35). The policy instruments of front-runners were screened from a range of sources including comparative studies and IEA country reviews. Instruments identified as defining action were isolated for deeper analysis. Sources used for the in-depth analysis included EU project reports, evaluations and peer-reviewed articles. To verify data phone interviews were held with experts from the chosen countries.

It is emphasised that only instruments that dominate policy action in the selected front-runners are described and assessed. These instruments represented the bulk of policy resource investment and were identified as delivering the main energy savings and $CO_2$ emission reductions. This approach was considered a useful way to limit and provide depth to the study. It is noted that some of the same instruments operate in front-runners but are not considered to form the focus of policy action. Under the Energy Performance of Buildings Directive minimum standards for major renovation are required and an Energy Performance Certificate (EPC) must be issued at construction, sale and rental of buildings. Therefore, all of the selected countries use building regulations and the EPC for existing dwellings. However, in Denmark these instruments form the focus of policy attention and are where the bulk of energy savings are expected in the near future. Meanwhile, Germany and the UK also implement building regulations and the EPC but use economic incentives and supplier obligations respectively as their primary means of reaching energy saving and climate change targets for existing dwellings.

## Assessment concepts

To understand the principles behind the instruments of the front-runner countries several reoccurring themes from literature were formulated as concepts and used for the assessment. Concepts are listed in Table 7.1 along with the questions they direct at the instruments and are discussed in more detail below.

A frequent assertion from literature on policy instruments is that *a combined instrument approach* is necessary to maximize strengths of individual tools and minimise weaknesses. This follows the notion that no one instrument can deal with policy complexities (Howlett 2004). Second, the need for *an incentivising and obligating balance* follows the notion that policy should represent a 'give-and-take-strategy' that combines restrictive and stimulative instruments (Bemelmans-Videc *et al.* 1998). *Long-term instrument support* is considered necessary to 'embed' energy efficiency, transform the market and allow support for higher levels of energy efficiency (Fairey and Goldstein 2006). Meanwhile, *non-generic instruments* are considered necessary in response to the diversity of the target group and the different barriers that they face. Two examples of this are private landlords and low-income households. Private landlords have the issue of the split incentive, where benefits of energy efficiency accrue to the bill payer, which may not be the landlord, while low-income households lack access to funds to improve the efficiency of their homes. Concepts from the energy performance literature include *primacy to energy efficiency* as the first goal of

**Table 7.1** Assessment concepts and corresponding questions.

| | |
|---|---|
| Instrument combinations | Are instruments combined to offset individual weaknesses and maximise strengths? |
| Incentivising/obligation balance | Do instruments combine restrictive and stimulative elements? |
| Long-term support | Are instruments embedded in a long-term framework? |
| Non-generic | Do instruments respond to the diversity of the target group? |
| Primacy to energy efficiency | Is energy efficiency considered the primary goal, followed by obtaining energy from renewable sources and, lastly, if necessary, obtaining energy use from non-renewables as efficiently as possible? |
| Whole house | Is the need for deep retrofit based on a whole house approach supported by instruments? |
| Energy sufficiency | Do instruments lead to a reduction in energy use? |

retrofit, followed by meeting needs from renewable sources and lastly obtaining non-renewable energy (if still required) as efficiently as possible (Rovers 2008). *A whole house approach* in place of single measures is considered necessary because deep renovation that draws on a complete range of energy saving measures to make a significant reduction in energy use is required to meet the ambition of climate change targets (Mlecnik *et al.* 2010). Lastly is the concept of *energy sufficiency*, based on an understanding that the end point is energy consumption reduction, not the implementation of a policy instrument (based on Wilhite and Norgard 2003). Effective monitoring and evaluation data are therefore crucial to link cause and effect.

The instruments that dominate the actions of front-runners are assessed against these concepts. Criteria used to assess instruments are whether the concept is weak (partly represented), moderate (concept is explicit in policy documentation) and strong (concept is explicit with associated results).

## Policy instruments of front-runners

### Germany

Germany's 2020 climate change targets are among Europe's most ambitious: 40% reduction of GHG emissions, 20% reduction in energy consumption and 20% increase in renewables by 2020 (OECD/IEA and AFD 2008). To meet targets the thermal retrofit rate is to be increased from 0.8% to 2% p.a. (Neuhoff *et al.* 2011, p. 3). The dominant policy instrument is the economic incentive programme operated by the federal development bank Kreditanstalt für Wiederaufbau (KfW) (Rosenow 2011). KfW loans and subsidies are co-ordinated with federal building regulations (Energy Savings Ordinance – EnEV) and are specifically geared to bring existing dwellings in line with, or beyond, new build standards. Alongside this, the EnEV issues component-based regulations applied during renovation trigger points and general retrofit improvement stipulations, such as insulating heating pipes (Engelund-Thomsen *et al.* 2009).

#### *KfW incentives*

Since 1996, KfW loans have targeted energy efficiency in pre-1979 buildings (Korytarova 2006, p. 7). According to a national expert interviewed during this research, funding has traditionally been announced on an annual basis. However, from 2011 funding has been fixed at €1.5 billion annually until 2014. Terms and conditions of the loans are viewed as highly attractive; they are long term, pre-payment is possible without extra charges and combination with other incentives is possible (Hamilton 2010). In 2011 interest rates were approximately 2.30–2.85% depending on the contract period (Rosenow 2011, p. 264), which is 1–2% lower than current market rates.

Five levels of loans are available for the 'KfW Efficiency House', the most ambitious of which is KfW Efficiency House 55, which represents 55% of the maximum primary energy requirement as specified by regulations for new build (KfW 2011). Repayment bonuses form an additional strong incentive; for example, 12.5% is taken off a loan if KfW Efficiency House 70 is achieved (KfW 2011). KfW incentives offer a considerable subsidy to support energy-based retrofit. Neuhoff *et al.* (2011, p. 8) found that one-third of the incremental costs to reach new build standard are subsidised and one-half if 55% of the standard is reached. In the event that a particular level cannot be achieved, financing is available for individual energy saving measures.

Over time KfW instruments have matured with a simplified application procedure, more concentrated mix of options and targeted information campaigns, which have been credited with increasing popularity of the programme (Hamilton 2010). Since 2006, approximately 2.2 million tons of $CO_2$ emissions have been saved annually with €188 million saved on household bills (Hamilton 2010, p. 62). Doubt about whether incentives are capable of reaching the 20 million dwellings requiring retrofit by 2020 has been aired (Hamilton 2010). Previous years have witnessed approximately 230 000 dwellings per annum being reached by KfW financing (cited in Hamilton 2010, p. 68), lower than expected to reach the 2020 target. While there may be doubt in terms of scope, few appear to question the ambition of KfW loans and subsidies. According to a national expert interviewed during the course of research in the first half of 2011 almost 40% of loans were for renovations pledging to go beyond new build requirements.

### *Assessment results*

In terms of the first concept of *combined policy instruments*, the synergistic relationship with KfW incentives stimulating renovation beyond minimum building regulations is plotted as 'strong' in Figure 7.1. The second concept based on an *obligating/incentivising balance* is considered 'moderate to strong' given that building regulations not only issue requirements during renovation but also issue general retrofit requirements for some components, with incentives available to reach these through KfW loans for individual measures. KfW incentives have operated since 1996 and now enjoy guaranteed annual funding until 2014. However, Rosenow (2011) notes that budgetary constraints reduced funding in 2010. Moreover, according to a national expert the funding guarantee until 2014 is considered novel, offering the market a certainty that was previously absent. Given that funding has traditionally been announced annually, and there is some uncertainty beyond 2014, the *long-term* nature of the approach is listed as 'moderate'.

In terms of the *non-generic* concept, private homeowners are the main recipients of KfW loans at 41% with private landlords at approximately 33% – figures that generally reflect the tenure division (KfW 2010). It appears that the instrument successfully reaches the private landlord sub-group. A national expert from Germany noted that repayment bonuses form an incentive for this group. Added to this, market forces, usually mute for the private rental sector, may have some power as supply is such that competition exists between private landlords. Less obvious is whether lower-income householders are reached. Fuel poverty is not a strong policy discussion point in

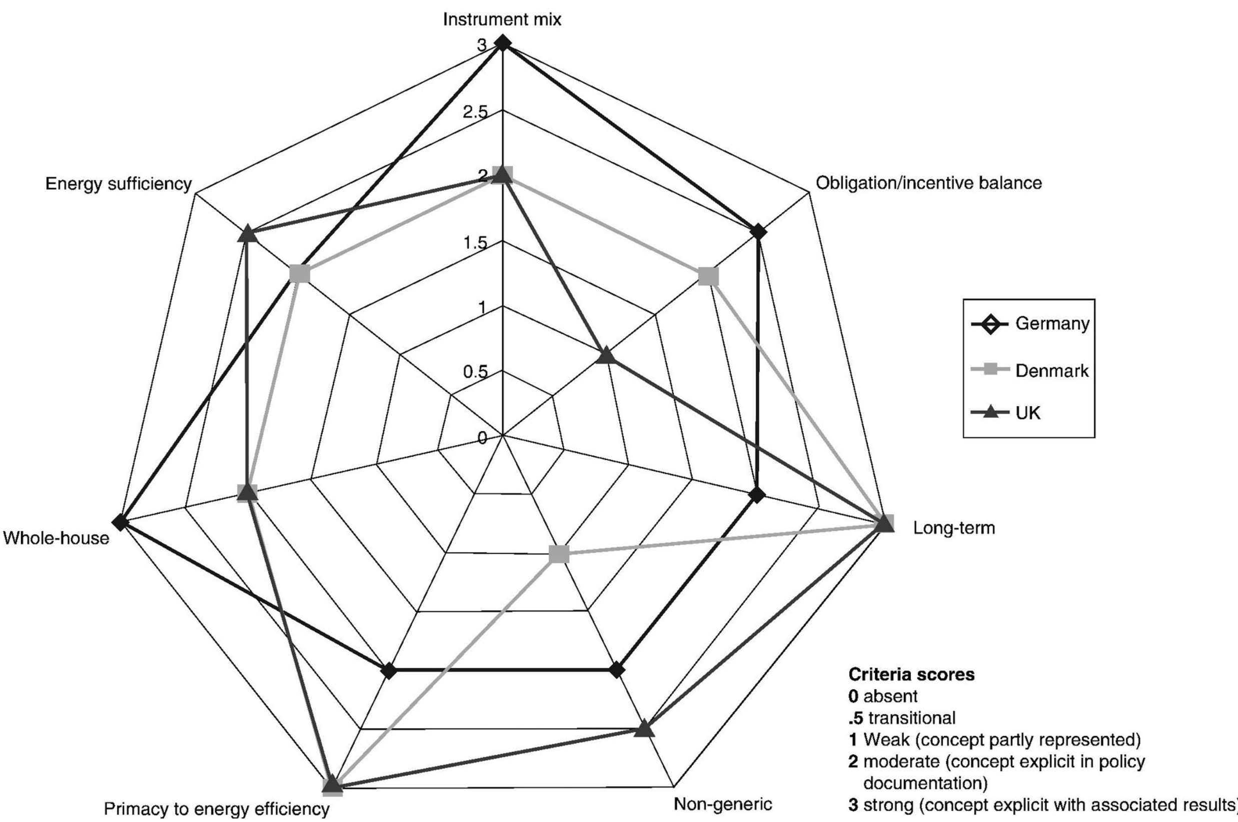


**Figure 7.1** Assessment chart.

Germany (Rosenow 2011). Moreover, KfW do not request or collect data on income profiles. According to a national expert this is because loans relate to the energy performance potential of the building and not the financial capacity of the applicant. Given that the often marginalized private rental sector is reached but the uncertainty about whether lower-income groups are reached, the non-generic concept is plotted as 'moderate'.

*Primacy to energy efficiency* is explicitly supported by the different KfW Efficiency House levels. However, support for individual measures within KfW does not depend on a building envelope thermal standard. As a result the primacy to energy efficiency concept is recorded as 'moderate'. Meanwhile, the *whole house* approach is explicit in the KfW Efficiency House levels. While individual measures are supported with KfW finance, this is in response to economic difficulties of reaching KfW Efficiency House levels for some dwellings. As a result, the whole house concept is considered 'strong'. A number of evaluations show that energy savings have been achieved with the KfW scheme (see Rosenow 2011). According to a national expert, recipients of KfW incentives must confirm that measures have been carried out but actual energy consumption is not monitored. Given some uncertainty about how sufficient energy modelling tools are, the *energy sufficiency* concept is plotted as 'moderate'.

## Denmark

Danish 2020 climate change goals include a 30% reduction in greenhouse gas emissions, 30% share of renewables and a 4% reduction in energy consumption from 2006 levels (DMCE 2011, p. 8). A long-term goal is fossil fuel independence by 2050 with a ban on installing oil heaters in existing dwellings from 2017 forming part of this long-term action (DMCE 2011). Strengthening of the building regulations for renovation and installation replacement and improved functioning of the Energy Performance Certificate (EPC) form the central policy instrument responses for existing dwellings (DMTE 2005; Hamilton 2010). It is planned that this approach will lead to a saving of 25% of current energy use compared to 2005 regulations (Hamilton 2010, p. 49). In the future, simultaneous strengthening of regulations for building components and obligations on energy companies are likely to play a greater role (DMCE 2011).

### *Building regulations*

The 2010 Building Regulations issue a comprehensive suite of component U-value requirements required during conversion, or alteration of individual building components (DMEBA and DECA 2010). Given that countries typically only issue regulations for existing dwellings during 'major' renovation this can be considered more ambitious than the norm. Requirements demand a definition of cost-effectiveness based on a calculation, which means that the energy saving measure must pay for itself within 75% of its expected lifetime (DMEBA and DECA 2010, p. 136).

Irrespective of cost-effectiveness, if elements such as external walls or roof structures are replaced they must meet U-value requirements. As well as these 'non-major' renovation requirements building regulations follow the definition of major renovation recommended in the EPBD. In the case of single-family houses, regulations during major renovation only apply to the part of the building undergoing renovation; for all other cases the regulations apply to the complete building. A link with the EPC is evident as the measures considered cost-effective during renovation, as well as outside renovation activity, are listed on the EPC.

Research identifies a considerable potential for renovation such that 30–35% of energy used for heating could be saved within a reasonable payback time (Gram-Hanssen and Christensen 2011). Whether this effect is reached will be hard to establish due to a lack of monitoring and evaluation. Although a large-scale evaluation of the national energy efficiency portfolio was conducted in 2008, building regulations and the impact on existing dwellings do not appear to have been included. It was noted that while impacts are not attributed to regulations with high precision, the opinion is that they have a strong market effect, especially in terms of the development of innovative products (Hamilton 2010).

### *Energy Performance Certificates*

EPCs were introduced to Denmark in 1997, predating their introduction through the EPBD and exceeding Directive requirements in ambition (Togeby *et al.* 2009). For example, EPCs are valid for five years instead of ten required by the EPBD. Additionally, recommendations in EPCs follow two trajectories: immediately feasible energy saving measures and measures feasible during a major renovation. The EPC in Denmark has suffered from well-documented implementation issues. In 2007–2008, it was estimated that only 50–60% of properties sold had EPCs (Gram-Hanssen and Christensen 2011, pp. 12–13). Although mandatory, EPCs were not associated with any particular promotional campaigns, which perpetuated a low level of awareness (Joosen and Zegers 2006). Empirical research demonstrated the importance of building and sustaining a good reputation in the energy certification system (Gram-Hanssen *et al.* 2007). However, a feeling that EPCs were too expensive and unreliable was pervasive (Joosen and Zegers 2006). Negative media attention created scepticism among the public, who considered recommendations in EPCs to represent 'copy and paste' efforts (Gram-Hanssen *et al.* 2007). Furthermore, key stakeholders such as estate agents were said to have been unsupportive (Laustsen and Lorenzen 2003).

Research on the effects of EPCs in terms of retrofit activity is at best inconclusive. One study found that EPCs had an impact on investment priorities with more technically demanding improvements conducted on dwellings with EPCs than those without (Laustsen and Lorenzen 2003). Analysing impact in terms of actual energy use showed that dwellings with EPCs did not demonstrate reduction in gas use over dwellings without, although whether a sustainable retrofit had taken place was not factored in (Kjærbye 2008). In terms of an effect on property marketability, 38% of a sample of Danish householders who viewed the EPC before making an offer on their property considered it important or very important when making an offer, showing a value for the EPC at the transaction juncture (Adjei *et al.* 2011, p. A264). The comprehensive evaluation of the national energy efficiency portfolio in 2008 concluded that the EPC was not cost-effective (Togeby *et al.* 2009). This conclusion was based on issues such as the €650 cost for the EPC often for householders not interested or ready to receive the information (Togeby *et al.* 2009) and is supported by data from the Kjærbye (2008) study stating that gas use between dwellings with an EPC and without was undifferentiated.

### *Assessment results*

*Combined instrument* action exists between the EPC and building regulations with, for example, EPCs being required after major renovation. Nevertheless, these instruments do not appear to form a powerful synergetic combination, especially when considering that the EPC, for a large part of the housing sector, does not guarantee energy savings. As a result, the policy instrument combination concept is charted as 'moderate' in Figure 7.1. The *obligating/incentivising balance* is also judged as 'moderate'. While obligations are considered strong with component requirements even for 'non-major' renovation, this concept is weakened by the absence of an incentivising balance. This has traditionally been poorly developed in Denmark. According to a national expert interviewed during the research, there are emerging proposals for the introduction of incentives like green loans as a result of policy in the Energy Strategy 2050.

Clear and strong elements of a *long-term strategy* are in place with a mandatory EPC introduced in 1997 and a clear role for existing dwellings in building regulations. The dominant instruments are grounded in legislation securing their persistence. The 2050 Energy Strategy provides a long-term view giving preparation time to the market. As a result, the long-term concept is plotted as 'strong'. Meanwhile, *generic instruments* define the dominant approach; therefore this aspect is plotted as 'weak' in Figure 7.1.

Danish support of component level requirements in building regulations demonstrates that thermal performance of the building envelope is central and, as a result, the *primacy to energy efficiency* concept is plotted as 'strong'. However, building regulations and the EPC focus on a measures-based approach. During the expert interview, it was noted that promotion of the *whole house* perspective takes place but it remains a major challenge to integrate it into an instrument while respecting the economic capability of householders. As a result, this aspect is charted as 'moderate'. Whether energy consumption is actually reduced because of instruments is touched upon in evaluations but not consistently monitored. While a comprehensive evaluation of instruments was conducted in 2008 it was based largely on cost-effectiveness. It remains that instruments lack clear and consistent monitoring frameworks to prove cause–effect. According to a national expert, although the cause–effect precision is lacking, correlation between instruments such as building regulations and energy consumption reduction is considered strong. Given that precision on whether instruments directly lead to expected savings remains incomplete, the concept of *energy sufficiency* is plotted as 'moderate'.

United Kingdom

The UK has one of the strongest policy backgrounds of the studied cases with the Climate Change Act issuing a statutory obligation to reduce $CO_2$ emissions by 80% by 2050 on 1990 levels (Ofgem 2011, p. 2). Alongside this is a statutory obligation to eradicate fuel poverty by 2016 (HCCLGC 2008, p. 16). Challenges associated with improving existing dwellings are heavily publicised. Over 40% of the stock contains 'hard to treat' features such as solid wall construction (BRE 2008, p. 1). Current action towards energy saving in existing dwellings is the much-applauded obligation on energy suppliers – the Carbon Emissions Reduction Target (CERT) (Höhne *et al.* 2009). This is a legal obligation on electricity and gas suppliers to achieve carbon emissions reduction targets in the household sector (DECC 2010). In its current and final phase CERT operates from 2008 to 2012 with an expected lifetime $CO_2$ emissions reduction of 293 Mt (Ofgem 2011).

In 2012 the policy towards existing dwellings is set to change with some unique instruments poised to enter the policy landscape. CERT will be replaced by the Energy Company Obligation. The 'Green Deal', an innovative financing 'pay as you save' arrangement attached to properties instead of owners/occupants will be introduced. A proposed Renewable Heat Incentive to be introduced alongside the Green Deal will be the first feed-in tariff system supporting heat generation (Ofgem 2011). The Energy Act 2011 provides for a minimum standard for private rental dwellings based on an EPC rating of E. This assessment remains focused on the achievements of CERT.

*Carbon Emissions Reduction Target (CERT)*

CERT has operated in some form since 1994 and applies to household gas and electricity suppliers with 50 000 plus customers (DECC 2009). Suppliers receive a carbon reduction target based on their customer base. A pre-determined carbon score is attached to energy performance measures approximately 40% of which must be achieved in priority groups such as low-income households (Ofgem 2011). Under a separate obligation – the Community Energy Saving Programme (CESP) – suppliers must meet specific targets in defined low-income areas and adopt a whole house approach in meeting these targets (Ofgem 2011). The enforcement body, Ofgem, has powers to fine companies for non-compliance. The cost of CERT is funded through increases in customer bills.

CERT is viewed extensively as a success in terms of suppliers achieving their set targets and societal cost benefits (Lees 2008; Ofgem 2011). Suppliers spent approximately €2 billion as part of CERT from 2002 to 2008 (Rosenow 2011, p. 266). Meanwhile, DECC (2010) states that over 7.5 million dwellings have been subject to full or part subsidy measures, giving an annual saving of £45 on household energy bills. During the 2005–2008 phase costs to consumers amounted to approximately £7 per fuel per year and £5 for low-income groups (DECC 2009, p. 7). In terms of the fuel poverty objective Lees (2008, p. 5) notes that in the 2005–2008 cycle over 1.1 million low-income households were assisted with fuel switching and insulation. However, CERT is not without its critics. An often-repeated one is the focus of the programme on 'low hanging fruit' (HCCLGC 2008). Negative media attention highlighted mass unsolicited mailouts of light bulbs. Insulation and lighting accounted for 61% and 26% respectively of carbon saved by CERT's third year (Ofgem 2011, p. 1). Independent evaluations have noted the 'lost opportunities' in dwellings receiving some improvement(s) (Lees 2008).

Whether CERT reaches across tenure groups is another point for attention. DECC (2010) questions whether the private rental sector and hard-to-treat dwellings benefit. Reinforcing this is the fact that the private rented sector comprises the greatest proportion of hard-to-treat dwellings at 50% (BRE 2008, p. 1). Parag and Darby (2009) highlight another potential issue with CERT as the passivity introduced to householders, arguing that they are not motivated in psychological, social or economic ways to reduce energy demand.

While CERT has won praise for the integration of social objectives, with 40% of measures targeted to priority groups, this is also a source of contention. It is argued that all households contribute through bill increases but not all benefit from energy saving measures. As a result, higher income households in receipt of measures are receiving subsidies from lower income groups if they have not received any CERT assistance (OECD/IEA and ADF 2008). In a similar vein, some energy suppliers claim that if the primary aim of CERT is $CO_2$ reduction then allocating a disproportionate amount of resources to lower income groups – the lowest energy consumers – is counter-intuitive (cited in HCCLGC 2008). The argument from these dissenting voices is that fuel poverty is better achieved through direct policies (OECD/IEA and ADF 2008).

### *Assessment results*

Multiple and innovative tools are in place or poised to tackle existing dwellings but as yet they do not form strategic combinations and therefore the *combined instrument* concept is plotted as 'moderate'. CERT is entirely incentivising towards the householder therefore the *obligating/incentivising* concept is plotted as 'weak'. CERT shows the strength of a *long-term* approach with short-term cycles for targets, with the result that improvements and adjustments are made and certainty is offered to stakeholders. As a result, the 'long-term' concept is plotted as 'strong'.

CERT and its preceding versions have deliberately focused on vulnerable households but the extent to which it reaches the private rental sector is unclear. Given that CERT does much for sub-groups but does not completely overcome obstacles the *non-generic* instrument concept is plotted as 'moderate to strong' in Figure 7.1. Although, at a macropolicy level, energy efficiency and renewable energy policy in the UK is often criticised for poor integration (Warren *et al.* 2011), at the level of CERT the *primacy to energy efficiency* concept is considered 'strong'. This concept was supported by the plucking of low hanging fruit and the importance of improving energy efficiency is apparent with the recent amendment to CERT, which requires that 68% of investment be dedicated to insulation (DECC 2010). According to a national expert, microgeneration measures performed under CERT are only approved if they are conducted in a dwelling that is efficiently insulated. Meanwhile, increasing attention to the notion of *whole house* retrofit is evident in CESP, which obliges energy suppliers to meet targets in low-income areas using this approach. Nonetheless, it is not yet the status quo and is therefore plotted as 'moderate'. *Energy sufficiency* is considered 'moderate to strong', given that energy companies must submit data on the completed measures and progress is tracked with regular publications and evaluations.

## Discussion and conclusions

The remarkable divergences between the instruments that define the approaches of the three selected front-runners mean that they are not directly comparable in terms of efficiency and effectiveness. In the past, the UK and German schemes were considered to generate comparable savings, though at higher costs for Germany possibly related to a baseline of more energy efficient dwellings (Rosenow 2011). The Danish case is less comparable, with resources more difficult to attribute to building regulations and the EPC. Comparison between the assessments for each countries' policy instruments are shown in Figure 7.1.

While the divergence makes it difficult to compare instruments in terms of effectiveness and efficiency it provides rich data on the principles and trade-offs when opting for certain instruments to lead policy action. Front-runners excel with some concepts but have difficulty in integrating others into their dominant policy instrument responses. The German case comes to the fore in the strength of the instrument combination, with financial incentives pushing renovation towards and beyond new build standards. However, this approach shows the vulnerability of funding commitments and a long-term path to low-carbon existing dwellings based on this approach is not publicised. Moreover, it is weakened by a reported poor participation rate. Meanwhile, the Danish approach excels in exploiting natural trigger points in existing dwellings during renovation and transaction. Milestones such as the elimination of oil heaters by 2017 show that regulatory standards will feature in the future on the path towards a fossil fuel independent Denmark. However, to meet the targets relying solely on these tools may not be sufficient. There may be a requirement to balance the approach with incentives. The UK approach, with 40% share of investment obligated for vulnerable groups demonstrates the strongest action to ensure that the dominant instrument reaches an often-neglected sub-group. Like the Danish approach, CERT shows the clear benefits of a long-term approach. Difficulties of infusing the approach with a whole house perspective remain challenging.

An additional point of interest is how trade-offs of focusing major policy efforts on a limited number of instruments are managed. Trade-offs are often neglected or poorly understood. The UK response is an exception with the planned introduction of a minimum EPC rating of E for the private rental sector, a sub-group that traditionally falls through the net of the main policy instruments.

Emerging from this analysis is the ongoing difficulty of designing instruments that achieve both high ambition and high participation. Even the instruments that rate among Europe's most ambitious are not considered adequate by many commentators. Concepts like giving primacy to energy efficiency and 'whole house' perspective, which could be expected to be commonplace in response to climate change targets, are not yet mainstream. Emerging strongly is the need for intensification of efforts, especially in view of medium- and longer-term climate change targets.

Front-runners offer both insight and lessons into instruments for existing dwellings – insight, because the action of European front-runners often influences European-wide policy (in this regard, regulatory standards are appearing on the horizon in Denmark and the UK), and lessons, because together the elements that make up the core instruments of Europe's front-runners form a powerful portfolio. Harnessing the power of energy companies in the UK shows how financial aspects can be spread and high levels of outreach attained. Linking incentives with ambitious standards in Germany shows that technical potential in existing dwellings is high. Investing in regulations and the EPC in Denmark shows that these natural moments and the potential they hold for stimulating energy saving should not be lost. Another crucial lesson revolves around confidence in the performance data about our progress to climate change targets. Even some of Europe's front-runners have yet to develop adequate monitoring and evaluation programmes that prove and link instruments with an actual impact on energy consumption.

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# Part 3

## Implementing and evaluating retrofit

# 8 Make no assumptions: The selection of domestic retrofit improvements

*Charlie Baker, Luke Smith and Will Swan*

## Introduction

At the core of the retrofit process is one apparently simple question; what do we need to do to a house to make it more energy efficient? This question is more complex than it initially appears. We might consider different criteria, such as budgetary constraints, or whether we are addressing fuel poverty or looking to reduce carbon emissions, all of which may shape the potential options (Simpson and Banfill 2012). We still need to select options with a specific understanding of the building and how these upgrades might function, not only in terms of their individual performance but also how multiple improvements might interact and what knock-on effect specific issues, such as revised architectural details, thermal transmission properties and improved airtightness, are likely to have. We have the need for a complicated melange of skills to effectively interact: architect, surveyor, technologist, building physicist, energy assessor, project manager and supply chain manager. Millions of houses will have to be addressed by the end of 2050 (HM Government 2010; MacKenzie *et al.* 2010) and we need to recognise that the availability of these skills is limited, as is their affordability. Given the proposed scale of the Green Deal (DECC 2010) and requirement for the training and development for the Green Deal Assessor role (DECC 2012), the development of an effective knowledge-based approach that captures these types of lessons and issues is essential. Current approaches, such as the Reduced Data Standard Assessment Procedure (RdSAP) and the related Appendix T (BRE 2012), used to identify appropriate energy efficiency upgrades within the Energy Performance Certificate, rely heavily on assumptions, making them subject to major change as new information becomes available, often at the site when work is commencing. Alternatively, they have a requirement for substantial input from experienced building professionals. The existing methods are therefore either inadequate or unsustainable when rolling out improvements on a large scale.

When considering an approach such as the Green Deal, we can identify the main areas that any retrofit advisory tool should help us address. The first element that needs to be addressed is the calculation of energy saved, as well as the resultant carbon

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dioxide emissions in the light of the application of upgrades. This is essential for the Green Deal, where a specific package of retrofit upgrades is considered viable based on the projected energy savings; a principle known as the Golden Rule. Second, the tool needs to contain technical knowledge. The tool should know what retrofit systems and technologies would be appropriate for a particular property. This may be a simple tool that identifies broad product ranges or a more detailed design tool that will identify very specific families of products, details and potential installation risks. The third element is a realistic cost base, to ensure that we understand the real costs of an upgrade. These three elements need to interact in an intelligent way; the linkages between technical solution, energy performance and cost are far from straightforward. However, we cannot, in our pursuit of addressing complexity, create a tool that cannot be widely accessible to practitioners. The scale of the problem means that the different layers of understanding need to be embedded into a usable and economic process. Here we discuss Urbed's Whole House Assessment Method, used for individual properties, and Fusion21's Stock Retrofit Assessment Tool. Both organisations shared underlying ideas and principles to help develop their individual tools, which are discussed here.

## Current energy modelling and assessment standards

### UK industry standard energy modelling for domestic properties

While there are a number of different energy modelling methods available, such as dynamic simulation techniques (Crawley 2008) and advanced static calculations, the Building Research Establishment Domestic Energy Model (BREDEM) (Shorrock and Anderson 1995) for example, they do not represent current standard practice when assessing energy performance for the existing UK domestic stock. The current standard is the Reduced Data Standard Assessment Procedure (RdSAP), which is used to produce Energy Performance Certificates (EPCs). Although useful in serving its intended purpose, as a tool for benchmarking the energy performance of homes on a like-for-like basis, there is a growing consensus among retrofit professionals that RdSAP is not suitable for assessing improvement options. It makes many assumptions, so as not to be overly invasive and to keep assessment costs down, but this is at a cost of accuracy. Survey work undertaken by Urbed and Fusion21 shows that once the detail of a property is investigated, RdSAP can produce inaccuracies as high as 35% from the full SAP equivalent, findings that were replicated by a number of Technology Strategy Board, Retrofit for the Future projects (TSB 2009).

Despite the inaccuracies in RdSAP, its ease of use, familiarity among many housing professionals and its role within the regulatory frameworks mean that RdSAP has become embedded as the energy assessment tool of choice in the UK. The latest version of RdSAP, version 9.91, will form the basis for the domestic property assessment within the forthcoming Green Deal, further entrenching RdSAP's position as the dominant modeling approach. Given that there is already a recognised margin of error around actual energy use of occupants as compared to RdSAP (Gentoo 2010: Willey 2012), multiplying this further due to approximations concerning the actual building can make the margin as high as 50%. This further erodes the viability of the model and makes it more likely that the 'Golden Rule' will be broken. A householder is in real danger of making sustainable retrofit choices that will not meet the savings that the model suggests, leading to a potential financial loss. The problem can also appear where a large-scale landlord is using RdSAP data to guide investment decisions. In this case, optimism bias may lead to the appearance of carbon reductions that are not borne out in reality.

The problem is likely to get worse as we need to achieve deeper cuts in carbon emissions. The first 60% of $CO_2$ reductions from most property types can be relatively easy to achieve cost-effectively (MacKenzie *et al.* 2010) but the last 20% of savings are made up of a number of more complex measures that need to be more accurately quantified. The upgrades required to meet higher levels of emissions reduction are less commonly deployed and therefore carry more installation risk. They are also, generally, more expensive and the reduction in energy use is a percentage of a now smaller amount. Effective modelling is required to ensure these approaches make sense and do not present a financial risk for the householder.

## Assessing properties for retrofit upgrades

A major part of the retrofit assessment process is in understanding the existing stock. The information held about the UK housing stock has traditionally been either archetype focused, for the purpose of developing and monitoring national housing policy, or low-precision, used for categorisation exercises and to 'grade' the energy performance of properties to facilitate a sale or letting. Much of these data is held by the Department for Communities and Local Government (DCLG), the Department for Energy and Climate Change (DECC) and organisations such as the Energy Saving Trust (EST), Landmark, the National Land and Property Gazetteer (NLPG) and the Energy Companies. These data are used to inform reports such as the English Housing Survey (EHS) (CLG 2012) and maintaining the National Energy Efficiency Data Framework (NEED) (DECC 2011), through to producing crude national and regional stock profiles. Although useful in aiding strategic thinking, the data are insufficient to determine street-by-street, property-by-property improvement solutions.

By far the most comprehensive, property specific, data gathering undertaken to date has been for the purpose of producing Energy Performance Certificates (EPCs). These have been a mandatory requirement for all properties on the open market since August 2007 and for all rented properties since October 2008. An EPC is underpinned by the Reduced Data Standard Assessment Procedure (RdSAP), in which inference algorithms are used to automatically deduce many of the data items (BRE 2009), reducing the time and cost associated with on-site surveys. As stated previously, the penalty for these assumptions is that the assessment is less accurate and the scope for evaluation of improvement options is limited. However, despite the fact that the 'reduced data' nature of the assessment procedure modelling is open to question, the data collected about property characteristics is valuable. Accredited Domestic Energy Assessors

(DEAs) abide to strict conventions and collect a number of key data items, including floor areas, ceiling heights, roof area, heating and hot water system type and efficiency, and the approximate construction type of key elements such as walls, floors and roofs. Sensitivity testing and Monte Carlo analysis undertaken (Hughes *et al.* 2013) highlights that both boiler efficiency and floor area, along with demand temperature and hours of heating, are the most important parameters in achieving accuracy with static calculation energy models.

The EPC gives an A to G rating, as found with appliances, to give people a broad categorisation of energy efficiency. However, experience with a wide range of users of EPCs, particularly in the social housing sector, indicates that this intended purpose has become lost in translation. Many incorrectly consider the results of an EPC assessment as an accurate reflection of performance and as a reasonable means to assess before and after energy use, $CO_2$ and running costs. A key cause to this appears to be the use of 'Appendix T' as a function within the RdSAP procedure to highlight potential improvement measures on the EPC itself. Appendix T is a library of energy efficiency improvements, each given a trigger linked to the RDSAP assessment form. For example, item Q within Appendix T version 9.91 (BRE 2012) recommends 'internal or external insulation to a U-value of 0.3' if the wall is of solid stone or brick construction and an as-built assumed U-value of greater than 0.6. This method of automation ignores system-built properties and offers assessors a limited ability to note other critical factors such as conservation constraints, wall surface conditions and exposure. This approach does not allow more specific upgrade specifications to be identified or altered and does not consider synergies between measures. This creates a disconnection between the property assessment process and the installation phase, particularly under the Green Deal. For example, assessors may model walls to a U-value of 0.3 and thus identify a finance package that meets the Golden Rule. However, an installer carrying out their own pre-installation assessment might find that such a performance level is not achievable given certain site constraints not noted by the assessor.

In addition almost no current systems take into account actual energy use of the current occupant; if they are to be repaying this money with savings from their utility usage, it is quite a considerable factor in deciding what will work. A homeowner who is underheating their home will not realise the savings needed to cover the costs of EWI.

## Key issues with current energy assessment standards

To help speed the whole assessment process, lessen the reliance on assessor judgement and reduce associated costs, a new approach must be taken to the way properties are assessed and to the way improvements are shortlisted and recommended. Some argue (Wetherall and Hawkes 2011) that new assessment approaches need to be adopted; however most domestic energy assessment tools used in the UK are based on the Building Research Establishment Domestic Energy Model (BREDEM), which has been developed and refined since the 1980s. It is this model that forms the basis for the full Standard Assessment Procedure (SAP), as well as RdSAP. Given that BREDEM has been so extensively tested and has become so entrenched in the sector, it seems logical to make use of its latest incarnation, full SAP 2009, when looking to more accurately baseline the performance of a property and make recommendations. Figure 8.1 illustrates some of the assessment methods currently available.

The full SAP 2009 assessment methodology goes a long way to overcoming the inadequacies of RdSAP by removing all of the inference algorithms and by taking account of more specific inputs, such as specific U-values for elements, size of window openings and some local site factors. An RdSAP assessment typically requires in the region of 90 items of data to be collected, while full SAP 2009 requires over 150. However, it is this improved granularity that is important in improving the accuracy of not only the baseline model but also the modelling of any potential improvement measures.

Some social housing providers are beginning to recognise this and are using RdSAP as a means to profile their stock, followed by the use of full SAP when considering upgrade options at a project level (Jones *et al.* 2011). Whilst it is widely acknowledged that the Green Deal assessment procedure must incorporate more elements of the full SAP procedure, there remain conflicts between the time it takes to do a survey, how to balance time, cost and accuracy of assessments and how the identification and recommendation of measures can be improved.

| | |
|---|---|
| Higher accuracy | **Dynamic Simulation Modelling** – Although very complex and time consuming, dynamic simulation models can be one of the most accurate ways to assess thermal capacities, air movements and the performance of building services (Morbitzer 2003). However, building a model for every UK domestic retrofit project would not be cost effective. |
| | **National Home Energy Rating (NHER), PassivHaus Planning Package & BREDEM-12** – All of these are very similar static calculation methodologies based upon degree-day models. They can take account of regional weather and occupancy patterns and can be specified to model energy use and estimated fuel cost for heating, hot water, lighting and appliances. Although typically used for compliance purposes they handle high levels of granularity and are increasingly used as design tools. |
| | **SAP 2009** – The Standard Assessment Procedure is the Government's preferred method for energy assessment of dwellings. It is an implementation of BREDEM (BREDEM 9) in which the heating calcuations are simplified and some of the flexibility of the inputs is removed. SAP is primarily used for demonstrating the compliance of new dwellings with the Building Regulations, but it is increasingly used to assess existing dwellings. Both weather and occupancy is standardised. |
| | **Cast Studies & Monitoring** – Lessons from projects delivered and in-use monitoring is invaluable to those specifying upgrades to similar properties. Such information may be categorised by house type, upgrade type or by geographical regions to aid understanding of what upgrades work best in certain scenarios. |
| Lower accuracy | **RdSAP 2009** – a slim lined version of SAP 2009 used to assess existing dwellings cost effectively. 'Least unlikely' default date are used for items that are difficult or costly to collect on site (e.g. ground floor insulation, window areas). Consequently RdSAP is a low accuracy modelling method. However the ratings and limited data collected may be used to give a working idea of the scale and nature of the sustainable refurbishment approach that might need to be taken, especially when looking at large quantities of stock at a strategic level. |

**Figure 8.1** Examples of energy assessment methods for domestic properties.

Issues and problems with current selection approaches

Having a model that accurately reflects what changes are made only serves as part of the story. In retrofit practice there are a number of detailed solutions, based on experience and associated modelling, that are starting to emerge. As stated previously, while Appendix T options might suggest external wall insulation, it does not necessarily give an answer that could be taken forward without significant further investigation. As we pass beyond the installation of basic measures and look towards higher levels of improvement, the issues of building physics will become more pressing and the failure to address issues of thermal bridging, condensation and ventilation are likely to cause damage to both buildings and reputations.

In the next section we will consider some of the emergent rules for domestic retrofit, based on experience of designing and delivering a number of projects where reductions of up to 80% have been achieved. We consider some of the main elements and some of the emerging knowledge-based rules that any assessment tool might have to consider. By understanding some of the issues from practice we can consider how models might be adapted to enable this knowledge to be captured, codified and utilised in future assessments.

## The development of rules for domestic retrofit

The rules that are outlined in Table 8.1 are based on the experience of over 30 retrofit assessments and a detailed consideration of the available technology in relation to our understanding of the building. The importance of capturing the rules in some form of structured system or process is the realm of knowledge management, where knowledge can be captured from 'concrete' practices gained from the experience of actually doing the work. This may then be codified so that it can be more easily shared (Nonaka and Takeuchi 1995; Boisot 1998), such as in the form of expert systems (Liao 2005), relying on rule or case-based systems to apply learning of new projects more easily. It is this type of codification of the knowledge base that is essential for the effective delivery of retrofit at scale, where fully training large numbers of assessors to high levels of technical competence may prove too costly and time consuming.

The practice of retrofit, as well as the understanding of post-installation issues, can give us an indication of the potential risks that need to be considered. Understanding these issues gives us a number of rules that might be considered in the constraints of any modelling tool. Table 8.1 highlights some of these factors.

The 'retrofit rules' need to address these issues or it will mean that both the installer and occupier are exposed to potential risks. The occupier may be left with non-performing improvements, or even potential defects introduced into the property. The installer or commissioner of the improvements may find themselves with a refusal for adoption or a customer service complaint, both of which have associated costs.

The issues that have been informally identified by the authors lead to rules that might be used to determine where a retrofit upgrade might be considered. These rules

**Table 8.1** Emergent issues for the development of the assessment model.

| Issue | Description |
|---|---|
| Aesthetic issues | Where there are architectural features or character properties, it may mean that specific options will be unacceptable |
| Disruption | Where the resident may be disrupted and therefore make an option unacceptable. This might be particularly true of elderly or vulnerable people |
| Access | Does the installation of the improvement require specific types of access and are they available? Does any machinery need special access or do improvements create any boundary issues? |
| Planning status | Is the property subject to any planning restrictions? |
| Determining the airtightness envelope | Where are the current air leakages that may be causing a property to lose heat? |
| Thermal bridging | Are there any points where there are thermal bridges or does the retrofit improvement potentially create them? |
| Ventilation and air quality | Has the development of the retrofit considered the balance between airtightness and ventilation? |
| Different building approach in same property | Is the building consistently constructed and have there been changes or extensions that have introduced different building techniques? |
| Technical solutions not in the model | Are there solutions available in the supply chains that are not in the model? |
| Design details | What standard design details are available? To achieve good performance and durability, robust details at junctions and openings are critical |
| Exposure | What does the issue of exposure mean for the retrofit? Is it a suitable solution given wind and rain exposure? |
| Interaction physical | What is the relationship between the measures physically? Are the building services adequately sized in accordance with the fabric heat losses? Do insulation systems adjoin as designed? |
| Interaction financial/energy efficiency | How do measures interact in terms of performance or cost efficiency? What is the correct pathway to achieve our given target, particularly when we may not complete the works all at once? |

can be used to make informed choices as to whether a retrofit upgrade is appropriate. Capturing these rules within our selection process means that we can have a richer understanding of the potential risks and issues that we might be confronted with during a domestic retrofit. It should be noted that these do not represent the only issues; occupant behaviours, for example, should be included in the decision-making process, but we have not chosen to cover them in full detail here, although we have considered issues of underheating. The next sections look at these rules in the following categories: adoption, regulatory, technical applicability, technical performance, buildability and risks associated with the interaction of measures.

## Adoption risks

Adoption risks are those where a householder might not adopt a specific retrofit solution in the first place. Aesthetics is a major issue for the UK, as many homeowners are attached to the character of their properties. For example, windows and doors may have features that should be retained, such as stained glass. Keeping such features is likely to improve the take-up of energy demand reduction works. Again, this is not archetype based – in many cases the features may have already been removed or imitated in replacement. However, where they still exist, thoughtful detailed secondary glazing may be considered or, where budget and aesthetics suit, encapsulated. Similarly, feature brickwork or masonry is not archetype specific and may be worth keeping, but the final decision will vary with context. For example, in some neighbourhoods there may be a mix of properties; some with simple feature courses and others that are far more elaborately decorated and a difficult decision will have to be made as to which features are most valued. Feature plasterwork will have a similar effect on the decisions around specification of internal wall insulation. Another important factor to consider as a major adoption risk is disruption. Approaches such as internal wall insulation, especially plaster replacement or taking down ceilings to install floor insulation in older cellars, can create huge amounts of dust and disruption for occupants.

## Regulatory risks

It is important to consider whether there are regulatory or statutory issues that might influence the selection of options. Planning is a major issue; any improvements that have a major impact on external features, even if accepted by residents, may fall foul of local planning officers. Issues such as conservation areas or listed status can limit the available options. The issue of planning also illustrates the importance of understanding not only the building being retrofitted, but also its wider context.

Another regulatory risk that might be considered is whether products are usable or approved within a specific context. Programmes such as the Green Deal and ECO may limit the choice of products that may be used on a property. Approved and tested products for the Green Deal may be found in Appendix Q.

Technical applicability and performance

The technical applicability of a specific solution is essential. Can it be applied in the given context and will it work into the future? This really requires the following three key questions to be answered:

- Is the solution technically appropriate to the structure?
- Is the solution buildable and can it be easily applied?
- Will the solution perform into the long-term?

These issues can be surprisingly complex as the examples below show.

Insulation to walls has some of the greatest capacity for variation beyond archetype. Internal insulation, to the kinds of levels expected over the coming decades, will cause building physics problems if being applied to the wall on to which the floor joists span. Porosity of masonry does not only vary by building age, but by brick type as well. External wall insulation (EWI) needs to work with moisture movement in buildings, while more expensive moisture permeable insulation needs to be used on vapour permeable solid walls, to allow moisture to escape. Heat loss calculations must, therefore, acknowledge the exposure of the property, as this will affect specification choice. Foam-based EWI, while theoretically suitable, may suffer at junctions, such as windowsills, where small amounts of movement in the covering render may allow moisture in behind the insulation. At best, this will cause decoration damage over time; at worst it will raise the moisture levels in joist ends in that wall, leading to dry rot.

This is further affected by the porosity of the wall to which it is attached and the ambient moisture levels in the house. The plaster features may be replaceable if skilled tradesmen can be accessed. Alternatively, it may be that a wall plaster replacement below the features will work using high-performance insulants such as vacuum insulated panels or aerogels, but only if the humidity is low enough for the cold bridge behind the feature not to do subsequent damage. Porches and bays need to be assessed; even small, cantilevered roofs over the front door may have to be removed and replaced in such a way that they do not bridge the insulation. Flat roofs over bays can be expensive to rebuild, and the brick 120° mullions, which divide the windows in the bay, are very difficult to insulate – externally they can look terrible, while internally they have to be done carefully as they can be very good sources of condensation if located next to joinery.

Roofs offer another set of variations that need to be identified and factored into choices. Overhanging eaves make fibre-based insulants possible to install, but their depth varies by region and designer. The clipped eaves popular in many older dwellings require either an extension to the main roof to cover the EWI or a parapet detail carrying the insulation up to the underside of a purpose designed gutter. Other elements of the construction may preclude either of these or require architectural remodelling of the building to make it possible.

All of these issues indicate the need for more detail. Understanding the different categories of building element and the range of features is important. As the examples show, variations between common building elements can create issues with technical applicability, buildability and performance risks.

Measures working together as a whole

The physical interaction between measures, when they are deployed and how well they perform can be significantly affected by other selected measures. This is particularly important if 'deep' or whole house strategies are adopted. Measures cannot be merely bolted on; there must be a careful consideration of their interactions, both physically and in terms of the performance of the property.

These most obviously manifest in terms of cold bridges and, when rectified through careful planning and design, can have a considerable effect on the performance of the building without considerable changes in cost. Critical interactions usually occur at the junction points between measures, where footing, floor, wall and roof insulation planes intersect, for example. This is demonstrated by calculations undertaken by Urbed, which showed that by simply ensuring there is a continuous layer of insulation with all significant cold bridges addressed, a 7% emissions reduction could be achieved on a standard 1960s semi-detached property. This is a significant number when looking to achieve an 80% reduction in $CO_2$ emissions from a property in a cost-effective manner. Building servicing creates further interaction issues. Solar thermal heat is notoriously difficult to make financially feasible, but the cost of some of the installation can be split if wood-burning space heating is installed. This interaction can also increase the effectiveness of the solar thermal installation to provide some space heating assistance (Urbed 2010).

Another aspect of considering a whole house retrofit is ventilation. Air movement has wide implications that are not picked up in detail in the current SAP-based models. Many houses, both new and old, suffer from poor air quality. The trigger point of demand reduction work needs to be exploited to ensure that the situation is not made worse and, where possible, improved. Opportunities for ventilation may well already exist in the property; they just need to be designed in. An airtight cellar may be pointless if it is a logical part of the air movement strategy for the building. Chimneys may be better fitted with controllable vents instead of being blocked entirely. Airtightness work is probably better concentrated on exposed parts of the property so that air leakage from parts less affected by wind levels can then be designed into an overall natural ventilation strategy.

## Addressing the problem of selecting retrofit improvements

Given the scale and the speed in which upgrades must be implemented, an effective methodology for assessing how the characteristics of different properties create options for selection of retrofit upgrades is essential. This involves bringing together the elements we have discussed within the framework of a formal process that can be easily implemented. Both Urbed's Whole House Assessment Method and Fusion21's Stock Retrofit Assessment Tool rely on such a rule-based approach. The 'rule-based' approach identifies property factors that lead to a product being included as a potential option, rejected or highlighted as carrying a degree of risk. This allows important 'cognitive rules' (Geels 2005), or the way things are done, which are constantly evolving as the industry learns more about retrofit, to be captured. The goal of both systems is to ensure that the knowledge is available and can be accessed in a structured way.

Both tools use the property characteristics designed in SAP as a design tool. By understanding the current built form of the property *and* its local context, the rules, such as the examples identified in the previous section, were captured to allow a more effective options appraisal that not only considered improvements in performance but also the wider rules discussed above. Buildability, long-term performance, adoption risks and potential interaction risks are identified within the model to support more informed choices. Figure 8.2 shows a section of the 'truth table' from the Fusion21 tool.

| | | Cavity wall insulation | | |
|---|---|---|---|---|
| Default performance levels = | Validation | 0.65 | 0.55 | 0.4 |
| Options / Factors | | Blown fibre e.g. Mineral wool, Rockwool & Cellulose | Expanded polystyrene beads (EPS) | Injected polyurethane (PUR) foam |
| No cavity | FALSE | N | N | N |
| Filled cavity walls | FALSE | N | N | N |
| < 50 mm cavity | FALSE | N | Risk – narrow cavity subject to detail survey to assess suitability | Risk – narrow cavity subject to detail survey to assess suitability |
| Unknow cavity width | TRUE | Risk – cavity width unknown so CWI suitability subject to survey | Risk – cavity width unknown so CWI suitability subject to survey | Risk – cavity width unknown so CWI suitability subject to survey |
| Cavity not filled / as built & pre dates 1975* | FALSE | Y | Y | Y |
| Exposure value = 1 | FALSE | Y | Y | Y |
| Exposure value = 2 | TRUE | Y | Y | Y |
| Exposure value = 3 | FALSE | Risk – high exposure level presents need for a detailed survey | Y | Y |
| Exposure value = 4 | FALSE | Risk – high exposure level presents need for a detailed survey | Risk – high exposure level presents need for a detailed survey | Risk – high exposure level presents need for a detailed survey |
| Built pre 1949 (bands A,B & C) | FALSE | Risk – property age presents a risk to buildability so CWI suitability subject to detail survey | Risk – property age presents a risk to buildability so CWI suitability subject to detail survey | Risk – property age presents a risk to buildability so CWI suitability subject to detail survey |

**Figure 8.2** Example of the truth table from Fusion21 retrofit stock assessment tool.

Building on the shortfalls of SAP Appendix T, the 'truth table' then utilises not only the modelling inputs but also the additional assessor observations to determine the suitability of a measure. In this example, the assessor has flagged a cavity width of less than 50 mm and a low exposure value, thus determining that blown fibre cavity fill insulation is not suitable and the other two options are subject to installation risks. The truth table includes over 120 improvement options and takes account of 100 input statements, some of which are identified by the assessor, while others are inferred automatically. Going forward, there is scope to build on this further to establish an industry standard expert system capable of capturing rules that help shortlist improvements and reduce the burden on assessors.

There is also clearly the potential for the development of a 'pattern book' or approved details, as can currently be found for new buildings (Robust Details 2012). The variety of building techniques that have been used in our homes is large, but given the scale of the retrofit task, the argument for developing this pattern book for the UK and effectively linking it to our assessment process is compelling.

There is a considerable resourcing implication in both these steps. Given the cost and availability of technically experienced advice, codifying that expertise into an expert system for all to use is logical. To enable delivery, assembling a database and a connected pattern book of best practice details is crucial. Furthermore, neither of these steps is a static one. There needs to be expert stewardship of both, and if these are the gateway to measures being deployed, product suppliers will want to know that there is an objective process. There is a danger that if any product is excluded or defined in a way that limits its use, legal challenges could be mounted.

## Conclusions and next steps

A little learning is a dangerous thing. Sustainable retrofit cannot be viewed as a simple task. Failing to understand the full ramifications of the choices we make can lead to major issues. The work being undertaken by Urbed, the University of Salford and Fusion21 is not being carried out in isolation. There are a number of emergent tools that are attempting to support the specification of sustainable retrofit options through rule-based and case-based approaches. It is clear that we do need more robust tools than are currently being used for the delivery of Green Deal Assessments. At best, further, more detailed, assessments and secondary visits are needed on properties, adding unnecessary costs. At worst, incorrect options are selected on the basis of broad assumptions and issues develop with the property and its occupants.

The scale of the sustainable retrofit challenge means that we need to develop better tools to capture the learning. This can be done by a number of approaches. First, the adoption of a more elemental approach is required; archetypes lead to too many assumptions. Large amounts of quite detailed survey information is collected through the EPC, so perhaps we should recognise its usefulness and simply build on it when looking to make design decisions. We should also consider how the existing RdSAP methodology should be further improved to allow for more accurate modelling.

The second issue is that we have to gather these cognitive rules more effectively. We have a large number of demonstrator and pilot projects, but those that have robust monitoring, not just of performance but also of construction and in-use phases, are limited. While this is not always possible, the building of effective communities of practice (Wenger *et al.* 2002) can provide a basis where rules and lessons can be shared and captured for wider use.

The third issue is that we do need better understanding of real energy use, including behavioural issues. The range of differences in energy use between similar properties may indicate that the physical nature of the property is a much weaker indicator of energy use than demographics, economic and weather data, as used in the National Energy Efficiency Database. Some sensitivity analysis should be undertaken to understand what factors have the biggest impact based on real data. In addition, there are clear gaps between some of the claims for performance, modelled performance and the actual performance of building products (Encraft 2009; EST 2010). We need to build an evidence base that helps us better understand what real performance is; otherwise we are potentially making false choices based on modelled information.

Many of the lessons we need to undertake sustainable retrofit are known, but they may not be disseminated widely. Refurbishment works are often more complex than new build (Egbu *et al.* 1998) and so some skills, while largely transferable, might need updating to address the new problem. It is unrealistic to expect a large number of people to acquire these skills, which are often high level, and therefore we need to make the knowledge actionable for the wider sector. The development of a knowledge management system, either as a management process or computer-based tool, is one approach by which we may capture the knowledge. However, the most important consideration is the processes by which new practices, products or processes are embedded, as there is a potential danger of creating a model that cannot learn and learning is what we need to be doing.

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# 9 Life cycle assessment of refurbishment strategies for historic buildings

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## Introduction

When approaching the design of a new building, it is possible to define a wide set of options and to choose between them taking account of the local climate, the minimum performance standards, the architectural context and the landscape. However, when approaching a refurbishment project the number of degrees of freedom is obviously lower. The retrofit of historic buildings introduces further limitations, especially when regulated through the decision-making processes of different local and regional authorities.

We consider different sustainable retrofit approaches for the former silk spinning mill located in Valmadrera, not far from Lake Como in northern Italy, which has been active since 1819. Due to its historic value, any physical intervention on the building should be authorised by the cultural heritage authority. For this reason, different possible wall insulation approaches are considered: a conservative retrofit, with a lower visual impact on the external façade, to preserve the historic value of the building, and a deep retrofit that includes thermal insulation on both the internal and external surfaces of the walls.

Article 9 of the 2010/31/EU Directive states that Member States shall 'stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings'. In achieving this objective, the energy consumption and the environmental impact of the operational phase of buildings are set to decrease. At the same time, the energy consumption and environmental impact of the construction and of the demolition phases will play a growing role. A life cycle perspective is therefore essential to evaluate the economic, energetic and environmental balance of a building, including those that undergo a sustainable retrofit.

*Retrofitting the Built Environment*, First Edition. Edited by William Swan and Philip Brown.

## Life cycle analysis in the building sector: A fragmented picture

Life cycle analysis (LCA) has been discussed in the building sector since the early 1990s and has become an important support instrument for designers (Chevalier and LeTeno 1996; Mahdavi and Ries 1998). LCA of buildings differs in many respects from the analysis of consumer products for which it was initially developed. A building generally has a longer lifetime, has bigger dimensions and is made up of several materials, each having different properties or functions. A building can have different uses, even for short time periods. Therefore, each building is a unique product and building LCA can be difficult to standardize. For these reasons, LCA in the building sector is a research field under constant evolution. Most of the published studies focus on a single material or a single building component, because it is difficult to define boundaries and methodologies for the analysis of a complete building. Extensive literature surveys have been published in recent years (Ortiz *et al.* 2009; Sharma *et al.* 2011). The studies may differ in terms of completeness (phases of the life cycle included, evaluation methods), transparency (description of the methodological assumptions) and scientific rigour. Perhaps more importantly, researchers may choose different assumptions and consequently their results can be difficult to compare. For example, differences may be highlighted in the choice of the functional unit, of the allocation procedures, in the disposal scenarios, in the electricity mix, in the impact categories and so on (Werner and Richter 2007; Lee *et al.* 2009). In particular, there is a need to revisit the definition of the functional unit and reference flows for buildings; the key point is the operational energy and the home functions included in the calculation (Cuéllar-Franca and Azapagic 2012) that may profoundly alter the impact assessment results (Frijia *et al.* 2012). An accurate definition of the functional unit has an important effect on the building's life cycle energy attributed to materials and construction, which can increase considerably with respect to the operational energy. In addition, the life span of a building ranges from 50 to 100 years, so accounting for technological progress might be a reasonable option, in particular when estimating the heating and/or cooling energy consumption over such a long period as the building life, but on condition that reasonable assumptions are made. Extending the system boundaries in the building LCA to include, for example, the management of waste produced in the operational phase can strongly affect the results in terms of impacts (Kua and Wong 2012).

These issues are just some of the challenges faced when considering the life cycle analysis of buildings (Tae *et al.* 2011). Several efforts have recently been devoted to the harmonisation of different methodologies for building LCA (Suh and Lippiatt 2012). For example, the Council of European Producers of Materials for Construction (CEPMC) has established a European technical committee (CEN/TC 350, Sustainability of construction works; http://www.cen.eu/) that is responsible for the development of voluntary horizontal standardized methods for the assessment of the sustainability aspects of new and existing construction works and standards for the environmental product declaration of construction products (König *et al.* 2010).

## Retrofit of a historic building

The case presented in this paper aims at evaluating different refurbishment strategies for an historic building: the former silk spinning mill located in Valmadrera, not far from Lake Como. In 1864 more than three hundred people used to work in this architectural complex. The LCA analysis for the retrofit was developed using three buildings, shown in Figure 9.1, on the site. Two of them were built in the 1820 s (the silk spinning mill and the house of the watchman) and are protected by the Ministry of Culture because of their special historic value; the third one was built in the 1960s and connects the two historic buildings.

### Retrofit approaches

The retrofit options that were analysed aimed at improving the energy performance of the three buildings through the insulation of walls. We do not consider substitutions of other parts of the envelope (roof, windows) or of the heating systems that can achieve further performance improvements in this level of analysis. For the two historic buildings, two different approaches are proposed: a conservative approach, with a lower visual impact on the external façade to preserve the historic value of the building, and a deep retrofit approach that includes thermal insulation on both the internal and external surface of walls. For the 1960s building only a deep retrofit is analysed. For all the strategies, two different options are compared: one that adopts synthetic materials and the other natural materials. A comparison is undertaken of two options that result in the same thermal transmittance and, therefore, the same energy performance.

The calculated thermal transmittance of the walls in existing historic buildings is 2 $W/m^2 K$. The conservative retrofit would reduce the transmittance to 0.66 $W/m^2 K$ (a 67% decrease compared to the existing situation), while the deep retrofit would obtain a 0.31 $W/m^2 K$ transmittance (85% decrease). The deep retrofit of the 1960s building walls will reduce its transmittance by 90% (from 3 $W/m^2 K$ to 0.31 $W/m^2 K$).

### Materials and wall layer design

The choice of the materials and the design of the wall layers were carried out with a view towards buildability. All the options identified can actually be adopted in real situations. The design options adopt only materials already included in LCA databases or already analysed in the literature, as well as some earth plasters that were analysed in a specific LCA investigation (Resi and Zannetti 2010). Tables 9.1 and 9.2 show the existing and additional wall layers foreseen by the conservative and deep retrofit of the historic building. Table 9.3 shows the existing and additional wall layers foreseen by the deep retrofit of the 1960s extension.

The conservative retrofit and the deep retrofit of the historical buildings are alternative solutions. The choice between them will depend on the decision of the authority in charge of the cultural heritage protection (*Soprintendenza per i beni Architettonici*


**Figure 9.1** Cross-sectional view of the three buildings: the silk spinning mill (left); the 1960s extension (centre); the house of the watchman (right) (Colombo and Salvoni 2010).

**Table 9.1** Historic building conservative retrofit wall layers.

| **Historic building Existing wall** | **Conservative retrofit Synthetic materials** | **Conservative retrofit Natural materials** |
|---|---|---|
| U = 2 W/m² K | U = 0.66 W/m² K<br>Painting (2 mm) | U = 0.66 W/m² K<br>Painting (2 mm) |
| External plaster (30 mm) | External plaster (30 mm) | External plaster (30 mm) |
| Bricks and stones (520 mm) | Bricks and stones (520 mm) | Bricks and stones (520 mm) |
| Internal plaster (30 mm) | Internal plaster (30 mm) | Internal plaster (30 mm) |
| | Insulating plaster: mix of lime, cement and expanded polystyrene (90 mm) | Insulating earth plaster (50 mm) |
| | Finishing lime layer (4 mm) | Finishing earth plaster layer (3 mm) |

**Table 9.2** Historic building deep retrofit wall layer.

| **Historic building Existing wall** | **Deep retrofit Synthetic materials** | **Deep retrofit Natural materials** |
|---|---|---|
| U = 2 W/m² K | U = 0.31 W/m² K<br>External levelling and finishing cement layer (3 mm)<br>Insulating plaster (70 mm)<br>Levelling lime layer (3 mm) | U = 0.31 W/m² K<br>External levelling and finishing lime layer (3 mm)<br>Lime and cork (70 mm)<br>Levelling lime layer (3 mm) |
| External plaster (30 mm) | External plaster (30 mm) | External plaster (30 mm) |
| Bricks and stones (520 mm) | Bricks and stones (520 mm) | Bricks and stones (520 mm) |
| Internal plaster (30 mm) | Internal plaster (30 mm) | Internal plaster (30 mm) |
| | EPS* board (70 mm) | Insulating earth plaster (60 mm) |
| | Finishing cement layer (4 mm) | Finishing earth plaster layer (3 mm) |

*Expanded polystyrene.

*e per il Paesaggio*). If the *Soprintendenza* wants to preserve the façade, then the designer will be forced to choose the conservative strategy. Otherwise the deep retrofit strategy can be adopted. The 1960s extension is not protected and it is likely that it will undergo a deep retrofit. Therefore, in the following pages, both the conservative and the deep retrofit strategies will only include a deep retrofit of the 1960s building.

**Table 9.3** 1960s extension deep retrofit wall layers.

| 1960s extension<br>Existing wall | Deep retrofit<br>Synthetic materials | Deep retrofit<br>Natural materials |
|---|---|---|
| $U = 3\ W/m^2 K$ | $U = 0.31\ W/m^2 K$<br>External fibre cement siding board (8 mm) | $U = 0.31\ W/m^2 K$<br>External covering of fir wood staves (3 mm) |
| | Cavity containing wood laths (100 mm) | Cavity containing wood laths (70 mm) |
| External plaster (30 mm) | EPS board (3 mm) | Cork board (3 mm) |
| Concrete (300 mm) | Concrete (300 mm) | Concrete (300 mm) |
| Internal plaster (30 mm) | Lime plaster (30 mm) | Mineralised wood wool board (60 mm) |
| | Finishing lime plaster layer (4 mm) | Earth plaster layer (15 mm)<br>Finishing earth plaster layer (3 mm) |

## Life cycle analysis (LCA)

This paper presents the evaluation of environmental impacts of the intervention on all the walls of the buildings considered. Accordingly, the functional unit adopted in the analysis is the entire surface involved in the opaque envelope retrofit of the three buildings (see Table 9.4).

The time horizon of the analysis includes the retrofit intervention and the operational phase of the buildings. The evaluation of the operational phase considers the primary energy demand of the building under the different intervention strategies. Table 9.5 provides the results obtained through the energy certification procedure adopted in the Lombardy Region (Regional Government Decree No. 5796). The Cened + software, freely provided by the regional government (www.cened.it/download) has been utilised for the energy certification. Only energy consumption for heating has been considered.

The results of the primary energy demand analysis show that the reduction of energy consumption is not satisfactory, as it would lead to results well above the current minimum standards in Lombardia, but this analysis does not consider substitutions of other parts of the envelope (roof, windows) or of the heating systems that can achieve further performance improvements.

The LCA was performed using well-known software in the field, i.e. Simapro (www.pre.nl). The data were derived exclusively from the Ecoinvent 2.0 database (www.ecoinvent.com) and can therefore be considered as secondary data (derived from literature). Only data regarding the earth plasters were derived from a specific analysis on primary data made available by the producer (Fornace Brioni, www.fornacebrioni.it).

**Table 9.4** Total vertical opaque surfaces analysed.

| **Building** | **Surface ($m^2$)** |
|---|---|
| Historic buildings | 1350 |
| 1960s extension | 151 |

**Table 9.5** Annual primary energy demand for heating.

| | **Primary energy demand (kW h/$m^2$-year)** |
|---|---|
| Present conditions | 279.2 |
| Conservative retrofit | 210.4 |
| Deep retrofit | 196.0 |

## Environmental impact indicators

Environmental impacts were assessed using three different indicators: global warming potential (GWP) (Forster *et al.* 2007), ecological footprint (Wackernagel and Rees 1996) and Eco-indicator 99 EI99 (Goedkoop and Spriensma 2001).

The GWP is a measure of the contribution of a gaseous emissions to the greenhouse effect and, consequently, to global climate change. The biological and industrial processes required to produce natural and synthetic building materials determine the emission of a number of different gases to the atmosphere. As each gas has a different capacity to trap heat, GWP is typically measured in kilograms of carbon dioxide equivalent (kg $CO_{2,eq}$) and must be referred to a reference time horizon. For instance, the 20-year GWP of 1 kg of methane is 72 kg $CO_{2,eq}$, which means that 1 kg of methane introduced in the atmosphere will absorb the same heat as 72 kg of $CO_2$ over the next 20 years. In our assessment, we used a time horizon of 100 years.

The ecological footprint was originally developed to compare the human appropriation of natural resources with the regenerative capacity of ecosystems on a geographic scale (from the regional to the global one) and it is increasingly used also in LCA analyses (Huijbregts *et al.* 2008). It measures environmental impacts in terms of land occupation. Every human activity requires biologically productive land and/or sea to supply natural resources and absorb waste. The ecological footprint is the sum of these areas, regardless of where they are located on the planet. Land use is subdivided into six categories, encompassing cropland, grazing land, forest, fishing grounds, built-up land and land for carbon absorption. This latter category represents the forest land that would be needed to sequester carbon dioxide emissions from the burning of fossil fuels. In the context of LCA (Huijbregts *et al.* 2008; Hischier *et al.* 2010), the ecological footprint of a product is measured in hectare years, resulting from summing up over time three major impact categories: direct land occupation for the production of natural resources, indirect land occupation related to nuclear energy use and land occupation to absorb greenhouse gases emitted when burning fossil fuels and the limestone for cement production.

EI99 aggregates different environmental effects. Widely utilised as a standard indicator for LCAs, it considers eleven impact categories: carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels (Goedkoop and Spriensma 2001). These categories are in turn grouped under three major categories (human health, ecosystem quality and resources depletion). Impacts for the different categories are eventually weighted and aggregated. Three weighting sets have been proposed to aggregate EI99 indicators: 'hierarchist', 'egalitarian' and 'individualist', reflecting three different social perspectives based on the cultural theory of risk (Thompson *et al.* 1990). The individualist perspective has a short-term horizon and scarce interest in low probability impacts. The hierarchist one balances short- and long-term horizons and has a consensus-based approach to risk. The egalitarian one has a long-term horizon and relies heavily on the precautionary principle. Using different weighting sets may lead to very different final impact estimates. In this work, we adopted the hierarchist weighting set because it is considered the most balanced among the three. Also, it gives a higher weight to greenhouse emissions, making it particularly interesting when comparing the results with those obtained with the other indicators. Aggregated environmental impacts are measured in 'points' (Pt), which are dimensionless figures. The scale of EI99 points is set in such a way that the value of 1 Pt is representative for one-thousandth of the yearly environmental load of one average European inhabitant (Goedkoop *et al.* 2000). However, the absolute value of the points is not very relevant, as the main purpose of the method is to compare relative differences between products.

## Results of the LCA

The impacts of the different retrofit options in terms of global warming potential are compared in Figure 9.2. The ecological options show a systematically lower impact compared to the equivalent synthetic options. The GWP of a conservative retrofit with natural materials on the historic buildings would cause ca. 50% less greenhouse emissions (16 versus 33 t $CO_{2,eq}$) than those produced using synthetic materials. In the case of a deep retrofit, the difference would be less remarkable (33 versus 39 t $CO_{2,eq}$), but still in favour of the ecological option. As for the operational phase, the energy performances depend only upon the retrofit type (conservative versus deep), rather than by the materials chosen (ecological versus synthetic), since the comparison is done considering the same thermal transmittance. Retrofitting guarantees a significant decrease in primary energy demand, which in turn causes a decrease of the environmental impact (Table 9.6). Both retrofit types achieve a greenhouse emission saving of more than 40 t $CO_{2,eq}$ compared to the present conditions.

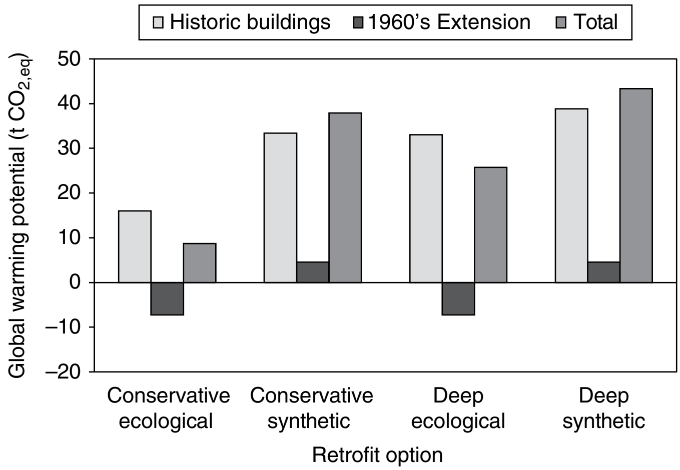


**Figure 9.2** GWP impact of the retrofit for the different design retrofit options.

**Table 9.6** Annual greenhouse gas emissions of the operational phase for different retrofit options.

| | **Emissions (t $CO_{2,eq}$/year)** |
|---|---|
| Present conditions | 188.2 |
| Conservative retrofit | 141.8 |
| Deep retrofit | 132.1 |

Retrofitting causes positive impacts (i.e. environmental costs), while the operational phase causes negative impacts (i.e. environmental benefits) thanks to the insulation. Therefore, it is interesting to calculate the payback time of the different intervention options, namely the time needed to compensate the greenhouse emissions generated by the retrofit with the decreased emissions during the operational phase. Table 9.7 shows the payback times associated with different intervention strategies. In all of the four scenarios considered the payback time is shorter than one year.

Quite surprisingly, the environmental performances of ecological and synthetic materials are reversed when impacts are assessed in terms of an ecological footprint (Figure 9.3). In fact, the ecological footprint of retrofitting with natural materials is larger than that based upon synthetic materials, in both the case of conservative retrofit (16 versus 12 hectares × years) and that of deep retrofit (23 versus 13 hectares × years). During the operational phase both options guarantee a decrease in footprint, thanks to the improved energy performances of the building (Table 9.8). The payback times of the impact are rather short in all cases (between 11 and 20 months;

**Table 9.7** Greenhouse emission payback time for different retrofit options.

| Retrofit option | Emissions caused by retrofit (t $CO_{2,eq}$) | Avoided emissions (t $CO_{2,eq}$/year) | Payback time (months) |
|---|---|---|---|
| Conservative-ecological | 8.7 | 46.4 | 2 |
| Conservative-synthetic | 37.9 | 46.4 | 10 |
| Deep-ecological | 25.8 | 56.1 | 6 |
| Deep-synthetic | 43.4 | 56.1 | 9 |

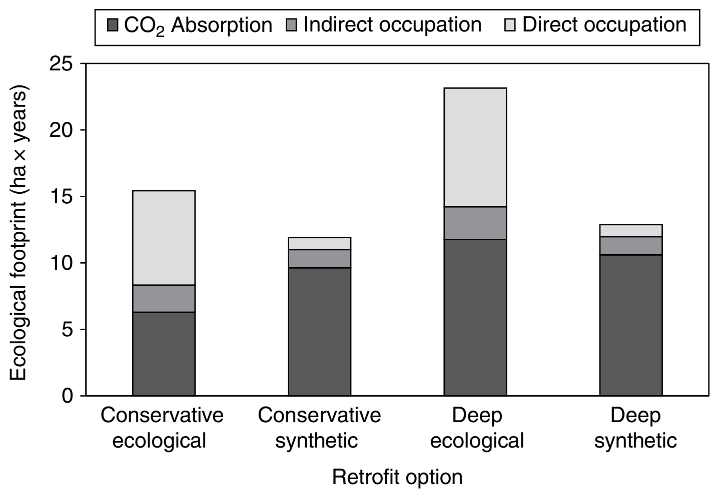


**Figure 9.3** Ecological footprint of the retrofit for different retrofit options.

**Table 9.8** Ecological footprint of the operational phase for different retrofit options.

| | Ecological footprint (ha) |
|---|---|
| Current conditions | 47.7 |
| Conservative retrofit | 35.9 |
| Deep retrofit | 33.5 |

see Table 9.9): also in terms of ecological footprint, a favourable environmental balance is achieved in less than two years.

The comparison of the different retrofit options through EI99 suggests, again, that using synthetic materials may cause a lower overall impact than using natural materials (Figure 9.4). However, differences are less marked than those obtained with the ecological footprint. In the case of conservative intervention, the overall EI99 score is

**Table 9.9** Ecological footprint payback time for different retrofit options.

| Retrofit option | Ecological footprint of retrofit (ha × years) | Avoided footprint (ha) | Payback time (months) |
|---|---|---|---|
| Conservative-ecological | 15.4 | 11.8 | 16 |
| Conservative-synthetic | 11.9 | 11.8 | 12 |
| Deep-ecological | 23.2 | 14.2 | 20 |
| Deep-synthetic | 12.9 | 14.2 | 11 |

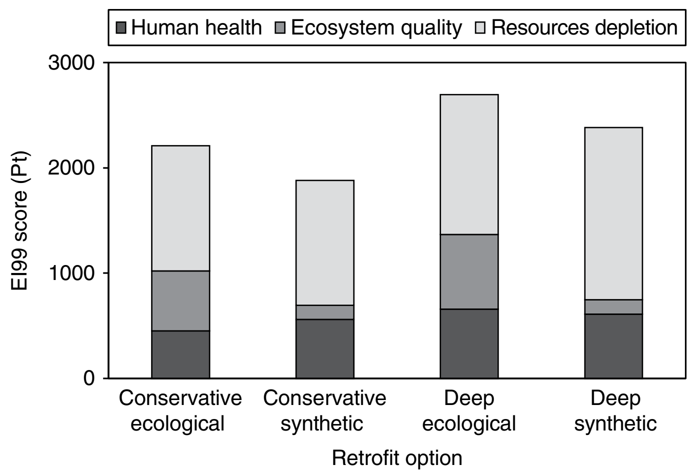


**Figure 9.4** Impacts of different retrofit options assessed with EI99.

**Table 9.10** Impacts of the operational phase for different retrofit options assessed with EI99; results are in (eco-)points (Pt) and refers to a one-year operation of the building.

| | Human health (Pt) | Ecosystem quality (Pt) | Resources depletion (Pt) | Total (Pt) |
|---|---|---|---|---|
| Present conditions | 1473 | 113 | 10448 | 12035 |
| Conservative retrofit | 1110 | 85 | 7871 | 9067 |
| Deep retrofit | 1034 | 80 | 7333 | 8446 |

ca. 2200 versus 1900 Pt for the ecological and synthetic options, respectively, while it is 2700 versus 2400 Pt in the case of deep retrofit. Considering the operational phase, all retrofit options guarantee a decrease of environmental impacts in all macrocategories (human health, ecosystem quality and resources depletion) compared to the present situation (Table 9.10).

## Discussion

The outcomes of our analysis are deeply influenced by the indicator chosen to assess environmental impacts. The more intuitive result is that obtained by measuring impacts in terms of GWP: using natural materials, like those envisaged in the ecological options, guarantees lower impacts than using synthetic materials, thanks to the absorption of carbon dioxide by trees and crops through photosynthesis and the consequent storage as carbon in the plant biomass. In particular, the use of vegetal materials for the retrofit of the 1960s building determines a negative net balance of greenhouse gas emissions; i.e. carbon absorption exceeds carbon emissions. Therefore, if the aim of the retrofit is to minimize impacts on global climate change, using insulating materials such as wood, straw and cork is always preferable to relying upon synthetic materials like expanded polystyrene, irrespective of the intervention (conservative or deep retrofit) chosen for the historic buildings. On the other hand, irrespective of the materials used, emissions saved during the operational phase thanks to the improved energy performance of the buildings allow a rapid payback of the emissions produced due to the materials used in the retrofit. Depending on the specific retrofit option chosen, the payback time ranges between 2 and 10 months, making the intervention clearly favourable over the expected life span of the buildings.

In contrast, a comparison of retrofitting options in terms of the ecological footprint seems to favour the use of synthetic materials, a result that may be surprising at first glance. Analysing the distribution of the impacts into the three major land use categories considered by this indicator (Figure 9.3), it is possible to verify that land occupation to absorb carbon dioxide emissions is the most important impact source for retrofit options based upon synthetic materials, while direct land occupation has a predominant role for ecological options. The production of vegetal materials actually demands more land than the production of mineral and synthetic materials, a fact that should be taken into account. However, it is worth noting that, even if the impact of natural materials may be higher in terms of quantity, it may be preferable in terms of quality. In fact, land occupied by industrial activities is often subject to strong disturbance, while the same land can retain most of its ecosystem functions if it is used for agricultural or forestry purposes. There are a number of examples of how the metric traditionally used for ecological footprinting, which is based on bioproductivity (i.e. it weights land occupation on the basis of world-average yield factors), does not correctly account for the actual impact of land use on biodiversity (Lenzen *et al.* 2007). For instance, the bioproductivity metric favours conventional against organic agriculture, or the replacement of ancient forests with monoculture forests, because of the higher productivity of the former options with respect to the latter (at least over a short time horizon and thanks to chemical and energy inputs). For this reason, an alternative metric based on land disturbance has been proposed (Lenzen and Murray 2003) attempting to reflect the current and projected future impacts on land cover, soil quality and biodiversity. Although this metric is largely designed for use in LCA, it has not been yet implemented in common LCA software (Freitas de Alvarenga *et al.* 2012; Mattila *et al.* 2012). Another major shortcoming of the ecological footprint is that it accounts only for impacts on the carbon cycle, while it does not consider the impact of pollution on other important biogeochemical cycles, such as those of nitrogen, phosphorus or sulfur.

The impact assessment based on EI99 is also favourable to synthetic materials. For both retrofit options (ecological and synthetic) the most important damage categories are those related to resource depletion caused by consumption of fossil fuels and impact of human health due to the respiratory effects of pollutant emissions. As for ecosystem quality, the most important impact of retrofitting with synthetic materials is linked to greenhouse gas emissions, while for natural materials land use is, again, the most important damage category. However, the performance gap between the different options is lower than the one calculated with the ecological footprint, because land occupation is only one of the several impact categories included in the aggregated indicator.

## Conclusion and further research

Sustainable building design raises multidimensional problems. Designers must often cope with potentially conflicting objectives, minimizing a range of environmental impacts while keeping costs reasonable. In this respect, a life cycle perspective is crucial to assess the full range of environmental impacts associated to all life stages of a building. The results presented here confirm the importance of a life cycle assessment based on different impact metrics, providing different, and complementary, viewpoints to the assessment of the overall environmental performances of different design options. On the other hand, our analysis highlights the need to develop indicators that are able to capture not only the quantitative differences between the impacts of different options but also the qualitative ones.

If LCA is used to support public decisions, the choice of proper indicators should address the objectives of the decision-makers. For example, if the main goal is the decarbonisation of the economy, GWP is the best indicator, while if the goal is a generalized reduction of environmental impacts, Eco-indicator 99 may be a better choice. Although ecological footprinting is an increasingly used method to evaluate sustainability from the scale of the single production process to that of the entire planet, it has a major shortcoming in that it only takes into account the quantity of land appropriated by a human activity, without considering the effects of this appropriation on land quality. In particular, the ecological footprint may be a useful indicator to compare options requiring a similar land use (e.g. to choose among different synthetic retrofit options), while it appears less suitable to compare options implying very different land use ways (e.g. to choose between synthetic versus natural retrofit options). In this respect, an ecological footprint analysis incorporating land disturbance would add crucial information to policy for long-term planning (Lenzen and Murray 2003).

The use of natural materials is experiencing a resurgence of popularity in the context of sustainable building. Further research is needed in order to include a wider range of natural materials in LCA databases. In this way, further comparisons may be developed among different retrofit options, all based on the use of natural materials.

## Acknowledgements

The results presented in this paper are based on the analyses of two Master theses conducted at the Politecnico di Milano (Colombo and Salvoni, 2010; Resi and Zannetti, 2010). Data for the LCA of earth plasters were provided by the producer Fornace Brioni.

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# 10 FutureFit: Lessons for the Green Deal from a retrofit large-scale project in UK social housing

*Alexandra Willey*

## Introduction

The UK is legally required to reduce its total carbon emissions by 80% by 2050, with an interim target of 34% by 2020 (Climate Change Act 2008). Greening existing homes has been identified as one of the biggest contributions that can be made towards these targets, as more than a quarter of the UK's carbon emissions come from our homes (Boardman 2007). The vast majority of homes that will be standing in 2050 have already been built (Boardman 2007), and this means that retrofitting, or low-carbon refurbishment, will need to be delivered on a significant scale. Rising fuel costs and future scarcity of fossil fuels is already a major issue for social tenure households (DECC 2008a). Of social households in the UK 17% are already thought to be in fuel poverty (DECC 2008b), where they have to spend more than 10% of their income on heating the home to a comfortable level. Several factors have the potential to exacerbate this situation, specifically recent housing and benefit policy changes, and rising energy costs. Ofgem has modelled consumer energy price increases of up to 34% for gas and 53% for electricity over the next 10 years (Ofgem 2009). These policy issues of climate change and fuel poverty (DTI 2006, 2007) provide the background for the Green Deal.

The Green Deal is a finance mechanism proposed by government to fund energy improvement works. It is based on the premise that the cost of energy efficiency works can be covered by upfront third party investment, which is then repaid through a long-term surcharge on the reduced energy bills for the property (DECC 2011a). The initiative is proposed to be entirely consumer-led, with homeowners and occupiers being offered a selection of energy efficiency improvements to their homes, resulting in a level of savings on their energy bills. The Green Deal's 'Golden Rule' means that savings must be greater than the additional repayments in paying back the cost of the Green Deal investment. Greg Barker, Minister for Climate Change, has been quoted as saying the policy aims to support the retrofit of 14 million households by 2020 (Matthews 2011). The full details of the policy were due to be covered in the

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consultation on the secondary legislation of the Energy Bill in autumn 2012. The final details with regards to the precise workings of the Green Deal have yet to be finalised and, arguably, there is still a low level of understanding concerning the actual practice of wide-scale retrofit.

Two successive Governments have identified social housing as a test-bed for the development of the sustainable retrofit market, first in the Household Energy Management Strategy (HM Government 2010) and again by the current Government in the Low Carbon Construction Report (BIS 2010). Several projects have been carried out that have started to investigate the process of improving energy efficiency in existing homes. A number of these have been exemplar projects, involving single properties, where a specific carbon reduction target has been set and often where the properties have been vacant or decanted. Other projects, such as the Technology Strategy Board's Retrofit for the Future, have focused specifically on technology and have had access to large budgets. Social housing has led the way in the development of the evidence base for practical implementation, the Pay As You Save Pilots (DECC 2011b), the Retrofit Reality Project undertaken by Gentoo (Gentoo 2011) and the Worthing Homes RELISH Project (Worthing Homes 2011). In 2010 there appeared to be a gap in research in terms of investigating the full practical implications of the sort of wide-scale retrofit the Green Deal is looking to introduce.

The FutureFit project looked to address this gap by undertaking the sustainable retrofit of 102 homes with the express aim of developing this understanding. The project had four main aims:

- To understand the *practical implications* of delivering large-scale programmes of retrofit.
- To identify *actual costs and actual energy savings* through a robust monitoring and evaluation process.
- To develop *best practice and guidance* on the delivery and funding of carbon reduction in existing homes.
- To *engage residents and stakeholders* in the design, evaluation and prioritisation of retrofit solutions.

The FutureFit study was a wide-reaching project that addressed a number of different issues with regards to the delivery of retrofit. Here we discuss findings specifically in the context of the Green Deal. We define the current processes and roles within the Green Deal and look at the different implications that the FutureFit data has for the Green Deal's implementation.

## The Green Deal

The Green Deal is a policy tool that will allow homeowners and businesses to make their properties more energy efficient at no upfront cost. The costs of any capital works will be paid through the costs savings through reduced energy bills. The model, in principle, seems simple and has been piloted through the Pay As

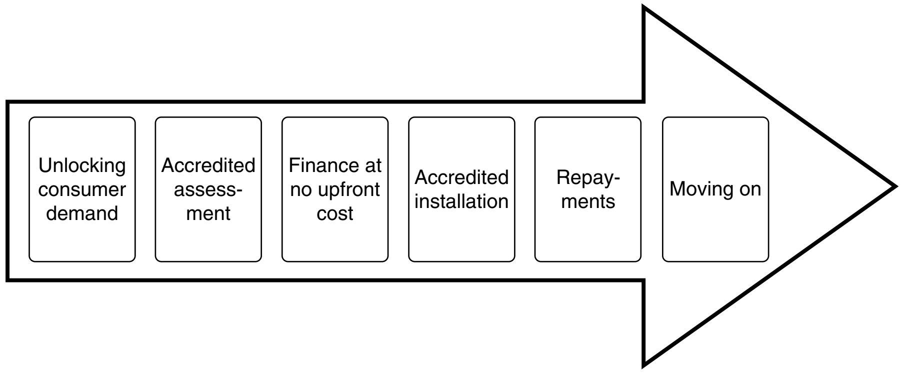


**Figure 10.1** Green Deal Process (DECC 2010).

You Save Pilots undertaken with social housing providers and businesses (DECC 2011c). However, there are a number of complexities in terms of roles and responsibilities, as well as the processes. At the time of writing the Green Deal is still in a consultation process (DECC 2011d) covering a wide range of issues from approaches to different tenures to the functioning of the Energy Company Obligation, the funding regime that will support the Green Deal. In addition, there is also the development of standards and processes that will govern the Green Deal, the Publicly Available Standard 2030 (British Standards Institute 2011) for installers and the National Occupational Standard for Assessors, which add further complexity. While there are many issues within the Green Deal, here we will focus specifically on the basic model (DECC 2011a), as shown in Figure 10.1. Each of these stages within the process is required to deliver a sustainable retrofit using a consumer driven model.

There are four key actors within the Green Deal process who will have different roles at the various stages. It is worth considering their roles prior to describing the process. These are the consumer, the Green Deal Provider, the Green Deal Assessor and the Green Deal Installer. The Green Deal Provider is the organisation with which the consumer has a contractual relationship. They provide the funding for the Green Deal improvements and receive the payments through a charge on the consumer's electricity meter. The Green Deal Assessor identifies the improvements that can be installed in a property and calculates the potential for energy savings. Finally, the Green Deal Installer is an accredited organisation that installs the retrofit measures in the home. The relationships between the three Green Deal actors have yet to be fully clarified in the final version of the regulations. Currently, it appears that these roles could be delivered by separate organisations or by a single entity.

As outlined in Figure 10.1, the first stage is concerned with unlocking consumer demand. This model is focused very much on individuals who make decisions about their properties. There are some variations to the model to reflect tenure, but the energy bill payer, usually the occupant, drives the model as decision-maker, whether they own the property or not. Adoption risk is a major issue for the success of the Green Deal and the market for sustainable retrofit might be currently viewed as being mainly composed of very early adopters (Rogers 1995). The model of consumer engagement and protection is still being developed. Issues of consumer protection and trust are essential for the market to be successfully developed. The next stage is concerned with the assessment of the property. The assessment serves two functions; the first is to identify a potential package of measures that might be used to improve the energy performance of the property and the second is to model the potential energy savings to ensure the Golden Rule is met. Currently, it is viewed at the initial assessment process, undertaken by a Green Deal Assessor, who will use an adapted version of the Reduced Data Standard Assessment Procedure (RdSAP) (BRE 2011), as is currently used for Energy Performance Certificates for the domestic market in the UK. This model will assess the current energy use and carbon emissions. It will also identify potential technologies that can be used to upgrade the home to improve the energy performance. It will select them based on the characteristics of the property using parameters outlined in Appendix T. Eligible products that may be used as part of a Green Deal package are contained in the SAP Appendix Q. The model will then calculate the potential costs against the potential energy savings to ensure that the Golden Rule is met and occupants are not left worse off. When these conditions are met, the occupant agrees to the upgrade and the repayment plan and the installation can proceed. The repayments are made through the electricity bill collected by the energy supplier and redistributed to the Green Deal Provider.

Each of these stages identifies issues that were investigated as part of the FutureFit project. Here we will deal with four key issues that are embedded within this process; resident engagement, assessment of properties, installation of measures and financial modelling. By attempting to replicate elements of a potential Green Deal process at a larger scale Affinity Sutton attempted to identify what the implications of the Green Deal would be for both themselves and the UK as a whole.

## FutureFit approach

While the aims of the project were concerned with building an evidence base and testing this against the Green Deal approach, there were a number of other factors that were considered in order to ensure that FutureFit addressed the questions as widely as possible. The research approach highlighted the following issues:

- The project should engage existing partners and staff, rather than bring in new skill sets.
- The sustainable retrofits would be economically driven rather than through 80% carbon savings as has been undertaken in a number of other retrofit projects. It was important that budgets reflected the potential reality of Green Deal retrofit.
- The sample of homes selected should reflect Affinity Sutton's stock, as well as the stock of the UK as a whole.
- A variety of locations should be selected across the regions.

To achieve these aims, Affinity Sutton retrofitted 102 homes around the country, 97 of which were occupied; 22 archetypes were selected based on basic property information such as built form (a flat or a house), wall construction and age. These were found to represent approximately 56% of Affinity Sutton's 'general needs' stock, i.e. not sheltered or specialist accommodation, and when broadly compared with the English Housing Survey (CLG 2011) was representative of 75% of the English housing stock. Once the archetypes were deemed representative, groups of archetypal properties were selected from around the country so that as wide a geographical spread as possible could be achieved.

The three different packages of sustainable retrofit works had budgets of £6,500 (low), £10,000 (medium) and £25,000 (high) and were applied across the archetypes. These figures were initially led by political thinking of the time – the low representing the then Conservative Green Deal, the medium the Labour Pay As You Save model and the high representing the more realistic figure suggested by the industry.

## Monitoring and evaluation

There were two main elements to the evaluation phases. The first was the evaluation of the process and the stakeholders within it and the second was the monitoring of the performance of the properties. Figure 10.2 highlights the different data collection methods, identifying what data was captured and by whom.

The data collected falls into a number of categories that have been used to assess the FutureFit Project:

- *Survey data*. These data were used to build on the initial archetyping work to provide a more detailed view of the individual properties. This included detailed observation of the building characteristics, as well as performance evaluation to assess issues such as airtightness.
- *Cost data*. The total cost of both the pre-works engagement, including surveys and tests, and the retrofit installation itself were monitored to establish a robust cost model.
- *Resident experience data*. Residents were asked to participate in surveys as well as keeping observational diaries of the retrofit experience. In addition, the Resident Liaison Officers also recorded any information communicated by residents during the life of the project.
- *Project delivery data*. Site managers, project teams and surveyors were asked to keep logs of issues. These recorded any issues, either technical or non-technical, that impacted on project delivery.

In addition to this, the properties were also monitored. The sample included 102 retrofit properties as well as an additional group of 50. These households were then placed into one of three different categories based on the interventions undertaken with the occupant: physical retrofit upgrades and energy advice, physical retrofit upgrades and no energy advice and energy advice only. The energy

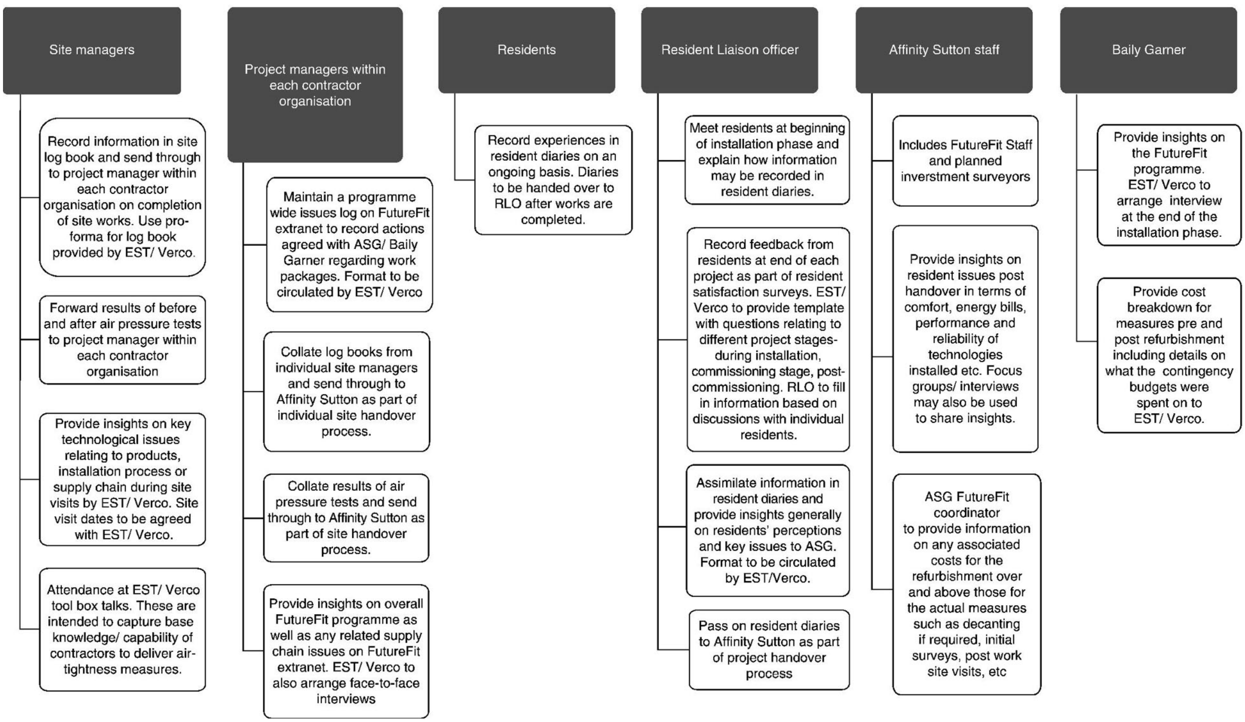


**Figure 10.2** Data collection methodology.

use of these groups, with the exception of the control, was monitored both prior and after the delivery of the different interventions. This was evaluated in terms of both energy cost savings and the reduction of carbon emissions. Additional studies were undertaken alongside these activities and are covered in the FutureFit Reports (Affinity Sutton 2011a, 2011b, 2012).

## Residents' adoption and in-use issues

In the FutureFit project energy improvement works were offered free of charge and from a trusted party. It should be noted that this does not reflect a real Green Deal engagement, which will be a commercial arrangement. Despite the offer of free works, resident take-up was low and access to the properties was also an issue. A basic invitation to take part in a free eco-project sent to more than 800 residents resulted in only a 4.8% response rate. Out of 294 phone calls made offering free energy upgrade works, 52% said no, 45% said yes and 3% said maybe. There were a number of wasted visits from contractors and two properties pulled out during the works phase. Among those residents who initially agreed to the works, 23% withdrew their permission, either leading up to or during the works period. They stated that the works were 'too inconvenient' or 'too disruptive'. Others said that they were moving house or blamed health or family issues.

From survey to completion, the number of visits per property ranged from 6 to 20. Many residents were keen to participate in FutureFit in order to save money on their energy bills. As a cautious approach had been taken about guaranteeing savings on energy bills, it was more difficult to get people engaged in the process early on. According to the Resident Liaison Officers (RLOs), contractor staff who deal with residents directly during the construction phase, once residents were engaged and taking part in the project, the incentive of a warmer home became more important to them than saving money. FutureFit found that the role of the RLO was key in explaining the project and its implications. They needed to be on hand during the works to resolve any issues and maintain resident engagement in the scheme. As a result, a requirement for training concerning the retrofit works and the implications for residents was identified as essential for resident-facing staff. This level of engagement has a cost attached. Figures estimate that the cost of engagement for FutureFit, including phone calls, letters, emails and visits, to be between £450 and £1,350 per property.

The majority of residents whose homes were retrofitted were satisfied with the level of disruption of the works. However, a quarter of residents felt that their understanding of how to operate the systems installed in both the low and medium packages was only 'basic'. Furthermore, delivery teams felt that resident engagement needed to go beyond getting a 'yes' to the works; residents needed to fully understand the installation process and the implications of adapting packages of works.

The resident engagement activity in FutureFit highlights three key problems for the Green Deal. The first is the obvious adoption risk. Work can be disruptive and the benefits may not be immediately apparent and this can be off-putting to residents. Although the sample is based in social housing, we can see that even with the offer of free upgrades, residents were still resistant to adopting. If this is combined with a new financial mechanism that may be complex to understand, addressing adoption risk will be central to the Green Deal's success. The second is the cost of engagement; there is a significant difference between engagement costs for different households, but it indicates that they have the potential to be a not insignificant proportion of project costs. This also creates potential issues where these costs may be incurred before a Green Deal is finally agreed, particularly if it is not clear who bears the risk of these engagement costs. We saw a number of withdrawals from the project and it is likely that after initial engagement right up to the signing of contracts, occupants may pull out for any number of reasons.

## Identifying upgrades

The process for identifying potential retrofit upgrades for a property needed to be robust and this is reflected in the pre-engagement costs. The different archetypes were identified and a full Standard Assessment Procedure energy modelling exercise undertaken. A fabric first approach was taken in selecting options, with the low and medium packages being identified as needing to be deliverable without the need for the residents to move out of the property. The measures were selected with the carbon cost-effectiveness, or kilograms of carbon saved per £, of the installation in mind. Cost modelling was undertaken for each archetype for each package. Physical surveys were then undertaken of the individual properties to create a detailed SAP model for each individual property within the programme. Finally, pre-work surveys were undertaken prior to the commencement of work.

It should be noted that a great deal of improvement work has already been carried out in social housing, with programmes such as ongoing boiler replacement and cavity and loft insulation being widely applied to the social stock. Estimated figures produced for the FutureFit project suggest that, since 1990, Affinity Sutton has already achieved a 24% carbon reduction across its general needs stock. This means that creating packages that result in high SAP improvements can be challenging. Although a reasonable projected SAP point improvement could be achieved for a relatively low cost, to reach the higher SAP levels, and so achieve the 80% carbon reduction target identified by UK legislation, measures must be installed that require significantly higher funding. Overall there is a law of diminishing returns with SAP – the bigger the SAP score improvement, the more it costs.

FutureFit found that there is a mismatch between two key parts of the retrofit process – the SAP assessment and the property survey. Although FutureFit adapted SAP assessment tools to suit traditional surveying practice, there was still a lack of consistency in the information gathered. The language within SAP differs from common surveying terminology; for example, SAP says 'heat loss wall' where surveying says 'external wall'. Equally, practical implications associated with specific retrofit upgrades are not always appreciated by the SAP assessor, with assessors identifying works that are unviable in reality. The specification of less than 1 kW p systems of photovoltaics was one example of this. Although they work in SAP models and new-build properties, they are not viable to fit in existing properties. FutureFit found that the current SAP model was not adequate to accurately assess homes for energy improvements. The new SAP model needs to consider all measures that could have an effect on energy in the home, such as radiator reflectors and occupation patterns, although this issue is currently being reviewed. Findings also suggest that every home is different, inside and out. To make the works practical FutureFit eventually had to produce 102 individual packages. The airtightness findings support this. There was significant variation in airtightness within archetypes with no clear trends emerging, even before the works. This highlights the potential uniqueness of each property. Given the scale of the retrofit challenge and the availability of building surveying, the energy expertise will be stretched very thinly. It is important that the tools we are using are robust and lead to the correct solutions for individual properties rather than relying too heavily on archetypes. These results also provided supporting evidence for the level of carbon saving works already carried out in social housing. On average, nearly half the archetypes were already better than the target airtightness before any works had been carried out. This suggests that few low-cost, high-value savings would be available in these properties.

## Installation

A significant proportion of the specified works were not installed. This was due in part to target packages not being reflective of individual properties or inaccurate stock database information. However, many uncompleted works were down to issues with residents or practical concerns. Some supposedly straightforward measures, like zoned heating and heat recovery room vents, were challenging to fit and often unpopular with residents who found installation too disruptive and the operation of the systems too complex. Several quick win measures were also refused by many of the residents. For example, residents did not want open fireplaces blocked up or their gas fires replaced. Both of these issues could potentially be overcome if residents were more engaged in the agenda and the supply chain trained to achieve this level of engagement. In several instances, contractors had to return to properties to remove works – including zoned heating and low-flow water attachments – because residents were not happy with their performance. For these works to have their desired impact and to ensure a smooth process, FutureFit findings suggest that the entire delivery team – including contractors, surveyors and RLOs – need training. This will make sure that the same message and levels of understanding are passed on to residents.

Practical issues were also a problem. FutureFit found that cavity wall insulation could not be fitted to individual flats within blocks, implying that an area-based approach needs to be taken when fitting cavity wall insulation to non-detached properties. Insulation as a whole posed challenges. Existing cavity insulation was often degraded, new internal insulation proved disruptive to fit and planning permission was refused to fit external render, despite the properties being outside a conservation area and other properties in the area having already been rendered to a similar specification. Medium packages could not be installed to four archetypes due to issues with residents or installation, or the high cost of further SAP improvements.

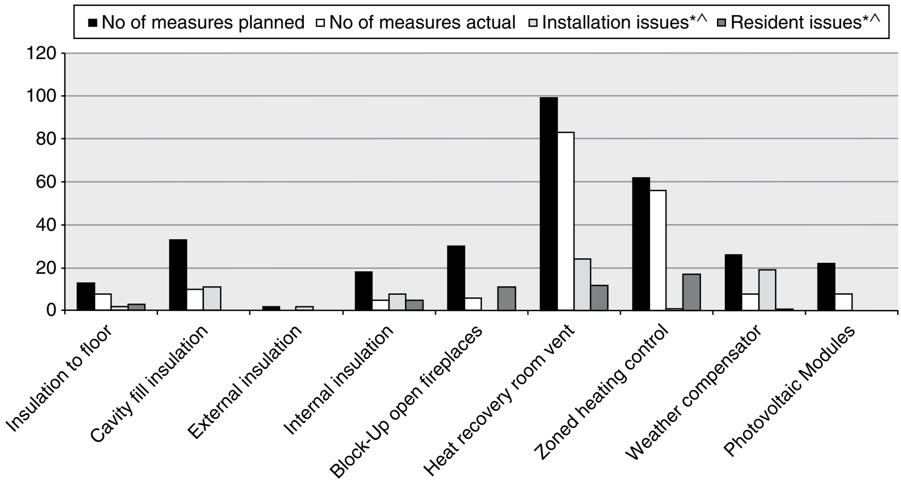


**Figure 10.3** Installation of measures.

Data collected from the installation teams using the FutureFit queries log tracked 166 issues (Figure 10.3), nearly half of which were technical, indicating a potential knowledge gap. The project found that although the supply chain is very keen to take up this agenda it will require training, commitment and volume if it is to be able to meet the Green Deal challenge. Decent Homes has been at the top of the agenda for the social housing sector in recent years with the standards due to be met in 2010 (DETR 2000). This means that energy efficiency in the home has not always been a priority. If the retrofit agenda is to proceed at scale, FutureFit suggests that training and awareness initiatives will be needed, along with a certified and consistent set of tools. Furthermore, close contact and regular communication will be necessary to keep all stakeholders engaged.

## Energy performance and financial modelling

The financial model has been built around the 'Golden Rule' – one of the core principles within the Green Deal. This requires that the Green Deal annual payment should not exceed the projected associated cost savings from energy efficiency measures for the duration of the Green Deal Finance arrangement. Working within this 'Golden Rule', the model assesses the financial value of the low, medium and high intervention scenarios. Discounted cash flow analysis was carried out taking into account the capital cost for work packages, maintenance costs for measures and the value of the energy savings over a 20-year period to generate the net present value (NPV) of the investment. As some packages included photovoltaic panels, the Feed-in Tariff as at October 2011 was included in value calculations. Energy use was calculated using SAP 2005, as real energy use has yet to be established. To provide a more accurate picture, the analysis uses

**Table 10.1** Net present value of energy savings and funding gap.

| | NPC of retrofit including O&M (£m) | Value of energy savings (£m) | Funding gap | $CO_2$ reduction | Average NPC per dwelling (£k) |
|---|---|---|---|---|---|
| Low | 283 | 156 | £130 | 18% | 2.9 |
| Medium | 439 | 218 | £224 | 23% | 5.0 |
| Hign | 959 | 478 | £487 | 34% | 10.8 |

actual capital costs from the refurbishment of FutureFit homes. These reflect the total costs of installing the work packages, including any associated or hidden costs, but excluding any engagement costs. The NPV model included a number of assumptions with regards to the life cycle cost of the retrofit packages, value share of the Green Deal and energy inflation.

Detailed monitoring of both the costs of installation and the projected energy savings have identified significant gaps between the potential value of energy savings and the cost of actually installing retrofit works, which would not be covered by any Green Deal funding mechanism. This funding gap, which is equivalent to £2,900–£10,000 per property (Table 10.1), does not include the engagement costs identified by FutureFit which, as previously mentioned, could be as much as £1,350 per property.

There are a number of ways this gap could be closed. Energy Company Obligation funding on a per property basis, along with packages designed purely to meet the Golden Rule, could start to close the gap. A major step could be to achieve economies through volume. FutureFit has shown that the specific nature of energy saving works can make this challenging, but it is the suggested consumer-led element of the Green Deal that makes it unviable. Achieving volume would require integration with existing major works programmes and a shift away from the suggested consumer-led approach. Yet even if the funding gap is resolved, projections show that the low package of works only results in an 18% reduction in carbon dioxide emissions. If the Golden Rule has to be adhered to, less $CO_2$ might be saved, since costs rather than carbon savings will dictate the packages. Although the medium and high packages achieve marginally better carbon reductions, the funding gap for them increases dramatically (Table 10.1). Taking into account the carbon savings already made in social housing, if Greening the Grid were to achieve a 20% reduction by 2050, and if the low package of works that has been adapted to meet the Golden Rule is applied across Affinity Sutton's stock, this still leaves a substantial black hole of funding if we are to reach the 80% target. Despite the bleak outlook, there are property types that do present a more positive outlook and two archetypes did break even (4 and 7), both 1930s end of terrace houses. These could be targeted first. Also these findings could help start the process of wide-scale retrofit by identifying where works packages could be refined to increase energy savings.

## Conclusions

FutureFit does raise a number of questions concerning the viability of the Green Deal. However, it does provide some evidence that there are opportunities to improve the general approach and move some way towards closing the funding gap. Process issues, such as using 'trigger points' by linking work with other disruptive works, such as repairs and maintenance or kitchen and bathroom upgrades, provides a chance to get past the disruption issue with residents as well as using resources more effectively. Improved knowledge around upgrade packages will provide opportunities for optimisation of technical approaches, with learning being cascaded through the supply chains. Work with supply chains could potentially look to ways to reduce costs through the better management of the identified risks, both in terms of resident and technical factors. There should also be a consideration of the financing models that are being used to upgrade stock. A full understanding of the costs of capital from different sources and business models must be established.

Affinity Sutton's FutureFit project has provided the social housing sector with a much-needed insight into how wide-scale retrofit, and the Green Deal in particular, might work in practice. The results begin to show not only what retrofit really means for all involved but also what can realistically be achieved. When FutureFit started, it was uncertain how the UK would discharge its legal commitment to reduce carbon emissions by 80% by 2050. While a great deal of that uncertainty still exists, the introduction of the Green Deal gives an idea of how this commitment will be delivered, at least partially, within the housing sector. The Green Deal was designed primarily as a funding vehicle for the owner-occupied sector and this report shows that, whilst welcomed, it does need amending for the social housing sector. FutureFit has identified a significant funding gap, which can only be fully resolved if Registered Providers work closely with the government to deliver a strategic approach to improving the energy efficiency and carbon performance of social housing. If this is limited to designing packages purely to meet the Golden Rule, which requires savings to be greater than the additional repayments, the amount of carbon that can be saved will be significantly reduced.

FutureFit has also shown that a lot more work still needs to be done to convince people of the value of carbon reduction in the home. Many residents are simply not interested in the retrofit agenda or having works undertaken to their homes – even when they are free. If the Green Deal is to work, the government will need to invest in promoting and marketing its benefits. What is needed is a strategic approach that promotes warmer homes at a lower cost. Energy efficient retrofit must be part of the integrated asset management programmes that Registered Providers are committed to. It then has the potential to reduce fuel poverty, improve the quality of people's lives, add real benefit to the local economy, create new jobs and training opportunities, and make significant inroads into meeting the carbon reduction challenge. Vital though the Green Deal is, it is not enough on its own. It is even more important that Energy Company Obligations, Feed-in Tariffs, the Renewable Heat Incentive and any other mechanisms are all part of a fully strategic approach to delivering energy efficiency in our homes. FutureFit is an important contribution to the understanding of the issues and challenges faced by the social housing sector. These are challenges that must be met if the twin objectives of reducing carbon and improving people's lives are to be delivered.

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# 11 Energy monitoring in retrofit projects: Strategies, tools and practices

*Richard Fitton*

## Introduction

The effective assessment of a property to understand its energy efficiency can initially appear to be a relatively simple task. However, when we investigate the field in more detail we recognise that there are a wide number of metrics that we can collect and a complex raft of reasons behind the numbers. Energy use within a property is driven by three main factors: the fabric, the systems and appliances that use energy within the building and the energy consumption choices made by the occupants. While the role of people is important, here we will put more focus on the issues surrounding the physical aspects of energy use. Using evidence to determine a retrofit strategy seems an obvious approach to adopt, but many of the decisions that are made in both new build and retrofit projects are based on energy modelling approaches, commonly the Standard Assessment Procedure (SAP) and the Reduced Data Standard Assessment Procedure (RdSAP), which are the current UK industry standards for assessment of domestic properties. While models are essential to an effective decision-making process, the potential weaknesses of an over-reliance on them are clear. Evidence on the actual against stated performance on a number of technologies has shown the gap between the two (Wetherall and Hawkes 2011). For example, the underperformance of urban microwind, as discussed in the Warwick wind trials (Encraft, 2009), shows that a lack of performance data on a specific retrofit technology can lead to investment in a technology that is not justified by its performance.

Energy monitoring can be summed up as the regular collection and analysis of data concerning energy use, as well as the various contributory factors that influence energy consumption, such as temperature or building fabric performance. Westergren (1999) defines an energy monitoring process as one that 'measures energy use in relation to internal and external climate in different types of single-family houses during periods with and without heating. It is also expected to provide a basis for analysis and evaluation of energy efficiency measures.' This could be viewed as a fabric-oriented

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perspective and this perspective does cover a large proportion of energy use. However, we should also recognise that unregulated energy use, such as appliances, is also part of the monitoring process, although this is often managed through behavioural change programmes with occupants rather than physical changes to properties fabric and systems.

Retrofit is still an emerging skill set; while many of the approaches and products are well known, the knowledge base to select the right options and deliver them is still emerging. Understanding the pre- and post-retrofit performance of a property gives us some indication of the potential improvement the retrofit measures have brought about. However, as we have stated previously, energy use is an interaction between the building fabric, the systems and appliances and the individuals who use the building (Guerra Santin *et al.* 2009). It is important to understand what factors are encompassed in any particular dataset. If we measure general energy use through bills or dataloggers, we are not only looking at the efficiency of fabric and systems but also behaviour; if we undertake a pressure test, we are solely considering the integrity of the building fabric. Although we do not consider human behaviour in detail in this section, it is essential to recognise where human factors are affecting outcomes. The mantra 'buildings don't use energy people do' (Janda 2011), which has become commonplace in the retrofit community, does have some truth, but the building and systems provide the vehicle for a households energy use. Poorly performing systems and fabric will undermine good behaviours.

In this chapter we consider two key elements of monitoring. First, we consider the types of issues we need to consider in the development of a monitoring strategy, such as identifying objectives. In the second part we look at the main tests and tools available to use when we are measuring the energy efficiency of buildings.

## Energy monitoring strategies

What do we want to know?

As with any research question, framing what we want to know will to a large degree drive what strategies and practices that we ultimately adopt. If we wish to look at the performance of a specific element of a property, such as a wall, our approach will be different as compared to a whole house test with occupants. There are a number of standards that are available in the development of a monitoring strategy. In terms of assessing retrofit, which we will consider here, the UK's Technology Strategy Board, a research funding body, has developed a set of guidelines (TSB 2012). These were specifically developed to address some of problems of predicted against actual performance of the energy use of buildings. The Energy Saving Trust, a UK energy advisory service, has also developed a range of standards for energy monitoring (Energy Saving Trust 2008), which identifies factors such as equipment used, accuracy and calibration, and frequency of readings. Both of these sets of documents are essential reading for any professional monitoring team.

Households use energy in a number of different ways. A commonly used concept here is to consider regulated and unregulated energy (Gill, 2011). Regulated energy is that covered by the building regulations covered by heating, hot water, lighting and any powered ventilation. Unregulated energy covers everything else, such as appliances and energy used for cooking. However, both of these categories of energy use can be strongly driven by human factors, giving widely different energy usage for the same property (Summerfield *et al.* 2010). A more useful approach might be to think of the research problem in a systemic way, drawing the boundary from sub-elements, as might be tested using building fabric tests, to the wider fabric, which may be tested using approaches such as co-heating or pressure tests. Systems such as heating and lighting may then be considered, with testing in situ for efficiency. Human behaviour may then be considered, if the whole household's performance forms part of the research question. Obviously, this can be expanded to consider communities or neighbourhoods, particularly in the context of communal energy systems. The effective drawing of boundaries based on the research question is an essential part of understanding what techniques can effectively be deployed (Von Bulow, 1989).

## When should we measure?

Once we have established the boundary of the research question, we also need to consider when we need to measure. If data are gathered at both the pre- and post-retrofit stages, then an accurate conclusion can be reached as to the effectiveness of the installation and provide robust evidence as to whether the project actually produced a building that is more energy efficient with reduced carbon emissions. Importantly, it can also help address what elements of the refurbishment did or did not work.

For a successful project it is essential that the data captured covers all of the events outlined in Figure 11.1. Where properties have been void, this may not be possible, but this approach outlines the key stages for occupied properties.

The *pre-start occupied* phase is useful to give a baseline. This initial data may challenge existing assumptions about energy performance of the property. Understanding normal occupancy may require measuring through an entire heating season (Energy Saving Trust, 2008) to understand different patterns of behaviour over the year. The *installation phase*, although not important in terms of an overall monitoring strategy, raises a number of practical issues. It is important to remove any of the monitoring equipment that is likely to be damaged by dust, such as temperature sensors and other sensitive equipment. However, equipment such as electricity monitoring equipment, if in a protected location, may be left in place. The *post-construction unoccupied* phase presents opportunities to consider tests that the occupant may find intrusive, such as airtightness testing or thermography. Some may consider these kinds of tests outside the field of monitoring, but where these are carried out as a comparative study of pre/post-retrofit measures then they might be considered to fall within the scope of monitoring, albeit with a different approach to traditional monitoring. As with all

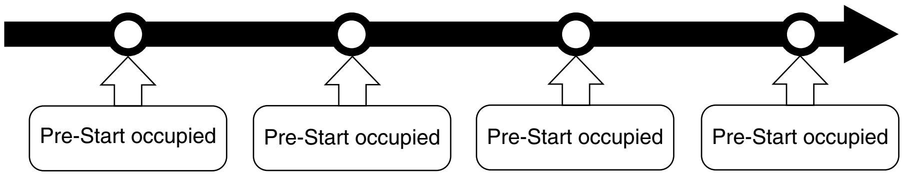


**Figure 11.1** Potential monitoring stages for retrofit.

monitoring, it should be carried out so that the two phases of data capture are carried out under similar conditions. For example, IR thermographs should be taken in similar weather conditions and of the same detail/façade locations. This will allow a true comparison to be carried out. Many of these tests are all made practically impossible to carry out when the building is occupied, as certain conditions internally and externally need to be met accurately with no disturbance. The *long-term occupied* stage is where many of the practical studies of retrofit have commenced, comparing the as-modelled data with the data collected in this stage (Gentoo Group 2010). This is not really a true comparison where we are assessing the impact of any retrofit interventions; rather it is an exercise in comparing the model with the real world data.

## What data and analysis strategy do we need?

Once we have established the scope of the monitoring and the timings of the study, we need to consider the data that we might require to help us understand our research question. The wider the scope of the monitoring, the more important it is to have data on potential influencing factors. If we are considering long-term energy use by a household, understanding the weather data, such as degree day data (Energy Saving Trust, 2008) is essential. Understanding the composition of a household in terms of demographics and lifestyle is also important (Gill, 2011), particularly when considering a cross-household comparison. Evaluating the performance of a physical retrofit needs to be understood in its wider context when considering in-use monitoring. An additional consideration is to identify, not only what monitoring and supporting data are required but also how much data we actually need. Given the sophistication of digital data collection and storage, it can be tempting to collect vast quantities of data. However, if we have many data points, unless we have the resources and the tools to analyse these data, we are creating difficulty for ourselves. Huge quantities of data, while potentially valuable, may be difficult to manage within the context of a desktop spreadsheet and a limited array of statistical tools. Larger datasets may require approaches such as data mining (Figueiredo, 2005) to effectively extract meaning from them. It is important to be clear what the analytical strategy might be and effectively plan and resource it.

Effective scoping and management of the monitoring process is essential prior to the deployment of resources. Monitoring can be time consuming and expensive. It is essential that the identified monitoring strategy can be delivered using the available resources. It is also important that resources are spent not only on monitoring techniques and data collection but that the analysis and reporting phases are also considered. In the next section we will look at some of the main ways of monitoring properties and consider some of the main issues in their use.

## Energy monitoring tools

### Energy bills, utility monitoring and smart meters

All occupants are entitled to accurate billing data (HM Government 1996) and this provides the most accurate measure of actual energy use. It may also be possible to chart use through the year, to assess seasonal variation, although this requires accurate and regular meter readings to be taken, rather than estimated data. A new requirement is the Annual Energy Statement, introduced in 2010. This provides information on both the energy used and the price paid over the year, although awareness has been poor (Cooper 2011).

There is a difference between billing/meter-read information and utility monitoring. Monitoring equipment will read live data from the gas meter or, for electricity; it will measure the actual power being consumed at a given interval. Most monitoring devices allow for these intervals to be very short (seconds and minutes rather than the days and months, given on meter readings and bills). This allows a profile to be built up, whether in a tabular or a graphical format. This type of high-frequency data allows the analysis of data to take place, and makes spotting trends in consumption patterns easy. This type of representation of data can also help in the diagnosis of faulty monitoring equipment using error-trapping techniques. Monitoring meters directly can be a complex problem; there is a wide variety of metering technology in use due to technological changes over the decades. This means that we must be prepared to monitor many different types of meter.

The current UK Government is committed to the installation of smart meters for both gas and electricity by December 2019 (DECC, 2012). Smart metering will offer two main components: accurate billing information, provided electronically to the meter supplier, and, second, feedback in terms of high granularity data concerning consumption. Additional data, such as voltage levels and $CO_2$ emissions, can also be transmitted to the consumer using an In-Home Display. The smart meter will electronically store 13 months worth of half-hour frequency data. This will be stored on non-volatile memory, so will always be present even after power cuts. The technical standards for smart metering are still being finalised at the time of writing (DECC, 2012), so these details may well change. However, it is important to note that when commencing retrofit works on a domestic property after 2014, when the large-scale rollout is due to take place, a check should be made for a smart meter on either one of the applicable utilities. If one is present then, providing the occupier agrees, there may be 13 months of high granularity data available to use. Additionally, if monitored correctly using a 'home area network' facility, the smart meter can be used to provide very accurate consumption figures (<1% tolerance) with a high frequency of reads.

This makes the data more accurate than that which can be gathered using the current transformer (CT) clamp method. Given the accuracy of a smart meter and the frequency of reads taken, they are certain to meet the requirements laid down in the TSB standards for accuracy and frequency (DECC, 2012).

### Gas

The most challenging utility to monitor, due to the differing number of meter types, is natural gas. When using retrofitted equipment, which will give the profile of gas use rather than just reading the meter at set periods, there are three main issues to be considered: *safety, permission and communication*.

The gas meter and the surrounding area is a hazardous area in terms of risk of explosion. It is for this reason that any devices adjacent to or fixed to a gas meter have to meet certain standards. These are commonly known as the Atex standards (EU, 2012). Due to this hazard, only metering products that meet this definition can be used in this zone. It is important to note that, although a standard domestic gas meter may be on the tenant's property, it very rarely owned by the occupant. In most cases the gas transporter, such as the National Grid in the UK, will own the meter. Many meters exist that have sockets (RJ-45 type) on the meter, which may or may not have a tamperproof sticker. It is generally considered that these sockets are not used to monitor the meters. It is far better and safer to use a proprietary solution.

There are several devices on the market available in the UK. To call these devices 'meter readers' is inaccurate, although this is the common parlance. These devices measure the red dials on the gas meter turning around. As these dials (or red needle) make a complete pass round, the readers recognise this using one of two ways: an optical sensor that can 'see' the needle turning round or measurement of the magnetic field generated by the rotating dials. Dependent on the configuration of the gas meter (older ones may measure in $ft^3$, whilst most modern ones will measure in $m^3$), the units will be in a volumetric rate of how much gas is being consumed. This will generally not be in kWh. To convert the cubic measurements to kWh consumption requires several inputs into a formula, including the calorific value and any correction factors attributed to the supply (HM Government, 1996). It is important to note that, when comparing gas consumption taken from logging equipment, as against billing information, that the volumetric component of the bill is compared and not the kWh figure as this can vary, due to the conversion processes that take into account factors such as the calorific value of gas.

### Electricity

Compared with the other utilities, electricity is the easiest to measure. Correspondingly most of the studies carried out on energy consumption within properties are on electricity consumption. The equipment needed to monitor electricity is widely available and inexpensive. It does have some safety implications, but they are not as onerous as those for gas monitoring. It is advised that the installation instructions are rigidly adhered to, as different manufacturers recommend differing methods dependent on its product. The simplest type of electricity meter uses current transformer technology to measure consumption. This measures the current flowing through the live cable between the main incoming meter and the consumer unit. As with all technologies, these devices should be fitted in line with the manufacturer's instructions, as discrepancies in the installation can lead to variances in the readings. For example, a CT clamp that is not perpendicular with the mains cable may give inaccurate readings due to the internal sensing method of the clamp.

It is often useful to have energy consumption data broken down into relevant circuits. This aids in visualising the consumption across the house and also in diagnosing issues concerning high consumption, such as poorly performing ventilation systems. Clearly this information will not be available prior to any retrofit project. However, as some of these works are slightly invasive, they should certainly be considered during a retrofit project, as the data that they provide can be very useful in terms of deeming whether the project is a success.

Many devices are available that can log the amount of power consumed by an individual appliance. It is also possible to monitor multiple devices that send data back to a central data-gathering source. These devices are relatively inexpensive, easy to fit and are particularly helpful, as many of the modelling packages that are used to predict energy saving omit appliance consumption. These data can be used to supplement modelling data in order to to understand energy consumption more fully.

## Environmental measures

Data collected from environmental monitors provide a context for the energy performance of a building.

### Internal climate

Much has been written on the subject of the 'take-back effect' or 'rebound effect' (Hong, 2006). This is where a household that has energy efficiency improvements increases their energy use to make their homes more comfortable. This phenomenon is often found where people may have been underheating their homes. In retrofitted properties less energy is needed to heat the home, making certain levels of comfort cheaper; the savings are reclaimed as heat rather than money. In a study carried out across 274 pre-intervention and 633 post-intervention dwellings (Oreszeczyn, 2006), it was found that, following either a heating system or insulation improvement, temperatures would rise by 1.6 degrees Celsius in the living room and would rise by 2.8 degrees Celsius in the bedrooms. A further study (Hong, 2006) found that on average between 65 and 100% of the savings offered by the measures installed were 'taken back' by the occupants by raising the internal temperatures of the living room and bedrooms. If we are to take account of this rebound effect, it is important that internal temperature is logged before and after the retrofit. This will indicate any changes in lifestyle that exist after the works have been completed. Coupled with the occupancy data, the results can be very useful in indicating any changes in lifestyle.

There are many ways of logging temperature in properties. The simplest solution is a stand-alone system that is battery powered. These are relatively hardy units and will be suitable for most occupied properties. A more complicated solution would be to use a multinode wireless system. This system will send all the data back to a central station. Some units will send data back to the practitioner over the mobile phone network for immediate analysis.

The issue of internal temperature monitoring is currently an area of research at the University of Salford. A current study noted that for a typical living room with a central heating radiator, the maximum variation in temperature when the room had stopped demanding heat from a thermostat was 10.5 degrees Celsius. This was the difference in temperature gradient between the skirting board height and ceiling height. This stresses how important it is to note where the sensors are mounted. Some issues to consider are:

- To measure temperature in a room relative to any correlation between the thermostat, it is essential to place a sensor directly adjacent to it. Failure to do so will give readings that do not relate to the thermostat itself.
- Sensors should always be placed out of direct sunlight; this avoid erroneous readings.
- Where possible the sensor should be placed in an airflow representative of the whole room, not above a radiator or a cold draught next to a door for instance.
- It is recommended to keep sensors away from cold surfaces, such as external walls, particularly if not insulated. The only exception to this, of course, is if you are trying to gauge the wall temperature rather than the surface temperature.
- The sensors should be kept away from all heat sources such as lamps or power transformers.

Another important factor of the internal environment to consider is humidity. Humidity itself arguably does not have a direct effect on the fuel consumption of a domestic property. However, the perception of poor air quality and 'mugginess' can lead people to allow for more ventilation in a property (Fang 2004). This can lead to unwanted and uncontrolled ventilation even when the heating is switched on. Changes in humidity levels in a building can also be an indicating factor of occupancy. Behaviour that can cause damage to the building fabric, such as drying washing on radiators in unventilated rooms, can also be detected if the sensors are well placed and of high enough sensitivity. As with the measurement of temperature, sensor placement is important. Humidity sensing equipment should also be located with care away from all sources of moisture, such as sinks, showers and tumble dryers.

### External climate

A significant factor in the running cost of any building is the external weather conditions. It is also one of the most variable factors in the UK, as we have extremely wide-ranging weather conditions. This requires the external weather temperature data to be normalised so that similar periods can be compared like for like. This allows for pre- and post-scenarios to be compared. The Carbon Trust provides an excellent 'practical guide' to degree-day usage (Carbon Trust, 2010).

Collecting local climate information generally requires a waterproof sensor arrangement mounted on a north facing preferably sheltered wall. Care should be taken to ensure that the sighting is representative of the locale. It should not be located in areas of direct sunlight, unless this can be accounted for as part of the data analysis. A tool such as a portable weather station will generally suffice but for longer-term logging a weather station can be mounted on the external wall of the building.

### Detection of movement

Occupants play a major role in energy use. Therefore, in terms of energy monitoring, to find out when a building or room is occupied is extremely helpful. A common way of doing this is to use passive infrared (PIR) detectors. Data can then be cross-referenced against energy use to identify possible energy wastage in a building. It is worth noting that PIR only detects movement of infrared emitting objects breaking its beam. As such it would not pick up sedentary people, but can also detect things such as pets or coal fires. These limitations require that the sensors are closely positioned and data well analysed. Using occupancy data will enable the practitioner to compare the occupancy of the building before and after the retrofit. A reasonable assumption would be that if a room/building is being used more, more energy is likely to be used.

## Fabric investigation

Many buildings in the UK have poor fabric performance, which in turn contributes to low levels of energy efficiency. If we consider that 65.7% of the average property's energy use is heating (Parker, 2011), then the role of fabric is vitally important in reducing energy use and carbon emissions from properties.

### Air permeability testing

Currently, compulsory air tightness testing only applies to new build property and large extensions (DCLG, 2010); retrofit projects are not currently included within these regulations. However, as we have become accustomed to the 'build tight, ventilate right' philosophy, there has been a growing demand for air permeability testing. The airtightness testing process is relatively straightforward; a large-diameter fan is placed in an external doorframe of the house. The test is only aimed at identifying unintended ventilation losses, rather than managed ventilation. All ventilation systems and vents are sealed over prior to the test. This fan pressurises and then depressurises the building. The rate at which the building then leaks air during this process is given in $m^3$ of air that leaves the building over a given period, per $m^2$ of floor area.

Testing should be carried out pre/post-retrofit to allow a comparison to be carried out. Some retrofit projects have also carried out tests midway through the construction work to make sure that all ducts and air infiltration paths have been correctly sealed as the work progresses. Examples of air leakage, some typical examples of typical unintended air infiltration points, are as follows:

- Chimney stacks
- Poorly fitted loft hatches
- Cracks in the building fabric
- Gaps in floorboards and poor wall/floor junctions
- Poorly sealed service entrances through walls.

Localised testing can be carried out under pressurised conditions using a small smoke pencil. This can be used along with a smoke machine to identify air leakage paths in roof details and windows, with the draughts being drawn into the building having an effect on the smoke, which is clearly visible. Pressurised testing is also a useful addition to infrared thermography, as described below.

### Thermography

Thermography, or thermal imaging, relies on the fact that any surface that is above 273 degrees Celsius will emit radiant energy. The thermal camera will convert this radiant heat to a visual image. The use of this method has increased significantly in the last 10 years. This is mainly due to the decrease in the costs of thermal cameras. The thermal image is mapped using differing colours, each relating to a specific temperature. This identifies, with careful interpretation, the amount of heat emitted by a wall, roof or other building element. There are several benefits associated with thermography:

- Large areas can be covered in very short periods of time, using suitable wide-angle lenses.
- When carried out correctly the difference between pre/post-retrofit can be illustrated in a way that is easy for the layperson to comprehend.
- A cost-effective way of gathering surface temperature readings for large areas.
- Defects/omissions in constructions can be easily spotted and re-inspected when completed.

As stated previously, thermography can be used with air pressure testing. The pressure draws air through leakage points and shows a temperature differential, which will be clearly shown in any thermal image.

However, thermography is methodology that requires careful analysis, a genuine understanding of building physics and a careful set-up/pre-survey routine. Without all of these an accurate thermographic survey is impossible. The British Standard for

Thermography (BS EN 13187:1999) (BSI, 1999) provides a robust model to help undertake thermography. This guide dictates how the thermography should be carried out and in what format the report should be structured.

### U-value measurement and calculation

U-values, which measure the coefficient of the heat loss through a building element, such as doors, walls and windows, are now part of the design process in most retrofit specifications. However, these figures are often produced using software and may not be strictly accurate in terms of how the building actually performs and how it will perform post-retrofit. In most instances no testing will be carried out to investigate an element's U-value. This is beginning to change as in situ U-value testing becomes more popular. Several studies have been carried out recently highlighting large differences between calculated U-values and those measured in the field. A recent study (Rye, 2010) found significant differences in U-values that were calculated using a software package and those that were measured on-site using heat flux meters. This was particularly true of traditional vernacular forms of construction such as rubble-filled stone and wattle and daub walls.

The monitoring process is relatively straightforward, but the equipment required is specialist and fairly expensive. The basic methodology involves two sensors placed either side of a building element and measuring the flow of temperature between the two (Rye, 2010). However, this relatively simple idea translates into a complex and time-consuming task.

### Co-heating test

Co-heating is a comprehensive monitoring approach in terms of assigning an energy efficiency figure to a building. The co-heating method is simple: the building is heated using electric heaters to 25 degrees Celsius. This must be done for a period of 1 to 3 weeks and is best undertaken outside the winter months. A differential of 10 degrees Celsius between inside and outside should be achieved. The energy consumed by the electric heaters to keep the building in a steady state condition is the amount of energy (in watts per kelvin) required to heat the building, which includes any heat loss through fabric and background ventilation. The full methodology is published in a paper published by the Centre for the Built Environment at Leeds Metropolitan University (Centre for the Built Environment, 2010). As the paper discusses, the list of equipment needed is lengthy, and precise, and there are a number of conditions that must be met. The methodology is highly detailed and the timescale of testing is long. However, the test is seen by many in industry to be a good standard for gaining a true figure of the energy efficiency of a domestic property.

## Conclusions

There are many methods of measuring the performance of retrofit interventions. Due to this, the decisions over which type of monitoring to use and when can be a complicated one. It is a decision that must be made right at the outset of the project if the practitioner is to make full use of pre/post-data. In fact, if a full study is to be carried out then this decision may be required up to 1 year before the refurbishment takes place on site. The decision-making process will contain many strands; economy will most likely come first in many projects. The cost of the equipment and expertise must be offset against the value of the information. If the building to be assessed is a trial property that mirrors the property attributes of many other properties that are also in line to be refurbished, then the findings of these data may be used to inform the decision-making process for the remainder of the properties.

Timescale is also an important driver for monitoring projects. Monitoring takes time to set up and once the project is complete then the data processing and analysis can also take some time. It is important that the data are made available in a format that is easily understood by decision-makers, who can effectively use it to compare pre- and post-retrofit, or to compare projects. The issue of occupant disruptions is also an important factor. You may require them to provide bill data, access to their homes and ensure that they do not damage equipment. This requires a level of engagement, but also a well-designed monitoring strategy to ensure that these types of risks are minimised. It needs to be recognised that domestic monitoring activities are undertaken in people's homes.

All of these factors bring us back to the issue of a well-designed, coherent monitoring strategy. We have seen the range of available data collection approaches that might be taken. The retrofit agenda has a real requirement for robust data to inform the evidence base. Only by appropriate collection and analysis can we achieve this. Poorly installed equipment, failing to understand the measures or weak analysis do not deliver the data required to help us ensure we are adopting the correct retrofit strategies.

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# Part 4

## Peoples and communities

# 12 Engaging residents in multifamily building retrofits: Reducing energy consumption and enhancing resident satisfaction

*Patricia Gee and Lucrezia Chiappetta*

## Introduction

The meaningful engagement of people with their energy use is often seen as central to lowering expenditure on fuel within the home and reducing greenhouse gas emissions. The central challenge to accomplishing this engagement has revolved around the absence of a reliable method of engagement. As energy performance contracting to fund energy, water and structural improvements has gained a foothold in North American social housing, the potential for enlisting residents as programme partners has gained increasing attention and investment.

In 2005, Toronto Community Housing (TCH) launched the Building Energy Retrofit Programme (BERP), an ambitious investment of over $150 million in building energy and renewal retrofits for selected housing communities whose buildings represented the highest utility consumption and most urgent need for renewal measures. Two energy services companies were selected to undertake the programme, each of which would work exclusively in assigned housing communities.

It is the view of TCH that tenants bring to the table a unique perspective on their living environment. Several years prior to the announcement of the BERP, TCH had encouraged the participation of tenants in shaping housing policy and had given them a voice on allocation of agency resources through a portfolio-wide system of elected tenant representatives, tenant membership on the board and a process for allocating some funding to local priorities voted on by tenants in each development. Consistent with this philosophy, TCH required that BERP contractors accompany the installation of energy retrofits and renewal measures with a tenant energy education and engagement programme.

*Retrofitting the Built Environment*, First Edition. Edited by William Swan and Philip Brown.

Under contract to Ameresco, a leading energy service company, from 2005 through 2010 the authors designed and delivered a tenant engagement (TE) and conservation training initiative that accompanied a five-year $90 million programme of energy and renewal investments in close to 9000 occupied apartments in 21 Toronto, Canada, social housing developments. The TE initiative was funded at approximately 1% of the overall construction costs.

The authors' approach, *TeamWorks©*, was characterised by shared decision-making and a high level of interaction with tenants in each development for a minimum of 24 months (more than half of the developments received three years of engagement). TE trainers employed hands-on demonstrations of conservation practices, customised construction communications, peer-to-peer outreach and training (Energy Advisors), participation incentives and rewards, and an off-shoot youth environmental stewardship programme with employment opportunities (Green Collar Corps). It drew upon principals of social marketing, adult education and civic engagement. Post-construction surveys of tenants who participated in tenant engagement and education activities indicated that their satisfaction with the energy retrofit and renewal construction was enhanced by these services (more explanation of this can be found below).

## Engaging low-income and multifamily households in sustainable retrofit

There are several reasons why addressing the energy and water use practices of low-income persons residing in multifamily buildings merits attention. The first is society's responsibility to assure energy equity – that those most in need are able to have access to the energy and water resources required to sustain a reasonable standard of living. Other issues relate to the poor condition of much of the housing stock in which low-income households reside, resulting in high per square foot consumption, the interrupted message of the market occasioned by utility allowances embedded in unit rents, frequent lack of unit metering and split incentives between the owner and the tenant, and institutional factors that create challenges to the delivery of consumer education in this market.

### Consumption patterns

Lower income residents use 28% more energy per square foot than higher income households, primarily because they live in older, less energy efficient dwellings (Energy Programs Consortium 2008). Increases in residential energy costs have out-paced income growth in low-income households, rising 33% on average since 1998 (Williams 2008).

In Ontario, the province estimates that electricity costs alone are expected to rise 3.5% annually over the next 20 years, but 7.9% over the next five years due to infrastructure investment needs (Lapointe *et al.* 2011). In 2006, Ontario households in the lowest income quintile are more than twice as likely as the average income household to heat with electricity (27.0% compared to 12.9%) (Low-Income Energy Network 2008). While Ontario renter households accounted for only 31% of all households, they comprised 66.4% of households in core housing need (Low-Income Energy Network 2008).

Like their tenants, housing agencies also will be adversely affected by rising utility rates. Already facing escalating building maintenance costs due to aging buildings and reductions in public spending, they will shoulder the increased burden of paying common area and unit utility costs.

## Behavioural strategies to achieve efficiency outcomes

The importance of altering behaviour is becoming an increasingly more visible and compelling attribute in the understanding of the requirements to accomplish meaningful reduction of levels of greenhouse gas emissions (Stern 2007; Dietz *et al.* 2009; Enterprise Community Partners Inc. 2011). Household behaviour has been a particular focus of policymakers and researchers over the past decade, and low-income households have arguably benefited most from various demonstrations in this arena (Ternes *et al.* 1988; Carroll and Berger 2008). Studies show that up to 20% of building efficiency outcomes depend upon resident behaviour (Dietz *et al.* 2009). Improved resident consumption practices would achieve appreciable energy savings for space heating end-use (Ternes *et al.* 1988).

Properly designed and delivered tenant engagement can go a long way to ensure that tenants and building owners realize the desired benefits of energy efficiency retrofits (Ho and Hays 2010). It also offers one of the best chances for long-lasting sustainable behaviour on the part of building occupants (Carroll and Berger 2008). However, energy use in multifamily rental housing has long been identified as a particularly challenging area for residential energy conservation efforts. There can be institutional barriers to tenant participation, such as landlord–tenant mistrust, poor training and expertise of building staff and trades, and lack of monitoring, evaluation and performance feedback (Ternes *et al.* 1988; DeCicco *et al.* undated).

## Challenges to marketing sustainable practices in the multifamily housing sector

Economic interest could be a strong motivating factor for adopting efficiency behaviours. Unfortunately, the Low-Income Energy Network (LIEN 2008) estimated that less than a quarter of low-income tenants in Ontario were paying separately for utilities (i.e. hydro and heating). When tenants do not receive directly the message of the market nor benefit from reduced costs, they have less incentive to conserve energy (Dietz *et al.* 2009). Furthermore, few tenants consider the environment and climate change as motivating factors for reducing energy consumption. While the environment does have importance among tenants, it is clearly not the tenants' first priority (Toronto Environmental Alliance 2008).

In multifamily buildings – like their commercial building counterparts – the theories and practice of engagement feature interactions among multiple parties: residents and building owners, managers, contractors and maintenance staff (Payne 2006). This kind of interaction requires a more extensive set of interventions to affect successful outcomes; it also suggests a broader range of impacts beyond energy use reductions, such as recycling rates, indoor air quality, the appearance of buildings, vandalism, staff job satisfaction, even the length of resident tenure.

It is the articulation of those principles that deserve initial attention. We have learned that no single concept of behavioural intervention can deliver consistent results, as measured by energy use reductions (Stern 2007). We have seen increasing evidence that in the short term feedback between occupants and trusted sources can yield use reductions of 5–20% (Parker *et al.* 2006; Sintov *et al.* 2010; Hallet and Kavazovic undated). Some of this suggests that combining competition with feedback offers a powerful combination of motivating factors. In addition, the use of trusted information channels and the delivery of relevant information, face to face, by respected 'experts' and/or peers have been seen to increase the effectiveness of outreach efforts (McKenzie-Mohr and Smith 1999). Gaining public commitments from target audiences for specific, measurable actions is another factor (McKenzie-Mohr 2011). So too prompts to action (e.g. buttons, coloured lids on recycling cans, signs), reinforcing social norms (i.e. reminding people what others do), incentives (e.g. cash, parties, recognition), strong messaging and reinforcing convenience (e.g. installing fluorescent bulbs rather than just giving them away) render behavioural successes (McKenzie-Mohr 2011).

Information on the construction process and the benefits of energy measures, as well as instruction on how to use new measures, are all critical. Residents are not typically consulted before energy efficiency measures are installed in their units; even though tenant buy-in will depend on how involved residents feel they have been in the decision-making (Chahal *et al.* 2012). Residents are often concerned that they will not know how to use energy saving equipment or that the retrofit technology will not work and dread the disruption caused by the installation of the measures (Chahal *et al.* 2012). As will be discussed shortly, when tenants were kept advised about the construction process throughout the BERP, and consulted for their opinions, they expressed stronger support for the project.

How behaviour change on a broad scale can be achieved has been a major problem in this area. Through extensive engagement and targeted information households can be supported to lower their energy consumption. Unfortunately, this is often impractical at any kind of scale. One approach, however, utilising community-based social marketing strategies has been shown to be both effective and practical, particularly when tenants see peers engaged, when incentives are offered and when marketing messages are tailored based upon tenant values and interests (McKenzie-Mohr 2011).

While the field of energy efficiency still lacks longer-term, multiyear evaluations of behavioural impact from interventions with building occupants, we are developing a preliminary framework of principles that collectively deliver effective engagement. A programme that spans many months, arranges for repeated interactions between trainers and tenants, employs multiple behavioural strategies and actions and is carried out by trusted agents should maximise the opportunities for short-term and more enduring impacts. The case study that follows illustrates many of these principles within the context of a behavioural approach employed in a multifamily social housing setting. While this chapter does not endeavour to document all these impacts it should be noted that the actions undertaken, and the principles of behaviour change employed, do have broader implications for applications of behaviour change to buildings and communities.

## The case study context: Toronto Community Housing

Toronto Community Housing (TCH), Canada's largest provider of social housing, owns 58 000 rental units housing 164 000 low- to moderate-income tenants in a mixture of high-, medium- and low-rise apartment buildings, and single-room occupancy group homes across Toronto. The stock includes subsidized rent-geared-to-income and market rate units. It is estimated that 90 languages are spoken among TCH's incredibly diverse residents. In addition to providing affordable housing, the TCH mission is 'to connect tenants to services and opportunities, and work together with tenants to build healthy communities' (Toronto Community Housing website, Mission Statement). Reflecting the city's residential stock in general, the TCH portfolio contains a preponderance of high-rise residences, approximately 350 concrete buildings aged 30–40 years old, which tend to be poorly insulated, in need of structural repair and require envelope, water heating, space heating and ventilation system upgrades. TCH estimates that it carries a backlog of $650 million in needed improvements, despite having invested more than $550 million in repairs between 2002 and 2007 (Toronto Community Housing website 2011).

In 2009 TCH reported that energy, water and waste management represent approximately 23% of their monthly operational outlay or $119 million (Toronto Community Housing website 2011). The majority of tenants do not pay directly for energy use, nor receive feedback on per unit consumption. Consistent with low-income tenants in privately-owned rental property, TCH notes that only about 25% of their residents pay any portion of their own energy costs directly.

Ameresco was awarded a contract to conduct the BERP programme in 19 TCH developments comprising 30 mid- to high-rise buildings and numerous low-rise structures with approximately 9000 units (including a 2008 expansion of the programme). The investment for energy retrofits, renewal investments and tenant engagement totalled approximately $90 million over the five-year period. The authors, via GreenRoots Strategies, were engaged by Ameresco to design and deliver a comprehensive tenant engagement and training programme with multiple elements that included, in its final year, a peer energy advisor programme.

The dearth of unoccupied affordable housing in TCH's property portfolio to which residents could relocate during the proposed major building retrofits required that tenants remain in residence during the construction. Retrofits of this magnitude involve frequent unit access, power and water shut-downs, and noise over an extended period, and cause significant disruption and aggravation for tenants. The tenant engagement and training programme had the added responsibility – beyond energy conservation education and training – for mediation of tenants' concerns about construction, tenant construction communications and facilitating tenant decision-making around renewal measures and amenities.

Major retrofit measures were selected in advance, based upon investment grade audits and prioritisation for the most urgent measures. They included hot water and heating boiler replacement, building automation system installations, riser repairs and replacements, installation of compact fluorescent lighting fixtures in suites and retrofits to common area lighting, HVAC upgrades, balcony door replacements and window refurbishments, and building envelope repairs. Renewal measures included balcony slab and railing repairs, roof waterproofing, suite and common area upgrades, security upgrades, playground and landscape upgrades, and $CO_2$ monitoring.

## TeamWorks©, tenant engagement and education

The case study, tenant engagement and conservation training programme, *TeamWorks©*, was conducted with the tenants in one set of buildings over a three-year period for the first phase and with tenants in a separate set of buildings over a second two-year phase. Tenants were housed primarily in high-rise structures, with some mix of townhouses and low-rise buildings as well. The programme gave tenants an opportunity to set priorities on a short list of measures identified in previous tenant surveys, to provide input on contractor practices to reduce inconvenience and disruption during construction, to review construction schedules, which allowed tenants to gain an understanding of the construction process, and to receive energy conservation training and incentives to model energy conservation behaviour among family members and fellow tenants. When introduced to the BERP, tenants in all participating communities were briefed at evening meetings on the major energy retrofits that would take place over the course of the next several years and advised of how this programme would differ from any past experience tenants may have had with smaller TCH building retrofits, e.g. scope, dollar investment and degree of tenant participation. In terms of the specific components of the *TeamWorks©* approach the full programme included provision for the following elements:

- Tenant leadership opportunities (Community Design Teams)
- Peer education and outreach (Green Team Energy Advisors)
- Intensive tenant – trainer interaction based upon mutual respect
- Tenant-designed guidelines for measures installers (embedded in installers' contracts)
- Environmental education on sustainable practices
- Tenant behavioural pledging to adopt efficiency practices
- Tenant-friendly construction communications
- Conservation prompts and promotional materials
- Participation incentives and rewards
- Facilitation of tenants' allocation of funding for local spending priorities (non-energy).

### Staff sensitivity training and communications guidelines for construction sub-contractors

Early feedback both from staff and tenant leaders underscored the importance of the ability of the project personnel to communicate with and treat tenants with respect. Negative experiences with previous building improvement programmes fostered a general distrust among tenants of anyone representing housing management, particularly relating to projects requiring entry into tenants' units. As part of the effort to facilitate respectful communications with residents, TE trainers conducted a 'sensitivity' workshop for Ameresco project coordinators. The session sought to dispel negative stereotypes about social housing residents, while presenting a realistic picture of the challenges staff would encounter working within the crowded inner-city housing buildings. With the input of tenants, Ameresco developed the Contractor Code of Conduct. The Code put forth a set of guidelines for sub-contractors on how to treat tenants with sensitivity and respect and was part of the sub-contractors' formal agreement. It addressed privacy and security issues, handling of tenants' questions and concerns, worksite clean-up and care of tenants' belongings during installations within units. Repeated breaches in conduct resulted in reassignment of installation workers and warnings to contractors and, by means of positive reinforcement, contractors were made aware when tenants acknowledged their exemplary performance.

### Community design teams

In each development, 'Community Design Teams' composed of tenants, TCH site staff and TE trainers formed the structure through which residents were provided with opportunities to become leaders, received conservation education, engaged in joint decision-making with housing staff about renewal measures and were kept informed about the progress of the retrofit. They also provided regular venues for tenants to ask questions about construction and express concerns.

The Teams for each housing community met in evening sessions monthly for the first three months, then bi-monthly thereafter for either a three-year period or a two-year period depending upon the programme funding phase. As needed, interpreters were present at meetings. Culturally appropriate refreshments were provided (with recommendations from Team members), childcare offered and conservation-related raffle prizes awarded to encourage attendance. Engineering and construction management staff reviewed proposed project measures and their installation status. Team members were allowed to vote on a short list of additional measures, which included community priorities such as: security systems, lobby and common space improvements, and playground equipment installations. Giving tenants an opportunity to vote on community priorities helped foster an early sense of ownership of the BERP programme, resulting in an increase in tenant acceptance of the retrofit measures that were pre-determined as priorities. The promise of regular construction update meetings, continued involvement in decision-making and tenant training further heightened the level of tenant involvement in the project. As both an incentive and a reward for participation, each Design Team received $2,000 to $4,500 to allocate to youth or general community activities. In addition, the Teams co-sponsored with TE staff high-visibility events and outreach activities.

A crucial aspect of the work was responding to the negative experiences tenants had had with building retrofits. This required TE staff to adopt activities to deal with tenants' distrust and scepticism during the initial phase of the programme. They involved Team members in the development of strategies to reduce the intrusion of non-programme concerns into meetings (e.g. conflicts with management, concerns about pest management). Trainers engaged in team-building activities with tenants to improve their ability to reach consensus when making decisions regarding renewal measure selection. To foster better understanding of the long timeframe that major retrofits can entail, the construction update report was adapted to show the various stages of a large construction project (e.g. design, vender selection, installation, inspection). Special care was taken to avoid providing measures, installation dates or scope detail that was too specific in advance of their being locked in, as changes were frequently viewed by tenants as 'broken promises' on the part of the housing agency.

### Environmental education and training

Interactive, participatory tenant education and skills-building training workshops alternated with educational outreach to the larger tenant community during bi-monthly Team meetings to provide hands-on experience with conservation practices and to enhance tenant roles as peer educators. Training workshops were casual and fun, offered with interpreters as necessary. Activities focused on major energy end uses such as lighting, space heating and cooling, domestic hot water use and plug loads. In addition, based upon tenant interests, educational materials were created relating to sustainable practices apart from building energy or water consumption, such as source reduction and recycling, sustainable purchasing practices, composting and use of green cleaning products. Team members were encouraged to pledge to adopt one to two conservation practices initially. It was intended to be an incremental pledging programme with more pledged practices added over time and public display of participants' names and pledges. Unfortunately, due to other programme demands, incremental pledging activities fell by the wayside.

### Project communications

Two weeks prior to Community Design Team meetings, meeting notices were displayed in building lobbies and beside the elevators on each floor. Attendance and minutes were taken at each meeting, distributed to tenants and posted in the common areas. Tenants who attended three or more bi-monthly sessions were given resource binders and canvas bags to store educational materials, conservation pledges, meeting minutes and construction progress charts. Trainers employed tailored messages and colourful graphic materials. Conservation messages were adapted based upon early interviews with tenant leaders, stressing improved comfort, reduced transfer of noxious odours from neighbours, healthy living and, to a lesser extent, environmental stewardship.

The package of educational and promotional materials was tailored for each community based upon tenant demographics and linguistic requirements. All written programme materials were translated into the dominant languages spoken in each participating building, including Farsi, Somali, Chinese, Arabic, Spanish, Tamil, Bengali, French and Korean. BERP bulletin boards set up in each community displayed community-specific programme materials, which were updated regularly. In addition to meeting notices and minutes and conservation prompts, photographs of Team members engaged in project activities were often displayed to personalise the participation of tenants and to promote peer interest. Team members co-wrote with TE staff quarterly project newsletters for distribution to Team members and TCH staff, to be displayed at each site.

### Green Team Resident Advisor Programme

In the last 12 months of the programme, TE trainers developed a peer-based programme that recruited particularly dedicated members of the Design Teams to serve as paid Green Team Resident Advisors in their buildings, working an average of six to eight hours a month. Resident Advisors participated in a three-day training event on sustainable practices, communication techniques, meeting facilitation and community-based social marketing strategies. They conducted apartment energy audits, hosted light bulb exchanges, facilitated informational workshops and lobby intercepts, and addressed their neighbours' questions about upcoming retrofit construction.

### Engaging building maintenance staff

Building maintenance personnel received on-site training for operation and maintenance of new equipment and renewed facility assets installed as part of the programme. Tenant engagement staff created a display poster for the maintenance staff offices that provided tips on efficiency practices and ways to reward tenants' conservation efforts. Maintenance staff received information on upcoming Design Team meetings, minutes and progress charts/reports. In some cases, maintenance staff attended the Team meetings and addressed tenants' questions and concerns about the measures being installed under the programme.

## Findings

A major challenge to undertaking extensive energy retrofits in occupied buildings is the upheaval during installation and renovation and the resultant discomfort for tenants. Tenants who do not fully understand and embrace the energy-related capital improvements to their buildings can undermine the savings and disrupt the retrofit process.

In July 2008, engagement staff surveyed 50 tenants who had participated regularly in the Community Design Team meetings. Comprised of 15 questions, the survey was designed to rate the tenants' satisfaction with the engagement and information strategies, programme impacts relating to building appearance and comfort level, as well as sub-contractor behaviour, knowledge and practice of energy/water conservation, and the likelihood of participation in future environmental education training. Tenants rated the tenant engagement initiative very favourably in terms of feeling respected as programme partners, the level of programme buy-in and having received improved service by construction sub-contractors. Virtually all respondents thought that the Community Design Teams were a useful mechanism to facilitate tenant participation (92%). A large majority (85%) reported that it is very important to practice efficiency behaviour. In addition, the tenant survey revealed the following:

- 86% felt that their feedback and ideas were listened to and respected;
- 80% said that being able to vote on measures and amenities was important to them;
- 88% of tenants found the measure updates and access to project engineers was useful;
- 76% believed that the Contractor Code of Conduct resulted in improved service;
- 33% of the survey tenants wanted to become peer energy advisors.

Tenants reported that they are doing more to save energy and water (39%) and now do more to conserve on lighting electricity use (37%), although it should be noted that objective evidence of changes in occupants' documented energy using behaviour as a result of the engagement programme was not recorded. A planned pre-intervention survey to establish a baseline on efficiency practices was never approved by TCH. As a result, it is impossible to know how tenants' responses about their conservation practices at the end of the programme might have varied from those that would have been given at the start of the programme in 2005. The lack of observational evidence of pre- and post-programme energy practices and of consumption data that isolated changes due to behaviour from those resulting from system and building improvements makes it impossible to gauge the accuracy of the self-reported behaviour. Given the five-year term of the engagement and energy education activities, one can assume that the 'baseline' on practice might have moved each year as the tenants gained more information and incrementally adopted (or not) conservation practices. Similarly, the absence of individual unit metering complicated the ability to isolate individual consumption, and thus to measure the impact of family level conservation behaviour. A valuable feedback mechanism that could have promoted and rewarded tenants' adoption of conservation practices was lost. With utility costs included in subsidized rent, the message of the market was interrupted, resulting in tenants having fewer incentives to conserve energy and water.

The tenant engagement programme failed to achieve the desired level of intensive face-to-face interaction with the majority of residents, which could have facilitated adoption of conservation practices on a scale necessary for the greater consumption impacts. The responsibility for construction communications and complaint mediation, though critical, greatly reduced the TE staff time available for community-based social marketing strategies.

## Conclusions

Tenant reports and the authors' experience working with tenants during intensive programme retrofits in occupied social housing support the authors' conclusion that programme outcomes can be improved through the application of well-designed and delivered tenant engagement activities. The level of tenant buy-in during disruptive retrofits will depend on how involved and respected tenants feel they have been and the quality of construction communications.

TCH reported that the outcomes realised from engaging residents as part of the BERP went beyond additional energy savings. Joint decision-making with tenants, opportunities for peer teaching and leadership, and the ability for tenants to influence programme design were essential. Tenant participation shaped and improved the BERP to an unprecedented degree. Better understanding, greater co-operation and continuation of sustainable behaviours have heightened the success of the programme.

The experience and expertise of TE staff working in social housing settings is a critical element for programme designers to consider. Knowledge of low-income residential energy use and behavioural strategies is necessary, but not sufficient. Ameresco design and construction staff frequently noted that the presence of TE trainers who were experienced working in multicultural settings with low-income persons and who had strong meeting facilitation and conflict management skills greatly enhanced their ability to keep the retrofit programme on target.

The lack of hard data on the impacts of behavioural strategies argues that future engagements include a pre- and post-savings measurement component. Added to improvements in demonstrated buy-in of tenants and satisfaction with otherwise intrusive efficiency retrofits, this tenant engagement model is a compelling strategy for housing agencies.

Our experience and findings reflect the importance of working with all building occupants – doing so over an extended period of time and utilising skilled, trusted third parties to initiate the activity. As stated in the introduction, we believe that well-managed resident engagement can pay dividends in arenas beyond energy use, from indoor air quality to resident satisfaction and longer tenures. While researchers and practitioners have learned a great deal in the past half-decade about what motivates desired behaviours and how to enlist tenants in cutting energy usage, this remains relatively uncharted territory. To advance our understanding and to spur more frequent and better such engagements, the authors put forward recommendations in three categories: (1) research, (2) training and certifications and (3) policy.

In research, we seek:

- longer-term evaluations examining the persistence of savings from behaviour-based programmes, spanning several years and featuring the inclusion of appropriate control buildings;

- additional demonstrations of tenant engagement featuring applications of multiple motivating principles: mutual respect, feedback, competition, the use of social norms, prompts, and incentives among them.

In the training and certification area, we recommend:

- for property manager and facility manager certifications, insert requirements for courses in both tenant engagement and energy efficiency behaviour principles;
- encourage US LEEDS (Leadership in Energy and Environmental Design) and European retrofit standards, such as Energy Performance Certificates, to include credit for the existence of tenant engagement curricula around energy issues.

For policymakers in the public and private sectors, we urge:

- adoption of incentives for behaviour-based energy usage reductions alongside capital investments by utilities, government agencies and carbon exchanges, with accompanying rigorous monitoring and verification protocols;
- encouragement by apartment building trade associations of strong resident councils and other structural forums facilitating tenant engagement among building owners;
- insertion in competitive solicitations for building capital improvement specifications for standards of tenant instruction in the use of new equipment and respect for resident property;
- adoption of energy use benchmarking for multifamily buildings to heighten awareness among all stakeholders of actions each can take to reduce energy consumption and greenhouse gas use.

With actions like these, tenant engagement as a community development strategy will no longer be an afterthought but a valued and intrinsic component to large-scale retrofit programmes.

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# 13 Ensuring energy efficiency at the individual level: Getting psychologically informed

*Philip Brown*

## Introduction

The arguments for why we need to reduce our carbon emissions have been well rehearsed at both international and national levels. The overarching driver stems from the need to reduce $CO_2$ and other greenhouse gas emissions but reasons such as energy security and production and supply costs also predominate. Within the United Kingdom (UK) the 2008 Climate Change Act set demanding targets to reduce emissions by 34% by 2020 and by 80% by 2050, based on 1990 levels. Reducing the amount of energy used in the domestic environment is of central importance as estimates have indicated that the UK domestic housing sector accounts for 50% of all greenhouse gas emissions (DEFRA 2009). Of these emissions, it is estimated that three-quarters come from space heating and heating hot water, and one-quarter from powering refrigeration, lights, ovens, washing and dishwashing machines, and consumer electronics (Retallack *et al.* 2007). Ensuring that when energy is required within the home it is used as efficiently as possible underpins one of the key strategies for reducing the proportion of greenhouse gas emitted. For the most part the UK's housing stock is old and energy inefficient. Therefore the current thinking pervading the field is that in order to reduce the carbon emissions from the domestic housing sector the existing housing stock needs to be radically overhauled.

The UK Government has been supporting the low-carbon refurbishment, or retrofit, of existing buildings in the domestic sector through a number of initiatives over recent years. These include the Decent Homes Standard (DHS) (DCLG 2006), the Warm Front scheme (see National Audit Office 2009), the Carbon Emissions Reduction Target (CERT) and the Community Energy Saving Programme (CESP). Warm Front, CESP and CERT have now been replaced by the Energy Company Obligation (ECO) and Green Deal in late 2012 (DECC 2011). These initiatives are seen, by the UK Government, as a radical approach to enabling the decarbonisation of the domestic housing stock. These schemes, and their predecessors, have all involved the deployment of various 'measures' (i.e. insulation, heating systems or

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other technology and materials that aim to increase the energy efficiency of the domestic housing stock). The prevailing assumption is that when retrofit measures are installed they should have a positive effect on the energy efficiency of the dwelling. However, at the same time it is acknowledged that the actual energy reduction achieved is often different from what was expected due to the complex array of human factors and social practices involved in energy use (e.g. Critchley *et al.* 2007).

## People, retrofit and energy use

Although many of the required technologies that can help buildings become more efficient already exist (e.g. insulation, efficient heat sources and digital controls, etc.) many remain underinstalled in our homes (Caird *et al.* 2007). Some of the issues underpinning slow adoption revolve around the up-front cost of installing such measures, particularly in the majority owner-occupier sector, a barrier that it is hoped the Green Deal in the UK will overcome. However, a number of other issues are also at play including: a lack of information as to the utility of measures, where to obtain the measures and how the measures are installed, their technical performance (Inside Housing 28/09/2012), consumer confidence in the technology, concerns about disruption and the interface/ergonomics of using the equipment, to name but a few. Similarly, to further complicate the area, in homes where technology is installed, the occupants of buildings do not always behave efficiently and interact with the technologies in the way that the designers of the technology expect (Stevenson and Leaman 2010). Furthermore, regardless of whether technology is installed it is clear that energy conservation behaviour has not yet become the norm (Yohanis 2011) and effects known as 'take back' or 'rebound' occur, where the household spends any efficiency savings on other energy consuming practices (Greening *et al.* 2000; Herring *et al.* 2009).

Since the 1970s domestic energy use, in terms of space heating, has increased by two-fifths (although it has fallen since 2004; see Palmer and Cooper 2011) and despite appliances becoming increasingly efficient, the sheer number of devices in our homes has meant that domestic electricity use has increased by around 34% since 1990 (Phillips and Rowley 2011). Although steps have been taken to address the increase, the pervasiveness of energy-intensive appliances (e.g. televisions, computers, games consoles, etc.), the rise in single-occupancy households, increases in disposable income and developments within our social lives, such as increasing mobility of different household members, home-working and '24/7' living, have all contributed to creating a landscape and culture that is contingent on significant levels of energy consumption, despite progress on efficiency elsewhere (Lilley *et al.* undated). While some people do seem increasingly disposed to purchasing A-rated (highly efficient) appliances, the energy savings from doing so have been offset by the 50% growth in the number of appliances in the home (particularly consumer electronics) between 1990 and 2004 (Retallack *et al.* 2007).

A rational explanation for these increases suggests that the main problem is one of information and awareness. The literature suggests that people, for the most part, appear largely unaware of how much energy they use and research suggests that they are rarely interested or engaged in the subject (Retallack *et al.* 2007; Whitmarsh *et al.* 2011; Yohanis 2011). The current and predominant thinking behind many campaigns that aim to reduce energy consumption is led by the position that once people have the correct information they would make the rational decision to lower their energy use depending on what they see as the most persuasive message (e.g. cost, ethics, social acceptability, etc.). As such a great deal of effort has been exerted in order to attempt to find out what people's attitudes to energy use are and try to change them, provide more persuasive information, provide feedback on actual energy use, find ways to offer people advice on remedial actions. This position, though, as Carrico *et al.* (2011) suggest, reflects 'a remarkably simplistic model of behaviour' (p. 61) and does not exploit the vast knowledge base that exists about why we do the things we do.

## Psychologically informed approaches to retrofit

Over time the focus upon ensuring a low-carbon domestic building stock has largely been generally approached through a technological lens within the broad area of 'building science'. This has tended to take both a 'fabric first' and product development focus where the priority has been on ensuring that the fabric of buildings and the technology deployed within buildings is as efficient as possible, in order to reduce the level of fuel needed for heating and hot water. However, it has become increasingly apparent that the interaction between a dwelling and its occupants has a major impact on energy use, as well as energy demand, which in turn affects the supply system. The need to understand why people do the things they do within a building has therefore risen to prominence, particularly over the last few years, although much of the pioneering work in this area can be found in the 1970s largely as a reaction to fears over energy security at the time (Stern 1992). As such, in embracing the inextricable link between the individual, the social context and the environment the adoption of a socio-technical approach has been advocated (Hinton 2010) in order to understand better the role of people as energy users in their homes.

This chapter aims to concentrate more on the 'socio' part of this approach in order to articulate the contributions psychological theory and research can play in helping to retrofit the domestic environment in order to help lower greenhouse gas emissions. Psychological research in this field has developed over the last 40 years, but has come to greater prominence, and thus studied with more intensity, over the last decade. The area is complex, and constantly evolving, which makes the popular reliance on simplistic models of behaviour particularly puzzling. This, however, could be in part a result of the failure of psychologists to communicate the findings of their discipline to broader audiences in ways that make sense. This was certainly the motivation for the production of the briefing note authored by Carrico *et al.* (2011) and aimed at policymakers in order to provide a general overview and signpost of the key lessons to be learned in order to help inform programmes aimed at reducing greenhouse gas emissions. The potential for contributing to lowering greenhouse gas emissions through interventions at the behavioural level is significant. Dietz *et al.* (2009)

estimated that in the United States if the most well-designed interventions were scaled up nationally this could reduce household energy use by 20% in 10 years. This chapter shares the motivation of Carrico *et al.* (2011) and provides a review of some of the key issues revolving around the adoption of retrofit measures and 'in-use' household behaviours. It is not the intention to provide a comprehensive review of the literature and studies but instead to provide a launch-pad from where more in-depth engagement with the psychological literature can be made. It is hoped that this can help broaden understanding as well as help turn that understanding into effective interventions.

## People and their interaction with retrofit measures

Most reviews into energy behaviours have tended to use a distinction, albeit crude, between the sorts of energy behaviours that are performed. These are usually thought of as 'adoption' behaviours (where people incorporate new equipment such as heating systems, insulation, appliances and so on) and 'in-use' behaviours (which cover how equipment, new and old, is used in situ). This distinction is useful in terms of conceptualising the problem as each differs in terms of their frequency in our daily lives, the cost associated with them as well as a range of other ways (Stern 2011). The distinction is important for two main reasons. First, the adoption of more efficient equipment generally has a greater impact on energy conservation than does changing how we use existing equipment (Gardner and Stern 2008; Dietz *et al.* 2009). Second, reducing our use of existing appliances, etc., can be associated with sacrifice and therefore is often resisted by users (Pierce *et al.* 2010). Unfortunately the majority of work within psychology has tended to focus on 'in-use' behaviours, which in part may be a response to the relative ease of measurement as a result of the greater frequency in daily life (Stern 2011). Very little attention has been given to adoption in psychological research, with the exception of a few studies of note (e.g. Yates and Aronson, 1983; Brown et al forthcoming). This is clearly an area where psychological research needs to be applied.

The majority of the attention of psychological research has focused mainly on communication, through the provision of information or feedback, the impact of social motives for changing behaviour, incentives, habitual behaviour and, to a lesser extent, prompts. Each of these aspects are presented below and briefly summarised.

### Information

The vast majority of work in the field of energy conservation has been in the area of communication. These are the most popular ways of trying to encourage pro-environmental behaviours and, as Stern (2011) states, are usually ineffective. These approaches usually take a 'rational' conceptual approach, which holds the position that once people have the correct information about the costs incurred in excessive consumption and/or the harm caused to the environment they will be more likely to

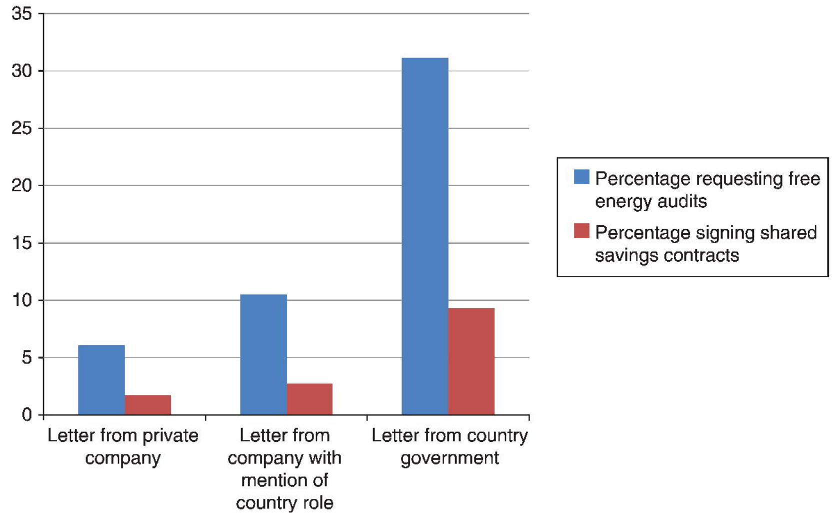


**Figure 13.1** Consumer response to the shared savings efficiency programme (Miller and Ford (1985), in Stern (1999, p. 473)).

change their behaviour and reduce their energy consumption. However, studies have tended to find that although providing information does improve knowledge this has minimal impacts on behaviour (Gardner and Stern 2002).

Where studies focusing on information provision have showed success, however, is where they have focused on how the information is framed. Gonzales *et al.* (1988) reported how framing retrofit in terms of avoiding loss, rather than achieving a gain, saw a greater uptake of financial uptake for retrofit measures. Similarly, Stern (1999) reported the findings from an experimental programme offered in Minneapolis in 1984 that shows how the source of the information is often as important, if not more so, than the information itself. In this programme an energy company reasoned that it could make a profit through improving homes for cold climates, investing over a long period of time and thus sharing the net benefits with those homeowners who agreed to take part (Miller and Ford 1985). The incentive to homeowners was lower energy bills and, in the future, a higher valuation of their home. Free energy audits were also offered by the company. Whilst in essence the firm was giving free money to those who signed up, only 6% agreed to take part in the first few months. As part of the marketing of the programme, the firm sent three different letters to eligible homeowners and monitored the effect on uptake. The first letter was on their own letterhead, the second informed people that the programme was co-sponsored by the county government and the third letter was sent from the chairman of the county Board of Commissioners. Figure 13.1 shows the different level of uptake for each condition.

Noting the dramatic increase in uptake in the third condition, and in line with Lorenzoni *et al.* (2007) outlining the barriers to effective information, we can infer that the increased uptake at each stage is due to the increased trustworthiness of the source of the information. Stern (1999) also notes that where incentives are offered, an investment in the delivery of information can be more effective than simply increasing the incentive, which can undermine the motivation to engage in the desired behaviour.

## Feedback

People like to know whether they have been successful in performing a particular behaviour. If someone takes showers instead of baths, uses their tumble dyer less or uses a microwave instead of a conventional oven they will only know how successful they have been if there is some mechanism for monitoring their use.

In studies such as that by Fischer (2008), the immediate or frequent feedback to participants about the amount of energy used or the cost incurred has yielded energy savings of between 5 and 12% of home energy use with the effect lasting for six months or more (Stern 2011). Historically feedback has traditionally been in the form of utility bills that are issued by a utility company every few months. These have tended to show the amount of units of energy used but the delay between use and receiving feedback, as well as how the usage is presented, has been seen as problematic. In terms of how usage has been presented there has been a move towards more graphic based descriptions to illustrate energy use. Roberts *et al.* (2004) conducted qualitative focus groups to explore consumer preferences for energy consumption feedback and found that participants considered bar charts, e.g. displaying quarterly energy use compared with the same quarter the previous year or with all quarters over the previous year, to be the best way of displaying energy use on bills. The inclusion of such information in utility bills has been found to result in energy savings of around 10% (Wilhite and Ling 1995). However, Nickerson (2003, p. 108) highlights that typical utility bills, even those that include more detailed information on energy use, are not detailed to the point where consumers can understand what household appliances use what amount of energy. For those who wish to increase their pro-environmental behaviours, this is a barrier to the increased knowledge needed to effectively change behaviour.

Similarly, the speed at which feedback is received, to be effective in changing behaviours, is crucial. In order for feedback to work it has to be connected to tangible rewards (i.e. financial benefits) by signalling material consequences soon after the behaviour was performed. Whilst all households should have access to their gas, electricity and, where installed, water meters, the act of regularly reading meters requires commitment on the part of the householder due to them often being placed out of sight. Nevertheless, research suggests that over a quarter of householders check their meters fairly regularly (Attan 1985; Darby 2006). It is doubtful whether this happens in significant numbers to make any meaningful impact on emissions as a whole. However, advancements in technology, for example the introduction of smart meters, have the advantage of being able to provide consumers with more regular, and in some case real-time, information about the energy that they use. Such meters have been found to be effective, alongside other variables such as goal setting and incentives, in reducing energy use (Darby 2006).

Darby (2006) reviewed the effectiveness of different types of feedback including basic metering without separate direct display monitors, key meters and keypad meters, the use of TVs and PCs for display, informative billing and time-of-use pricing. The report concluded that direct feedback results in savings between 5 and 15%, compared to 0 to 10% for indirect feedback. Simple free-standing displays placed elsewhere in the house that are in constant communication with the main meter and are easier for people to access have been found to produce savings of between 10 and 20% (Wood and Newborough 2003; Mountain 2006).

Similarly, the provision of information on energy use in real-time through web-based feedback (high resolution) was compared with weekly meter readings in college dormitories (low resolution) by Petersen *et al.* (2007). They found that, combined with the incentive of a competition between the two groups, those who received information in real-time reduced their electricity consumption by 55%, compared with 31% for those who received weekly meter readings. Whilst the savings made are considerable, studies of tailored feedback that include incentives obscure the findings. It is true that those in the high resolution were able to save more energy due to knowing exactly how much energy each individual appliance used; it is not clear if such savings would be made without the incentive. The authors conducted a post-competition survey, in which students reported that they would continue conservation practices, although no follow-up on actual energy use was conducted post-competition and therefore it is not known whether or not the behaviour was successfully sustained. Temporary financial incentives are also not feasible in the long term considering that behaviour is often not sustained upon removal of the incentive. If incentives are to be combined with feedback for more widespread application, the incentive must be continuous and viable in the long term.

### Social motives

There are a variety of ways in which social motives have been employed to encourage energy-conserving behaviour. These include using 'models' who demonstrate the desired behaviour (Geller *et al.* 1982; Hopper and Nielsen 1991), using messages from friends (Darley 1978), utilising social marketing (McKenzie-Mohr and Smith 1999) and appealing to personal goals (Kranz and Kunreuther 2007). The most cited concept utilised in this area is known as social norms. Social norms is a broad term and is used to refer to those rules and ways of behaving that we all draw upon in order to occupy social space. They are rarely written down, or indeed verbalised, but they serve as a framework for us to use in order to help us understand how to behave in our communities and our daily lives. Within the area of energy conservation they have mostly become synonymous with a closely related concept of peer pressure.

People are influenced by what they perceive as being acceptable to others in society (Cialdini *et al.* 1990) and such acceptance can be viewed as being a tangible incentive to act pro-environmentally, just as not being accepted is a disincentive (Cook and Berrenberg 1981). Harnessing the principle of conforming to norms is useful for two main reasons: first, by seeing others perform certain behaviour we can use the knowledge these pioneers have gathered. Second, we tend to be rewarded by conformity; we like people who behave as we do. Coupled with the fact that knowledge and social support are more available to those who conform, compared to those who do not, makes doing as others do very persuasive indeed.

This was illustrated well by a study that showed that when people knew the actual energy use of a 'typical' householder – shown on a utility bill – this was a more effective determinant of reductions in energy use than more explicit messages based on social responsibility, environmental protection or other factors (Nolan *et al.* 2008). Interestingly, when asked how important knowing how much energy other people used was, participants rated it as the least important motivator and cited reasons of environmental protection and benefits to society as the primary reasons for changing their behaviour – showing that people are not always aware or willing to discuss the explanations for their own behavioural change.

### Incentives

Researchers have explored the way in which financial and non-financial incentives can be deployed to change behaviours, for instance, by using time-of-use electricity pricing, rewards for reducing energy use and financial incentives for investments in energy efficiency appliances and measures (Stern 2011). Tax reductions are one way in which behaviours can be reinforced by providing incentives to behave in an alternative way, thus reducing or curtailing a particular behaviour. Incentives such as bottle return schemes and car sharing lanes work in a non-financial sense. However, it is worth bearing in mind that incentives tend to work best where they are provided closely in time with the target behaviour and are clearly linked to the behaviour being rewarded. Where an incentive ceases to be in place it is unlikely that the behaviour will continue.

Incentives will not be suitable for all energy reducing behaviours due to the complexity needed to maintain the system. Also, if the incentive is too large this can have a negative effect as people become suspicious and wary that the new behaviour/item will have negative consequences for them – a 'too good to be true' conundrum. Incentives, though, appear to work better for single decisions such as the purchasing of expensive items such as technology and/or retrofit measures (Clayton and Myers 2009). A number of schemes have been developed that use a combination of punishment and incentive to encourage sustainable behaviours. Carbon trading schemes and pricing tariffs both utilise this model. Because reduced consumption usually entails reduced costs, many schemes designed to curtail behaviours may also include monetary incentives.

## Habitual behaviour

When people use energy they are in effect consuming the benefits that arise from services provided by products rather than consuming energy for its own sake. Conceived in this way it makes sense to conceptualise people as unwittingly and habitually inefficient as opposed to being intentionally wasteful (see ESRC, undated). A number of research studies have highlighted the fact that, apart from changing the thermal properties of a building, installing efficient heating systems and completely changing the value system of whole sections of our societies, the next best way to tackle energy inefficiency is to understand and change habitual behaviour (Ouellette and Wood, 1998; Verplanken and Orbell, 2003; Abrahamse *et al.* 2005).

Many of our behaviours that have an impact on our environment (consumption of goods, travel choices, waste and energy use) were established when environmental issues were not such a concern as they are today. Thus through repetition such behaviours have become habitual. The problem with habits is that they are largely subconscious behaviours for, without them, as Neal *et al.* (2006) point out:

> … people would be doomed to plan, consciously guide, and monitor every action, from making that first cup of coffee in the morning to sequencing the finger movements in a Chopin piano concerto.

In one study in the US researchers found out that many, if not most, energy consuming behaviours could be characterised as unconscious or habitual as opposed to being a result of rational decision-making. Maintenance of habits, they found in some cases such as choice of washing machine settings, came down to an attitude of 'if it works, why change it?' and the knowledge of how to use more environmentally friendly settings on appliances did not necessarily result in their use (Pierce *et al.* 2010).

Changing habits is a very difficult process and current literature places it in the realm of behavioural psychology. The use of persuasive messages or greater information are, for the most part, ineffective in changing habitual behaviour as new information is not taken on board by people when it contradicts their habitual behaviour and it is not seen as important when not recognised as being relevant to one's situation (Jager 2003; Verplanken and Wood 2006). Jager (2003) outlines a number of methods aimed at breaking habits and argues that the best way to break a habit is to make it impossible to perform the behaviour. However, it may be possible to simply modify some habits. For instance, placing light sensors in rooms that disable lights from being turned on when there is sufficient natural light, or light from other sources, in the room may be effective in breaking a habit of turning on lights when entering a room.

One of the strongest, and frequently overlooked, determinants of behaviour is what is allowed or enabled by the physical and social environment within which we live – these are known as behavioural affordances (Clayton and Myers 2009). Some actions that would promote sustainability or energy efficiency are simply not available options in some situations. When thermostats are installed in homes in inaccessible places or out of view, the householder cannot easily act to reduce the energy used. Similarly, in commercial settings when workers do not have control over heating and lighting systems these inhibit the individual choice to stop or reduce (curtail) energy use. Even when actions are physically possible, a lack of information about how to perform them presents a further barrier. In such cases the individual's motivation to reduce their energy use and other internal factors are effectively irrelevant.

## Prompts

The use of prompts is an under-researched area in the field of sustainable behaviour and the studies that have examined their impacts often combine them with other methods such as raising awareness of social norms. Nijhuis (2007) reports a study conducted by Cialdini *et al.* (1990) in which they manipulated the messages to hotel guests to re-use towels, rather than requesting they be washed after one use. They found that familiar messages such as 'Help save the environment' resulted in a 30% re-use, rising to 44% when they attempted to induce social norms with the message 'Join your fellow guests in helping to save the environment'. Bringing the behaviour of peers even closer to the individual with the message 'Seventy-five percent of the guests who stayed in this room used their towels more than once' saw towel re-use rise to 50%. Clayton and Myers (2009, p. 150) also note that framing prompts in a way that is congruent with individuals' world views may increase their likelihood to engage in pro-environmental behaviours. As an example, they cite a student co-op house that had stickers on the light switches with the slogan 'Flip off capitalist power' along with a caricature of a person's face that had the light switch positioned as the nose.

The turning off of lights is perhaps the easiest type of behaviour to prompt and measure as the behaviour requires little effort on the part of the individual. Luyben (1980) studied the effect of prompting college lecturers to turn off the lights in the classroom by reminding them that there was no class scheduled after their own and reminding them to turn off the lights when leaving. Observing the baseline behaviour prior to the experimental group receiving prompts, he noted that 67% turned off the lights after their class, rising to 80% when the prompts were introduced.

However, as with other methods of behaviour modification, the real question is whether a durable change can be achieved, that is whether behaviours increased or decreased during intervention can develop into new habits. As things are currently understood prompts appear to be no more successful at this than other methods. Marshall *et al.* (2002) studied the effect of motivational prompts on stair use in an Australian healthcare facility and found that whilst the desired behaviour increased after the first intervention, it returned to baseline levels once the prompts were removed and did not increase again once the prompts were re-introduced. The question therefore for all those working in the field of energy efficiency behaviour change is not simply what behaviours can be changed, but how interventions can effect durable change.

## Conclusions

The literature available concerning the need to increase energy efficiency and methods of achieving it is vast, covering many different disciplines including those outside psychology. This chapter has aimed to provide an overview of some of the key issues arising out of psychological research as applied to energy efficiency. It is clear that unless households are compelled to install retrofit measures, buy energy efficient technologies and behave in certain ways in their homes, understanding some of the reasons why people do the things they do is crucial.

Although a strategy of using information is the default setting of many of those people and agencies concerned with helping to ensure households reduce their energy consumption, the literature identifies this as generally ineffective as a whole. When steps are taken to ensure the message is framed optimally and presented in the most persuasive manner does a greater impact then follow? We can also learn that whilst it is tempting to throw money at incentivising take-up of products, this can also be counterproductive and de-motivate potential participants. Although for some people cost is truly a barrier to taking the plunge with retrofit measures, this might in reality be an issue for a smaller proportion of people than is generally thought. It is posited that instead of increasing incentives the extra resource may be better placed on ensuring the message is presented in the best way possible.

We also know that when we are performing a certain action the only way we really know how we are doing is if we receive some sort of feedback. The contemporary response, particularly in the UK, to lowering household energy consumption is the mass rollout of domestic smart metering technology. Whilst research has shown this to be an effective method of reducing energy use it is not a sufficient method on its own. To be effective over the long term research has suggested combining feedback with incentivising through competition and other mechanisms, as well as ensuring that the way feedback is delivered makes the best use of psychological knowledge.

We all strive to fit in with our peers and follow the many complex and hidden rules of behaving in the society in which we live. This is why harnessing the power of others (and more specifically our desire to be like others) is so important for energy efficiency and sustainable retrofit. Many studies have demonstrated the effectiveness of social norms, particularly in broad pro-environmental actions, but very rarely have they been studied as potential influences on the adoption of retrofit. This is a significant gap in the knowledge base (Stern 2011) and one that should be addressed to maximise the resources available under mass retrofit programmes. Care, though, will need to be taken to ensure that the unintended consequences of harnessing social norms as a tool to influence behaviour are minimised. For instance, one study found that although attempts had been made at raising the incidence of littering via various advertising and awareness raising campaigns there had actually been very little decrease in the amount of litter found. The researchers in this study found that the phrasing of the message, unintentionally, appeared to reinforce peoples conformity – albeit in an anti-environmental way (see Clayton and Myers 2009).

This chapter has only been able to cover some of the main findings from psychological research and these findings challenge some of the taken-for-granted assumptions used in the normative deployment of large-scale retrofit programmes. However, some of these findings pose challenges for psychological research as many of the investigations into behavioural interventions have tended to focus on evaluating the effects over a set experimental period. If we are serious about understanding more about people's behaviour with respect to efficiency there is a need to focus on how a lasting change can be effected. Securing tangible change in energy conservation behaviour is an issue that appears to have eluded researchers, so far, and is an issue that needs to be addressed if the reduction in emissions targets is to be achieved.

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# 14 Barriers to domestic retrofit: Learning from past home improvement experiences

*Becky Mallaband, Victoria Haines and Val Mitchell*

## Introduction

The United Kingdom (UK) Government has set targets of zero-carbon homes for all new builds by 2016; however, a significant problem in carbon reduction lies in the houses that already exist, with approximately 75% of the houses that will exist in 2050 already built (Wright 2008). There are many changes, both physical and behavioural, that can make a house more efficient. Changes in a household's behaviour and habits can play a big part, as can decarbonising the grid by using renewable energy. In addition, the retrofitting of energy saving technologies into existing homes is expected to play a significant role in reaching the UK's carbon reduction targets. Within the existing UK housing stock there are many homes that present particular difficulties when trying to improve their efficiency and can be classified as 'hard to treat'. According to the Department for the Environment, Food and Rural Affairs (DEFRA 2008), statistics obtained from the English House Condition Survey indicate that there are 9.2 million dwellings that would be considered hard to treat in England (43% of the total housing stock). These include (Energy Saving Trust 2008, 2009):

- Homes with solid walls
- Homes with no loft space
- Homes in a state of disrepair
- Homes without a connection to a low-cost fuel such as oil or gas
- Homes where staple energy efficiency measures cannot be fitted.

Solid walled houses, i.e. those without a cavity, make up 6.6 million or 31% of the total housing stock (72% of the hard-to-treat stock) (DEFRA 2008). Solid walled houses tend to have lower Standard Assessment Procedure (SAP) ratings than those with cavities. It is not possible to implement cavity wall insulation into these properties, which is widely regarded as a very cost-effective way of improving the SAP rating of a house (Centre for Sustainable Energy 2006) and so these homes require alternative measures

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to become energy efficient. Given the number of UK homes involved, the challenge of improving the energy efficiency of this sector of the housing stock is significant.

Of the 6.6 million homes in the UK that have solid walls, 4.5 million are owner-occupied (DEFRA 2008). Many of the previous schemes and initiatives for retrofit within the UK have not been aimed at owner-occupied houses and have limited funds on offer or are only available for those on low-income levels or benefits. This means that there has been a large sector of the market that is unable to benefit from or make use of these schemes. In addition, many of the schemes only provide 'mainstream' retrofitting options, such as cavity wall and loft insulation, which means the owner-occupied, solid walled houses are largely not catered for. The UK Government's 'Green Deal' policy introduced in 2012 is intended to provide, through loans, the funding necessary to carry out whole-house energy saving refurbishments, but these still require the householder to be motivated to carry out the improvements. Clearly, ensuring policies and technologies are appealing and acceptable to householders is key. To make retrofit appealing and engaging, it must be ensured that the needs of householders are met by the technologies on offer, as in many cases householders will be funding such measures themselves. It is therefore imperative that understanding the requirements of householders is gained in order to maximise the uptake of retrofitted energy saving measures.

## Home improvement and domestic retrofit

The energy efficiency of a house may be improved as an additional advantage of home improvement, but rarely seems to be the main incentive for change. As energy saving measures are yet to be retrofitted into UK homes in large numbers, focusing on why and how people undertake home improvements can provide understanding of the context within which the retrofitting of energy saving measures will take place. With a view to identifying 'trigger points' (defined as the times in the life cycle of a home where energy saving measures could be fitted as part of a wider home improvement project), the Energy Saving Trust (2011) highlighted three primary barriers to home improvement: Information and Awareness, Hassle and Cost. Carrico *et al.* (2011) suggested that a multiple approach strategy is needed from policy makers along with the provision of information in order to achieve reduction in domestic energy use, e.g. measures to increase motivation, reduce mental effort along with more relevant information.

The variation in people's attitude towards energy and the environment does pose significant challenges to those trying to engage householders in the development of measures and systems. Jackson (2005) talks of the complexity of changing people's behaviours and how individual behaviours are deeply embedded in social and institutional contexts. He describes how people can feel 'locked in' to unsustainable behaviours in spite of their best intentions. Each individual household will contain a mixture of preferences and practices that will influence the installation of technologies and the way home improvement is carried out (EAGA 2009). It is therefore very important to ensure that people are engaged in the process of retrofit and to see how it can work individually for their household. This means it is necessary to understand what would motivate householders to implement different measures and how the design and installation of technologies can be adapted to best appeal to the householder. It is commonly accepted that not all of the population will make an effort to increase the energy efficiency of their house, not only through lack of resource, but lack of understanding, ability and willingness to act. The willingness to act is of key importance; Yohanis (2011) found that although 77% of householders surveyed had a general awareness of energy and environmental issues, their adoption of energy saving measures did not reflect this. Other research suggests that lack of action is due to the fact that people believe they personally have limited impact on climate change (Lainé 2011). However, the same report states that more than 53% of British consumers surveyed would be prepared to take action to limit climate change, with 71% of these willing to insulate their homes even if that entailed some short-term disruption.

A report by Consumer Focus (2011) identified some of the particular challenges facing the installation and uptake of solid wall insulation. They highlight that solid walled houses are diverse and complex and therefore require bespoke solutions. They also point out that 'making good', which is of particular importance when installing in owner-occupied houses, can comprise up to 50% of the project costs. In conclusion, they recommend that investment in product development and innovation is urgently needed in order to reduce costs and to improve acceptance of solid wall insulation by householders.

A UK home improvement survey carried out by Halifax (2009) found that 55% of householders had undertaken some form of home improvement during the previous 12 months. They also found that the two main motivations behind these home improvements were to improve the look and design of the house (44%) and to update and modernise the house (38%). Another study found that 57% of householders described their motivation to make improvements as a desire to create a nicer living environment (AA 2009). The UK recession and the consequent fall in house prices has impacted upon householders' decisions to sell and renovate with high levels of home improvement occurring in 2009 and 2010. This is likely to have been caused by a number of factors. One suggestion is that householders have changed their attitude towards their property and are now seeing it more as a 'home' than an 'investment' and are therefore more likely to spend money on home improvements (Anon, 2009). The fall in interest rates for savings may also have impacted the trend, as householders realise that whilst their savings are not gaining any interest they could provide better return when invested into improving their home. More competitive labour costs may also have an impact on the decision to improve.

Janda (2011) believes that occupants are often overlooked and are poorly understood even though they play a very significant role in the built environment. It is essential that we are able to understand more about householders in order to influence their choices and behaviour in relation to retrofit. Fawcett and Mayne (2012) state that:

> Very little is known about why individual owner occupiers choose to undertake eco-renovation, who those people are, the influences on that choice, the role of professionals in guiding renovations, whether and how inhabitants live differently post-renovation and so on.

In order to uncover this decision-making process fully, it is important to also understand the reasons why these improvements are not carried out.

Shove (2003) explains that the way we use our homes is grounded in 'habits, practices and norms' and whilst these do shift and change over time, this is usually a consequence of cultural factors and social expectations that are not easy to influence. Householders may act unsustainably out of pure habit but also because it is socially acceptable and usual to do so (SCRT 2006). Such unsustainable behaviours are so embedded in our daily lives that education and information are unlikely to facilitate the desired change (Jelsma 2006) and for new behaviours to be successfully adopted by householders, they need to become social norms (SCRT 2006).

## Uncovering the barriers

There have been a number of examples of whole house energy saving refurbishments, which tend to be undertaken as a major project, requiring the householder to move out of the property for an extended period whilst their home is gutted and rebuilt. The UK Government's Technology Strategy Board has funded demonstrator whole house solutions to improve the performance of the entire property with a goal to make deep cuts in carbon emissions under its 'Retrofit for the Future' programme. Whilst this gives us an indication of the potential energy savings to be gained from major refurbishment, often at a significant cost, it does not present a realistic proposition to the mass market, in terms of willingness to undertake this type of project and being able to fund it, in particular.

In order to inform the development and installation potential of future energy saving measures, we looked to past home improvement experiences of householders. Whilst these do not necessarily give us an indication of how people in the future might take up energy efficiency measures, many home improvements are directly linked to saving energy, e.g. replacing a boiler or hot water tank, upgrading a radiator, installing loft insulation, fitting carpets, replacing windows or addressing draughts through improvements to the building fabric. By looking at these real examples of past practice, it is possible to predict, from a grounded evidence base, how people might undertake energy efficiency improvements in the future. The study took a user centred design approach, following the approach of ISO 9241-210:2010, which states:

> Using a human-centred approach to design and development has substantial economic and social benefits for users, employers and suppliers. Highly usable systems and products tend to be more successful both technically and commercially.

Twenty households were drawn from the East Midlands region of the UK who met the primary study criteria of owning and living in a solid walled house (see Figure 14.1). There were 66 permanent occupants in these households, 34 of whom were interviewed.

**Figure 14.1** Typical solid walled properties within the sample area.

Participants were selected using a purposive sampling approach so that they represented a wide range of family structures, incomes and social statuses, house and household types. While this was never intended to be a statistically representative sample, it allowed for a snapshot of different domestic situations to be explored, using a maximum variation sample (Marshall 1996). Participants were chosen from a sample frame of owner-occupied, solid walled houses in Leicestershire in the UK. Data were collected through two semi-structured interviews with each household, carried out on two separate occasions. The interviews were carried out in the participants' homes, in a room of their choice, for a comfortable environment and to allow visual cues that would prompt both the participants' recollection and ensure that researchers could note contextual factors relating to the responses given.

The information included in this chapter was obtained through the first visit, which aimed to find out about the home improvements that had been previously carried out by participants, focusing on exploring the motivations, barriers and enablers. The first section of the interview was a timeline exercise that was designed to uncover the different home improvements that had been carried out in the house (described in more detail in Haines *et al.* 2012). The householders were encouraged to openly discuss the changes and improvements they had made to their home. They

**Figure 14.2** Timeline equipment.

were asked to give the rationale for purchasing the property and to discuss the changes that had been carried out from the point of purchase onwards. As the conversation progressed, the home improvements were marked on the timeline, with the use of a set of magnetic schematic illustrations designed particularly for this study (see Figure 14.2).

The participants were also asked to give an indication of the level of disruption that the home improvement caused. They were asked who had performed the improvement and whether it had been completed as a DIY task or whether professionals had been used, as well as discussing any problems in the process. The interview data were analysed using a thematic analysis approach where comments were identified and sorted into themes that had emerged from the data.

## What are the barriers to home improvement in the UK?

There are many factors that can influence and motivate people to make improvements to their houses, but we know less about the things that prevent or delay people from making these changes: *the barriers to home improvement*. We discuss these barriers here. Whilst focused on people living in solid walled housing, many of these barriers are relevant to all householders.

### Householder values and preferences

Pre-existing values and preferences held by householders are strong and cover a range of topics. They relate to the physical appearance of the house, how aesthetics are prioritised, financial values, quality, craftsmanship, use of professionals and those relating to the perceived worth of making improvements, to name a few. The following quote from one of the householders demonstrates how the combination of aesthetic values, craftsmanship and new technologies can become a barrier to home improvement:

> I don't want PVC [windows], I like this style of house, I like wooden window frames, we're in a conservation area,[but] there's no restriction on whether you have PVC, but to me it spoils the house, the aspect of the visual pleasure that you get from looking at skilled work. This window is fantastic if you look at all the work that's gone into it. It gives it character… People have said, 'why don't you have double glazing' – I don't like double glazing, sorry! (Female, aged 70)

Whilst this example may demonstrate that people are resistant to change associated with modernisation, there seems to be more fundamental issues relating to the character and aesthetic appeal of traditional homes. Regardless of the predominant reason, the overarching issue is that some people are still resistant to retrofit and introducing new technologies into their homes and this resistance needs to be overcome. If this resistance to retrofit or modernisation is widespread it could have a significant impact on uptake of new energy saving technology within homes.

A surprisingly large number of householders in our study spoke passionately about their windows, particularly those whose houses were built in the early twentieth century that still had the original window frames and sometimes even glass from this period. Householders highly valued these features, boasting of the greater levels of skill and time invested in creating them.

Of course, preferences do not just refer to things within the house, but often what people value the most in their lives. For some, their house is just that, a house – a building where they reside when not at work or elsewhere, with which they have little emotional attachment. Such people may not wish to spend more than necessary on maintaining and improving their home, but would rather spend their money on holidays, education, etc.

> I'd quite like the kitchen decorated but it's not going to change my life, so it's not really a priority. (Female, aged 40)

> I don't think by spending big sums of money [on the house] it will make us any happier, so there's not much point. (Male, aged 51)

In contrast, other households place such a high value on the quality and expense of items that they need to delay making improvements in order to live to that standard.

> It's not finished, … I'm so picky, I like really expensive things and really nice quality and sometimes you cannot have everything in one go. You need to buy little by little, if you see something you like you buy it, if you don't like, I wait until I find something. (Female, aged 31)

If the preferred technology, retrofit option or expected level of quality is not available, then it is likely that this type of householder would not settle for less and their action would be delayed. It is necessary therefore that ranges of energy saving technologies are made available to suit different budgets and preferences.

Obviously, within a household, there is more than one set of personal preferences and it is highly unlikely that multiple members of a household will hold identical views on everything! Therefore, conflicting values may result in further delays as partners try to agree on what is needed. The values of householders can therefore provide significant difficulties for policy makers. If householders do not prioritise the home improvements that could be made over other expenditure or do not consider that the measures on offer meet their quality standards, then it will be hard to encourage them to make the changes necessary to meet domestic carbon reduction targets without enforcing changes through policy and regulations.

### Cost

It is of little surprise to find that cost provides a significant barrier to home improvements. Householders may not be able to afford their 'ideal' product or solution, having to save for significant periods of time in order to finance alterations, or being prevented from making any changes at all, due to insufficient funds. Some households are able to manage the financial strain by 'chunking' the improvements and doing sections at a time. One householder told us how he was only able to improve his windows by replacing small numbers at a time:

> We had some [windows] done a couple of years ago … we had most of them done [but] then there was something like 3 upstairs that we didn't have done because we didn't have the money. (Male, aged 50)

Cost as a barrier is not purely a matter of being unable to afford to make a change. Although there may be disposable income available, improving the house is not always seen as a priority and therefore funds are allocated elsewhere.

> My feeling about that is I can cope with [the leak] and I'd rather spend my money on something else like extravagant holidays or buying a load of books or whatever. (Male, aged 65)

This closely links to what householders value and prioritise. Without challenging and changing existing social norms it is likely that necessary energy saving changes will not be made by many households. The key to success may be to make energy saving aspirational, so that people value the changes it brings, whether these are tangible benefits such as improved comfort or a more pleasant home environment or intangible ones, such as pride in improving DIY skills or being seen to be 'doing the right thing' for the environment. Increasing public awareness will be an essential step towards changing social norms.

Some householders with a lower income are unable to pay for improvements at all, but instead have to depend on their own DIY skills, the goodwill of friends and family or government grants. For this group of people, policies such as ECO and the Green Deal need to ensure that there is minimal or no cost to the householder or that there are DIY options available. It is necessary to ensure that information and awareness of grant schemes reach those householders who could benefit from this type of help. It is important to remember that they may not be looking to improve their home as they may believe it is not financially viable; therefore information needs to be widely available in the public domain and at the right time in the process, which may be even before the decision-making has begun. It is also worth noting that in many cases those with a very low income due to reliance on a government pension may live alone and may feel vulnerable when allowing unknown professionals into the house. They may feel far more comfortable with tradespeople who they have used before and who are known to them. If grant schemes stipulate who carries out the work then this may therefore present a further barrier to the uptake of energy efficiency measures for many on low incomes.

### Professionals

Although there were plenty of positive experiences involving the use of professionals to undertake home improvements reported by our householders, sometimes the reliability or quality of work was not up to the expected standard and so this acted as a barrier to further home improvement. Issues can range from failing to provide quotations, workers not turning up, generally poor service and bad attitudes to work. The following quotes illustrate the unreliability of workers experienced by householders:

> It's actually harder than you think to get reliable tradesmen; it really is quite difficult. You ring them up and try and get them round and you get quotes and it just takes forever. It can't be that difficult. If it was my business and I conducted it in the same way by turning up when I please and leaving it weeks and weeks to get a price in, I wouldn't have any work! (Male, aged 50)

> We tried to get professionals in [to fix the flat roof]. The ones that did arrive couldn't do it. The ones that probably could have done it, never turned up, so I've done it, and it's alright for a bit. (Male, aged 65)

Householders described problems with the quality of work, such as a lack of appropriate skills, poor workmanship and the inability to solve problems when asked. These either related to a poor general skills base or poor skills specifically related to dealing with an older property that was hard to treat. In one house, the wrong type of product had been used. This caused the householder significant distress as it was felt to have devalued the property. In other households, improvements had to be either 'made good' by the householder or redone. One householder had to threaten to sue the company before they would agree to repair damage caused through the failure of their product. Other issues mentioned included the difficulty and expense of accessing good tradesmen, the legal necessity to have a specialist professional for certain jobs, bad attitude of tradesmen to householders and professionals not taking into consideration householder's needs, concerns or knowledge of the property.

In order to ensure the appropriate and sympathetic retrofit of solid walled houses, there must be an increase in the knowledge of professionals relating to these properties.

It may be helpful for a recognised standard or badge for those that meet the necessary standards – an accreditation scheme focused on specific property types, for example. If, as this research suggests, the priority of the householders is the condition and character of their property and not its levels of energy efficiency, then bad experiences of professionals is likely to reduce the possibility of householders 'risking' any additional damage or devaluation through further retrofit. Refurbishment services need to understand what the householder values and build a relationship with them, in order to establish a bond.

## Time

Householders often feel that they do not have enough time to make home improvements. This not only includes the home improvement itself but also the time needed to look around for ideas, identify suitable professionals and make decisions on changes. Comments from our householders relating to the absence of specific home improvements such as 'I haven't got around to it' suggest that, for some, any spare time is spent doing other things. It would appear that the barrier of 'time' is not necessarily the lack of time, but purely the householder's perception of time. This is closely related to the personal capacity of the householder – some people felt that they had limited capacity to make home improvements, perhaps due to their life stage or other commitments, whilst others relished having an ongoing home improvement project.

Households who find that 'time' prevents them from making home improvements to their house are likely to be more receptive to professionals offering a project management approach to home improvement, e.g. recruiting a trusted professional to both undertake and manage the improvement process, including the sourcing of required specialists, purchase of materials, etc. Similarly, if it is easy for the householder to contact and commission a particular supplier whom they know and trust, then tasks will be perceived as less onerous and so more likely to be undertaken. Such householders may also respond positively to being approached by professionals soliciting work when they have not found time to investigate potential options for themselves, but trust is still likely to be a key issue in such circumstances.

## Property features

Of the 4.5 million homes in the UK that have solid walls (DEFRA, 2008), many have particular features that can make home improvement more complex. This can include period features and problems relating to the design and layout of the house (see Figure 14.3).

The most common example of this is evident when replacing windows in older properties, where non-symmetrical features and non-standard window recesses can make it difficult to install modern windows. Unusual or misshapen features can also lead to the need for bespoke and therefore more expensive solutions, which can deter householders from making changes. Some properties have been irreparably changed

**Figure 14.3** Common property features and layout of solid walled houses.

or damaged by previous owners, which has a long-term impact on the changes the current owners are able to make. In addition, uneven floors and non-standard foundations can prevent householders from making changes. In some cases, where properties have been adapted from commercial to domestic use, original features and layout remain that restrict future home improvement, including the implementation of energy efficiency measures or technologies. The shape of older properties and the close proximity to neighbouring houses also causes householders frustrations when it prevents them from extending to meet growing family commitments. In some cases, this means that the household has to move to a different property in order to meet their needs.

The property features commonly found in solid walled houses and the barriers these introduce when implementing home improvements are of particular importance when trying to increase domestic retrofit, as many hard-to-treat homes from the Victorian era and earlier present similar issues. The barriers relating to property features are of particular importance when viewed in conjunction with people's attitudes to older properties. Many of our householders wanted to keep their property 'in keeping' with other houses in its location or houses from its era, which may be seen as maintaining part of our national heritage. They spoke with a definite fondness for the features commonly found in older properties, such as high ceilings, deep skirting boards, ornate ceiling mouldings and intricate brickwork. Even if householders have the motivation to make energy efficiency changes to their homes, it is possible that older property features will still prevent these changes from being made.

Therefore it is essential that the design of the retrofit process, products and relevant policies allow older properties to keep their character and style, whilst still improving their energy efficiency.

## Other barriers

Although the barriers discussed here are those that appeared with highest frequency in discussions with householders, there were a number of other barriers that were uncovered in the interviews. The household's stage of life sometimes prevents or delays home improvement, e.g. starting a family, entering older age or having elderly parents living with the family. The perceived size or difficulty of a task, including the thought of what needs to be done prior to the job being completed, can also be a barrier. Some householders are overwhelmed by the difficulty of a job and so fail to do anything at all. Perceptions of how regulations might affect home improvement also prevent work from being undertaken. Householders perceive that there might be difficult issues to resolve and so are put off pursuing a project. These concerns may be unfounded, but are sometimes based on the bad experiences of others. Perception of the level of possible disruption that the home improvement might cause to the household and daily life is also a significant barrier. Experiences from previous jobs can affect perception of future likely disruption. This barrier is also related to the life stage, as the impact of disruption can increase at different stages of life. The weather or commitments associated with a particular time of year, such as school holidays or Christmas, means that some home improvements only occur when they fit in with other events in a household. It is also not uncommon for householders to have problems getting hold of suitable parts or products to improve their house in keeping with its age, as some traditional parts have become difficult to obtain.

The decision to undertake a home improvement requires the members of the household to reach a consensus on what should be done, how it should be done and whether the cost is justified. In some of our study households and often numerous times within a household, the lack of consensus between household members meant that an improvement was delayed until a decision or compromise could be made; this delay could last for many years. This relates to the perceived personal or emotional capacity of an individual or household to take on a task when they do not feel able to undertake a home improvement, perhaps lacking motivation or energy. There may not be any tangible reason behind the decision – just the householder's own impressions of their capacity at that time. People described themselves as 'burying their heads in the sand' over home improvement decisions. A lack of information, receiving contradicting information or misunderstanding can lead householders to misjudge the size, scale and type of home improvement required, as well as not appreciating the likely benefits. Finally, householders can be reluctant to carry out home improvements if they expect to move in the near future. However, opportunities to increase the resale value may encourage retrofit at this stage.

## What does this mean for the future of domestic retrofit?

This chapter has highlighted and discussed a range of interrelated and sometimes rather intangible barriers to making home improvements to older, hard-to-treat homes. These build upon the three primary barriers of Information and Awareness, Hassle and Cost, identified by the Energy Saving Trust (2011). The Green Deal has been designed to relieve the financial barriers to making energy saving improvements to existing homes. However, it is thought that many householders will still resist taking advantage of the scheme because of the wider social and emotional barriers to change. Whilst social norms are deeply embedded, it is possible for them to shift and new behaviours can develop into new norms (Shove 2003). We have unpacked a range of barriers that can cause inertia or even halt projects for many years. Factors relating to personal capacity, perceived difficulty of a job, likely disruption and inability to reach consensus with a partner have all been highlighted as reasons why home improvements have not been undertaken as expediently as they might have been.

The barriers discussed show that many of the factors are particular to older properties. Many householders choose to live in older properties at least partly because of their character and appearance. Features are lovingly restored and preserved even in the face of compelling financial reasons to modernise. There is clearly a need to better understand the priorities, values and aspirations of these owner occupiers who choose to live in harder-to-treat homes. This is needed in order to equip both policy makers and building professionals with the specialist knowledge that is needed to sympathetically retrofit energy saving measures whilst maintaining the character of the house and overcoming the idiosyncrasies of older properties. The depth of older property-related knowledge held by many of the householders spoken to was surprising, causing great frustration when professionals did not share the same specialist knowledge. Clearly, competent and appropriately skilled professionals are required to meet the expectations of these householders. In addition, householders need to be able to trust the professionals and contractors who are part of the retrofit process. The Green Deal hopes to address this issue by accrediting certain contractors, which allows them to carry out work financed by the Green Deal, but this accreditation process may not be sufficient to instil a sense of trust amongst householders. It is essential that professionals are able to build a working relationship with a householder; to ensure both parties understand the work to be undertaken, that a reasonable level of communication is available and to ensure that the householder can trust the professionals to respect the character of their property.

The desire by householders to carry out work as do-it-yourself (DIY) projects also needs to be acknowledged, addressed and, where possible, made an available option for retrofit. Those householders who enjoy and gain much satisfaction from performing DIY improvements to their homes are unlikely to want to suffer any reduction in savings because they have had to pay someone else to do the work. In addition, it is likely that the pride and emotion felt by many towards their older properties is strongly linked to the personal efforts that have gone into the home improvement process. We have seen television advertisements for home improvement stores that tap into the 'I did that' pride of working on one's own home and it is important to remember that simply paying a professional to do the work is unlikely to provoke the same emotional attachment and response. It is also important to facilitate the kind of piecemeal approach to home improvement that householders seem to prefer. It seems rare that householders will allocate a large block of time to get everything done, but would rather do smaller jobs spread out over time. Households may commit to doing one home improvement a year and do not feel they have either the time, personal capacity or finance to do any more than this, or to sustain the level of disruption for any period of time. It is important that policies such as the Green Deal enable householders to carry out work in a similar fashion to the way they have been used; expecting too much change at once may well result in a lack of action.

New initiatives will also need to address the issue of planning and building regulations. Rigid policies do not allow householders the flexibility that they have had in the past, which can lead them to find 'workarounds' or to seek professionals that will 'bend' the rules. The choice of professionals to carry out home improvements on a house is influenced by more factors than purely their skill to do the required job. Many householders valued knowing the professional above their specific skills. General tradesmen who are familiar to the householder may therefore be favoured for jobs above specialists because they are trusted and because of the convenience of using the same person or firm for a number of jobs instead of having to source and hire a number of different people. It is imperative that future major retrofit programmes are able to accommodate this.

It is worth remembering that the rate of change that people are willing to tolerate is remarkably slow, as a result of the barriers identified here and elsewhere. At some point there may be a need to bring in an element of compulsion, to enforce a level of change, especially if large numbers of households are expected to make big changes within a relatively short period of time. However, even if a degree of coercion is introduced then retrofit will be most successful when the needs and behaviours of householders are taken into account.

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# 15 Low-energy design for non-experts: Usability in whole house retrofit

*Marianne Heaslip*

## Introduction

Housing currently accounts for 26% of the United Kingdom's (UK) carbon emissions. Reductions in emissions from this sector are considered easier to achieve relative to other sectors and it is therefore likely that the housing sector will be required to achieve at least an 80% reduction in emissions by 2050 (Swan *et al.* 2010; European Commission 2011). With at least 80% of the housing that will exist in 2050 already built, it is this mass-market that must be addressed (Boardman 2007). However, there is emerging evidence of a 'performance gap' between predicted and actual energy use in buildings, often blamed on 'user behaviour', which could endanger these targets (Gill 2010; Kinver 2011; Spring 2011). At the same time frustrations experienced by residents of new-build low-energy housing schemes have highlighted usability as a significant issue – for occupant satisfaction and potentially also for energy use (Bell *et al.* 2010; Monahan and Gemmell 2011). However, studies that link resident attitudes and satisfaction with energy use and physical outcomes are rare (Stevenson and Leaman 2010).

The Technology Strategy Board (TSB) 'Retrofit for the Future' programme aimed to achieve an 80% reduction in carbon emissions from individual homes (Technology Strategy Board 2009a). This was an applied research programme funded by the UK government with the aim of testing retrofit solutions. Eighty-seven projects were undertaken in total, covering over 100 homes, all in the social housing sector. The author was a member of the design team in two of these projects, covering ten houses in total. Seven of these households agreed to participate in further evaluative research during the first year of occupation of the newly retrofitted homes. These case studies considered the resident's ability to achieve their everyday goals with 'effectiveness, efficiency and satisfaction'.

Usability was a focus for this study because of its potential to shape and influence the design process. It acknowledges that the success of any 'technological' system is dependent on the relationship between the technology and the people who use it, with

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each influencing the other. This places more responsibility – but also potentially more power – in the hands of the designer. In the context of low-energy building design and retrofit it means it is not acceptable for the designer to simply blame 'user behaviour' for poorly performing designs. Usability has proved to be valuable in the evaluation of whole house retrofit, explicitly linking 'behavioural' and 'technological' aspects in context and bridging a gap in the research identified by others. It also suggests that usability needs to be approached both strategically and tactically, considering the diversity of users and their goals and habits, as well as the design of controls.

## Why worry about usability?

Usability is a common concern in software, web and product design (Green and Jordan 1999; Rubin and Chisnell 2010), and there is increasing interest as to how this can aid more sustainable behaviours (Lockton *et al.* 2008). Originally popularised by Donald Norman, his observation of the common occurrence of 'mechanical ineptitude' led him to look for causes other than 'human error'. His seminal book, *The Design of Everyday Things*, suggests that it should be possible to design complex products and systems that can be used without frustration and also without constant reference to an instruction book (Norman 1998). He advocates a user-centred design process and states that the designer should not see a simple dichotomy between errors and correct user behaviour, but that '… the entire interaction should be treated as a cooperative endeavour between person and machine, one in which misconceptions can arise on either side' (Norman 1998, p. 140).

Usability is therefore not only concerned with the attributes of the product but is also defined by the understandings and cultural influences of the users. Good usability is achieved when the designer has considered the goals of the user at a strategic level and made the 'conceptual model' of the design visible to the user (Norman 1998, 1999). The tactical usability of a product in the design of controls is insignificant if its purpose is not valuable to the user (Rubin and Chisnell 2010, p. 10). Usability is therefore defined as much by the person attempting to use a product, their goals and the context in which the product is used as by the innate properties of the product itself (Wever *et al.* 2008, p. 8). This is encapsulated in the International Organisation for Standardisation (2002) definition of usability:

> The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

This user-centred approach to design is perhaps one of the reasons for the success of a company like Apple, which is able to mass-produce intuitive designs for increasingly complex products. Buildings may not be mass-produced in the same way, but the work of the PROBE studies and the Usable Buildings Trust, amongst a few others, has shown how the principles of usability can be applied to research and design in the built environment and can be key to the success or failure of buildings (Way and Bordass 2005, p. 355; Usable Buildings Trust 2012). Indeed, former Apple designers are moving into building control design (Wollman 2011) – though, as will be argued here, usability in buildings should cover a range of issues broader than the design of thermostats.

Much of the research on low-energy housing to date has focused on quantitative evaluations of new technologies and building physics or attitudinal surveys of residents, with little crossover between the two. Whilst necessary to improve physical infrastructure, the focus on technology in isolation has been criticised for ignoring the social and psychological aspects of energy use (Guy and Farmer 2001; Stevenson and Leaman 2010). There is also now a growing interest in how people actually use and operate buildings and the impact of this on energy use (Churcher 2010; BSRIA 2011; Monahan and Gemmell 2011). Due to this, 'user behaviour' has sometimes been blamed for the 'performance gap' between design-stage predictions and actual energy use in buildings, and for the failure of energy efficiency programmes – with 'comfort takeback' a particular concern in retrofit (Technology Strategy Board 2009b; Gill 2010; Stevenson and Rijal 2010, p. 550; Kinver 2011; Murray 2011; Spring 2011).

The idea that 'buildings don't use energy, people do' (Janda 2011) is a potentially attractive one for the construction industry, as they can claim to have only limited influence (BIS 2010; Zero Carbon Hub 2010). However, the evidence to support this stance is inconclusive, with many studies cited being decades old and from contexts that differ from the super-insulated homes now common in both retrofit and new build. It is also contradicted in UK housing by case studies of recently completed low-carbon housing that show much of the 'performance gap' to be due to incorrect assumptions in design stage modelling, poor detailing and construction quality control, and poorer than predicted physical performance of heating and ventilation systems (Wingfield *et al.* 2008; Bell *et al.* 2010; Zero Carbon Hub 2010). Statistical analysis and modelling of the existing housing stock, both in the UK and abroad, has found that the built fabric and the performance of heating systems are the most significant factors in energy use in homes, with user behaviour a lesser and often dependent factor (Firth *et al.* 2010). It would therefore seem sensible to re-examine these issues in the context of higher performing physical infrastructure required to achieve an 80% carbon emissions reduction target.

Despite this, the proposition that user behaviour has some influence on energy use still appears to be sound within limits, with multiple-case surveys of recent low-energy housing developments showing a significant difference in energy use between households in physically similar properties (Gill *et al.* 2010). However, as has proved to be the case in Passivhaus standard developments, this variation may be about a very low mean – 50% of not much is still not much (Feist 2012). Programmes to influence user behaviour in more standard homes have shown measurable results (Guy 2011; Worthing Homes 2011) – though whether these changes are permanent or temporary is difficult to determine.

'Attitudinal' programmes on household energy use have been criticised for failing to recognise constraints such as user knowledge, psychological factors, social norms, habits, socio-demographic patterns and physical conditions, all of which act to limit and 'lock-in' particular behaviours (POST 2010; Philips and Rowley 2011). By instead examining behaviour in context we can see that individuals should not be considered as rational free agents and that research should attempt to understand the dynamic relationship between these social and material worlds (Moffat and Kohler 2008, p. 264). A 2009 TSB seminar criticised the idea that people wilfully mis-use buildings to waste energy, as often seems to be assumed by those who blame 'user behaviour'. Instead people simply try to achieve their aims in a given context and it is up to designers to understand better both user aims and context (Technology Strategy Board 2009b). A study of Danish housing showed that even those who want to reduce their energy use may not be able to do so because of lack of knowledge or physical and design constraints (Gram-Hanssen 2010). With the retrofitting of existing buildings described as 'a myriad of tricky interacting problems' (Lomas in Technology Strategy Board 2009b, p. 12) it seems that a focus on usability, which is concerned with precisely these interactions, may prove useful.

## Housing: residents and context

Housing is among the least 'complex' of building types. However, as environmental performance standards have increased, so has the level of technological complexity in homes (Cole 2008; Stevenson and Rijal 2010). Increased building system complexity can result in unintended consequences and 'revenge effects', as users struggle to understand and control systems, or even to diagnose problems and carry out maintenance. If anything, these concerns should be greater in housing, where residents are in effect untrained facilities managers (Stevenson and Rijal 2010).

To achieve the UK's carbon emissions reduction commitment, the majority of homes must undergo some form of retrofit in the next few decades. In considering who might inhabit these homes, the work of Donald Norman is again of interest. He suggests that whilst 'pioneers' are willing to suffer inconvenience, expense and effort, the mass market is much more interested in convenience, reliability, price and appearance and much less interested in the technology itself (Norman 1999). To date, retrofit has been developed mainly by enthusiasts with a high level of personal and professional interest in the subject (for example, my colleague, Charlie Baker, a member of the UK Superhome Network (SEA undated; Baker 2009)). As such, they are unlikely to be representative of the wider population, where take-up of even small-scale energy efficiency measures is low despite the 'objective' advantages (Oxera 2006). Whilst we know that the 'users' in the case of whole house retrofit are the broad spectrum of the UK population, little is known about how they will respond to the technologies of whole house retrofit.

## Effectiveness, efficiency and satisfaction

This raises the following questions: 'Can people exercise effective control through the interfaces provided?', 'Are they able to do so efficiently in terms of effort, energy and time?' and 'Are they satisfied with the results?' (Leaman and Bordass 1997). Post-occupancy evaluations of low-energy housing have shown that users often have a poor understanding of technologies and control systems, resulting in a lack of effective control with potential knock-on effects on energy efficiency and user satisfaction (Macintosh and Steemers 2005; Bell *et al.* 2010; Stevenson and Rijal 2010; Monahan and Gemmell 2011; NHBC 2012).

Combe *et al.*'s study of the usability of heating controls found that of 12 participants set a simple programming task on their heating system interface, 8 were unable to complete it (Combe *et al.* 2011, p. 89). Rather than blaming the users for their lack of understanding this failure is instead ascribed to a failure on the part of designers to consider the cognitive, manual and visual abilities of users. Elderly users in particular struggle with tasks that require visual and manual dexterity, suggesting a need for inclusive design strategies (Critchley *et al.* 2007; Hong *et al.* 2009; Combe *et al.* 2011; NHBC 2012). However, whether an inability to programme heating systems is significant in terms of energy use is debatable. Most users in the Combe and Critchley studies were still able to control their heating, although by using the programmer as a manual switch. Interestingly, and perhaps counter-intuitively, Shipworth's study of UK central heating systems found no statistically significant difference in energy use between those who control systems manually and those who use timers and thermostats, raising questions about the Energy Saving Trust's claim that advanced heating controls result in average savings of 17% (Shipworth *et al.* 2010, p. 65). Case studies of air-conditioning units have found similar results (Kempton *et al.* 1992; Lutzenhiser 1992). 'Better' controls as currently understood may not necessarily result in reduced energy use. Rather than simply assuming that more and better timers, thermostats and programmers will result in reduced energy use, user response needs to be better understood to find the appropriate place within the control system for users, and thereby maximise potential energy savings.

A move away from automation, which attempts to solve the problem of user behaviour by removing the user from the control loop, may in fact be beneficial (Nicholl and Perry 2009). A framework of usability leads us to consider what the implications might be if the design goals assumed by automated systems do not match the variable needs of the users (Leaman 2000; Stevenson and Rijal 2010). They may also lock unquestioning users into patterns of higher energy use – for example where the assumed design comfort temperature is higher than the user's actual comfort temperature (Stevenson and Leaman 2010, p. 438). Similarly, they may lead to reduced satisfaction, with potential impacts on the success of a scheme or acceptance of a technology (Nicol and Roaf 2005, p. 338). Heating systems controlled solely by a thermostat with no boost function have in some cases resulted in residents replacing the thermostat with manual controls or introducing a 'boost' in the form of plug-in electric heaters (Crosbie and Baker 2010, p. 75). These concerns are significant in any mass-market programme where individual household performance may be affected, but also in perceptions and therefore wider take-up of the technologies involved.

## User goals in whole house retrofit

Whole house retrofit as a context for research and intervention has an advantage in understanding user goals and practices, as residents are likely to be in situ. Current practices can be investigated and designs can attempt to accommodate actual user behaviour (Crosbie and Baker 2010; Gill *et al.* 2010; Gupta and Chandiwala 2010). Residents have complex and interrelated goals, many of which vary over time and context; these are likely to include thermal comfort, saving money, avoiding waste and good aesthetics (Crosbie and Baker 2010; Gram-Hanssen 2010; Stevenson and Leaman 2010). At the same time, designers of low-carbon housing often work towards a set of tightly defined targets, driven by regulations, industry standards and design stage modelling using methods such as SAP (Standard Assessment Procedure). These design models are rarely subject to sensitivity testing. In contrast, a key conclusion from the PROBE studies was that designers should seek to accommodate a range of potential needs, rather than design to specific targets, in order to make buildings more resilient, rather than tightly coupled and fragile (Leaman and Bordass 2007).

Space heating was responsible for 53–58% of energy use within UK homes in 2007 (Firth *et al.* 2010; Swan *et al.* 2010). In a super-insulated home it is likely that this proportion will be much reduced. However, the importance of thermal comfort to resident satisfaction, and the need to ensure that low-energy design targets are met, means it is worth examining space heating systems in retrofit in some depth. The notion of thermal comfort is widely debated and theories of adaptive comfort have gained ground in recent years. These suggest that rather than being a purely physiological phenomenon, thermal comfort is dependent on the perceived degree of user control as well as climatic, psychological and cultural influences on the user. As a result, it is suggested by Roaf and others that, within reasonable limits, there is no need for internal environmental conditions to be tightly controlled for thermal comfort to be achieved (Roaf *et al.* 2009; Humphreys *et al.* 2011). Whilst the majority of research in this area has been carried out in non-domestic environments, a number of studies have shown that actual comfort practices in homes can vary significantly from the assumptions made in regulatory energy models like SAP (Critchley *et al.* 2007, p. 155; Hong *et al.* 2009, p. 1233; Gupta and Chandiwala 2010, p. 539; Shipworth *et al.* 2010, p. 51). This suggests that there are actually two potential performance gaps in our homes; the first in energy use, the second between assumed and actual comfort-related behaviour (Brown and Cole 2009, p. 229).

Normative standards may themselves influence the goals and expectations of residents. If, rather than being purely physiological, user's goals are shaped by their technological and cultural context, can this lead to houses designed to accommodate technologies that satisfy unquestioned norms rather than physical needs (Shove 2003, 2004)? This tendency was demonstrated in the case of the Salford Eco-House where residents demanded what they recognised as a standard central heating system with a gas boiler, even though none was required to achieve physiological definitions of thermal comfort in these super-insulated homes (Brown *et al.* 2011).

Given the above, is it possible for designers to turn this on its head and create environments in which people can 'make themselves comfortable'? Can comfort be viewed as an achievement by the user, rather than an attribute of the building (Shove 2003, p.36)? This links back to notions of usability and calls for a greater understanding by researchers and designers of the complex interactions between people, technology and environment. 'Interactive adaptivity' is suggested as part of the toolkit for low-energy building design, with the potential to increase both user satisfaction and energy efficiency (Stevenson and Rijal 2010; Brown and Cole 2009; Cole *et al*. 2008). The presence of adaptive opportunities, that is the ability of users to control and change their environment, relies absolutely on the presence of good usability. By encouraging designers and others to consider not just the technology but also the goals and the abilities of those using it, and the interactions between these, usability may be a key factor in the success of 'whole house retrofit'.

## Unanswered questions

Usability helps to resolve the dichotomy between 'behaviour' and 'technology'. It also encourages an investigation of the diverse needs of users and opens up opportunities for designers to maximise energy savings. Failures in usability have been shown to have adverse effects on energy use and user satisfaction. However, much of the above discussion relies upon studies of new-build low-energy housing, rather than being specific to whole house retrofit. Many figures given for energy use in whole house retrofit are based on modelled rather than measured values (SEA undated; Technology Strategy Board and AECB undated) and few studies of user satisfaction appear to have been conducted. Though likely to change in coming years with the completion of programmes such as TSB's 'Retrofit for the Future', there is currently a dearth of information on usability in low-energy housing in general and whole house retrofit in particular.

## Case studies

To improve our understanding of whole house retrofit and the potential relevance of usability it is important that we not only find out 'what' is happening in households but also 'why' and the 'how'. In order to illustrate the complexity of usability, the remainder of this chapter outlines the findings from a recent research project. This examined the behaviours and motivations of users through case studies in a real world context – in seven physically and geographically similar homes that were part of the TSB 'Retrofit for the Future' programme. The multiple linked case study format allows emergent themes to be compared across similar circumstances, providing a rich dataset for analysis. The case study methodology drew on the PROBE studies and the work of others in building performance evaluation (Stevenson and Rijal 2010) and took the stance that building research '…should be no more than one step away from a design decision' (Leaman and Bordass 2001, p. 130). A mix of qualitative and quantitative, established and innovative data collection methods were used, in an effort to 'triangulate' the data in this complex, multivariable context (see Table 15.1).

**Table 15.1** Data collection methods.

| **Method*** | **When?** | **Recorded?** |
|---|---|---|
| Project design information. As a member of the design team, the author had access to detail drawings, outline specifications, SAP calculation sheets and project team meeting minutes. These data have been used to provide information on the context of the case studies examined. | During design process | Drawings, schedules, minutes. |
| Initial interview. This semi-structured interview took place as soon as possible following the completion of works in the residents' own homes. This was intended to gather initial impressions and ask questions of the residents' motivations for involvement, as well as testing attitudes towards technology and environmental issues. | Within 1–3 months of PC | Notes and audio recordings* |
| Unstructured resident diaries. At the initial interview the researcher supplied each resident with either a small notebook or hand-held video camera so they could record issues they felt were significant to them. | From initial interview to final interview | Written and video recordings |
| Main interview. A semi-structured interview conducted at the end of the first heating season in the retrofit households. Its aim was to gather more in-depth information on users' experiences, focusing on usability and thermal comfort. | 4–6 months after PC | Notes and audio recordings* |
| Walk-through and usability surveys. These were conducted at the same time as the main interview. The walk-through was resident led, so areas of concern were highlighted. The format for the usability survey was adapted from the BCIA control design guide (Bordass *et al.* 2007) | 4–6 months after PC | Video recording, usability survey form and notes* |
| Final interview. This took place in the residents' homes in Autumn 2011, approximately one year after the completion of the work. It was an opportunity to check on summer conditions and changing user perceptions. It was also a chance for the researcher to check initial findings with the residents. | 11–13 months after PC | Notes and audio recordings* |
| BUS questionnaire. This standard format questionnaire was delivered during the final interview, licensed from the Usable Buildings Trust. | 11–13 months after PC | Questionnaire form completed by resident |

(*continued*)

Table 15.1 (*Cont'd*)

| Method* | When? | Recorded? |
|---|---|---|
| Energy and environment dat.: The author was given access to the BSRIA online monitoring database. Where possible, data from this were also checked manually on site during visits. | Continuously from installation of monitoring kit; meter readings, bills and spot checks during site visits by author | Automatically transmitted to online database, administered by BSRIA on behalf of TSB; research diary |

*Residents were only recorded with their permission. In cases where residents did not wish to be recorded, fuller notes were taken.

## Household context

The houses in this study were all three-bedroomed mid-twentieth century built social housing with front and rear gardens. All were lived in by the same residents before and after the retrofit works. Data on prior performance is limited, though anecdotal evidence suggests that they were uncomfortable and expensive to heat and available utilities bills support this. The TSB 'Retrofit for the Future' programme set absolute design targets for total carbon emissions and primary energy use of 17 $kgCO_2/m^2$/year and 120 $kWh/m^2$/year respectively – to include both 'regulated' emissions from heating, lighting and ventilation and 'unregulated' emissions from appliance energy use and cooking. This was calculated at the design stage using SAP (Standard Assessment Procedure) 2005 for regulated emissions and a customised extension sheet provided by the TSB to cover 'unregulated' emissions. The design team was keen to keep costs and disruption to a 'replicable' level and a construction budget of £25,000–35,000 per house was set. A 'fabric first' design approach was taken, prioritising savings through demand reduction with a high-performing built fabric and efficient services – reducing space heating demand by around 90%, reducing hot water demand through water efficient fittings and reducing electricity demand by the use of efficient lighting and 'master switches' for appliance circuits. Different combinations of heating, ventilation and renewable energy technologies were trialled in each house, following interviews with each of the residents to glean information about lifestyles and acceptable levels of disruption (see Table 15.2). Construction works took place during summer and autumn 2010. A variety of ages, genders, occupancy patterns, household structures and levels of cost and environmental consciousness and technical confidence were present across the seven homes (see Figure 15.1).

## Complexity and control

Findings from this research point to the importance of the relationships between complexity, control and comfort – and thereby also user satisfaction and energy use.

**Table 15.2** Household design specifications

| REF | house type | GIA | walls | roof/ loft | doors | windows | floor | bridging | air-tightness | verrtilation | heating + hot water | solar | water | lighting | electrical | cooking | white goods |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A** | semi-detached | 82.6 | external wall insulation to 0.15W/m².K | Loft insulation 0.1W/m².K. Insulated air-sealed loft hatch. High performance insulation to prevent cold bridge at eaves. | New high-performance doors –1.0W/m².K | New high-performance triple glazed windows –0.8W/m².K | external insulation trench –0.44 W/m².K | thermal bridging Y-value maximum 0.5 | 5 cu.m/hr/m²@50pa | Trickle vents + room MEV in bathroom and kitchen | SEDBUK 'A' Rated 28KW Gas Boiler | 2.4KwP Solar PhotoVoltaic System | Low-Flo showerfed from mains, 2/4l flush WC, spray taps, clocl+spray tap in kitchen | CFLs throughtout | Master-switch – downstairs and upstairs | Gas hob, electric oven | A++ Fridge Freezer and washing machine provided |
| **B** | semi-detached | 82.6 | | | | | | | | Humidity controlled passive stack system | SEDBUK 'A' Rated 28KW Gas Boiler | 2.4KwP Solar PhotoVoltaic System | | | | Gas hob, electric oven | |
| **C** | semi-detached | 86.6 | | | | | insulated new solid floor –0.19 W/m².K | | | MVHR | solar thermal + 12KW electric boiler bak-up | solar thermal – 8m² aperture evacuated tube collectors + 500L stratifying thermal store | | | | Induction hob, electric oven | |
| **D** | semi-detached | 86.6 | | | | | | | 3 cu.m/hr/m²@50pa | MVHR + exhaust air heat pump system | Solar thermal + exhaust air source heat pump (EASHP) | solar thermal – 4m² aperture evacuated tube collectors + 200L thermal store + 200l store in EASHP | | | | Induction hob, electric oven | |
| **E** | mid-terrace | 79.5 | | | | | new solid floor to rear –0.19W/m²K, suspended floor to front –0.15 W/m².K | | | MVHR | SEDBUK 'A' Rated 12KW Gas Boiler | solar thermal – 8m² aperture evacuated tube collectors + 500L stratifying thermal store | | | | hob, electric oven | |
| **F** | semi-detached | 79.5 | | | | | | | 5 cu.m/hh/ m²@50pp | Humidity controlled stack system | Wood burning stove with back boiler | solar thermal – 8m² aperture evacuated tube collectors + 500L stratifying thermal store | | | | Gas hob, electric oven | |
| **G** | semi-detached | 79.5 | | | | Replacement glazing units only | external insulation trench to rear 0.3 W/m².K, timber floor to front to –0.2 W/m².K | | 3 cu.m/hr/ m²@50pa | MVHR | SEDBUK 'A' Rated 28KW Gas Boiler | 2.4KwP Solar PhotoVoltaic System | | | | Gas hob, electric oven | |

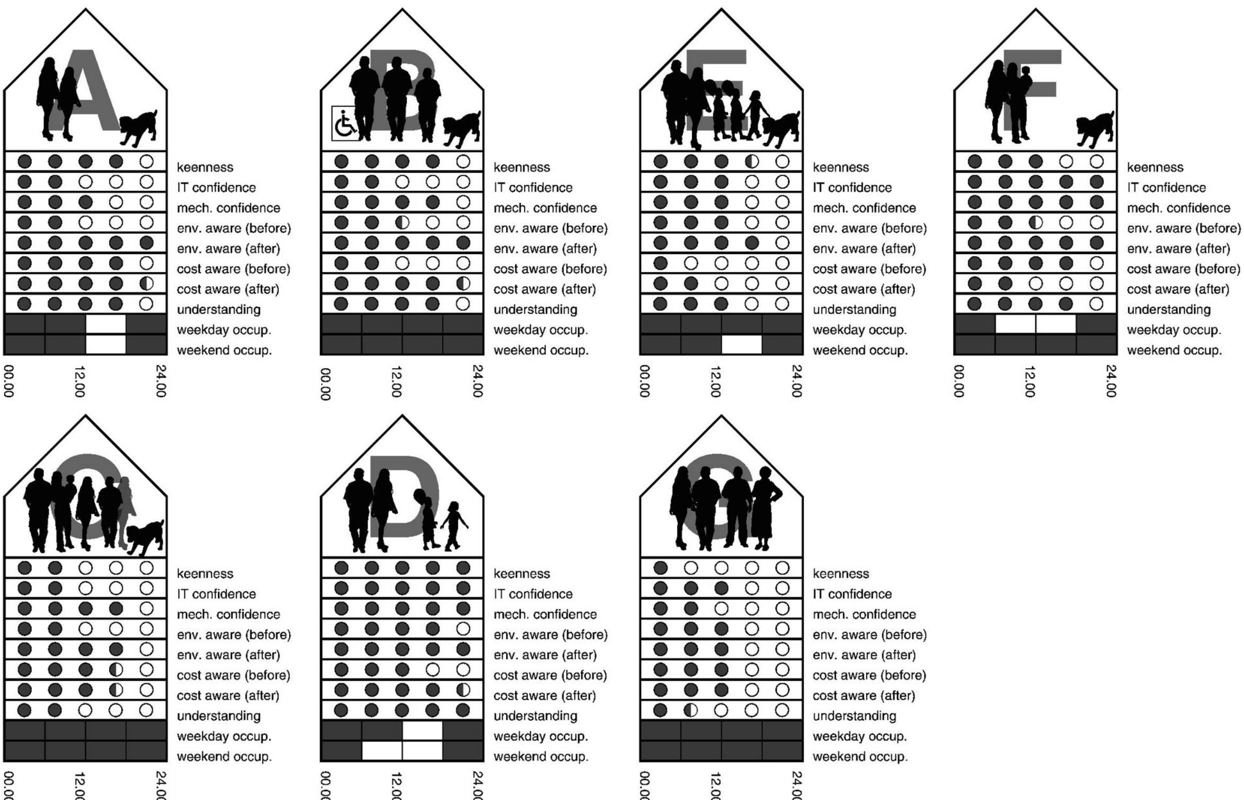



**Figure 15.1** User information.

However, they also demonstrate that these relationships are not straightforward and can sometimes be surprising. The heating system is examined in depth in each household, because of its central role on energy use and thermal comfort.

Households A, B and G have the most conventional heating system – a high-efficiency condensing combination gas boiler providing both space heating and hot water. Each has a programmable digital control with a timer, thermostat and range of pre-set options. However, none of the households use this enhanced functionality. Instead they use the programmer as a manual switch, flicking the system on and off to 'top up' the heating as needed, with the room thermostat acting as a limiter. Residents said they preferred to use the system in this way as they felt it gave them more control over comfort and the amount of money they spend on heating, and because they found the control panel overly complex. In Household G the perceived 'fiddliness' of the control panel was a particular issue for the elderly residents. These findings support the research of Combe and others into the usability of system controls and the failure by designers to consider the visual abilities and manual dexterity of the users. However, the also appear to contradict the assumption that manual control of domestic heating systems is inherently less efficient. All of these households are either below or just above the design targets for energy use – despite higher occupancy levels than assumed by SAP and also despite issues with airtightness and the MVHR system in Household G, which led to higher than expected ventilation heat losses. Households A and B are well below the design energy targets (see Figures 15.2–15.5). This may be due to their lower apparent comfort temperatures, which this system of control can accommodate easily (see Figure 15.6). Some of this may also be down to the milder winter of 2011/2012, though this is unlikely to be the sole explanation, as the same pattern is not repeated across all houses in the study. The failure to use the full features of the programmer is not detrimental in these houses, supporting the findings of Shipworth and Lutzenheiser described above and providing further evidence to question the EST claim of a 17% saving in energy from the use of more advanced controls – at least in the case of super-insulated housing.

All of the residents of these households reported a high degree of satisfaction with the systems and the thermal comfort provided, and all report a high degree of control (see Figure 15.7). Residents reported that there was no need to use the timer to 'warm the place up' before you get out of bed in the morning, in from work in the evening or even when arriving home from a few days away in the middle of winter. In these super-insulated houses, turning the heating on is an active choice when the residents feel the need. It seems likely that this influences the amount of fuel used by these cost conscious residents. They have been able to control these systems in a way that is highly responsive and adaptive to changing needs and circumstance – such as the activity levels of the residents (one resident reported that the heating is not required at all if the washing machine is on or if they are doing active housework). Though they are not using the programmer as intended by its designers, the presence of a simple on/off switch has enabled this altered use – and the high level of user satisfaction and effective control in meeting their goals.

The remaining households in the study had a higher degree of automation and complexity in heating system design. Increasing complexity does not automatically lead to detrimental effects. However, it does appear to place a greater emphasis on the

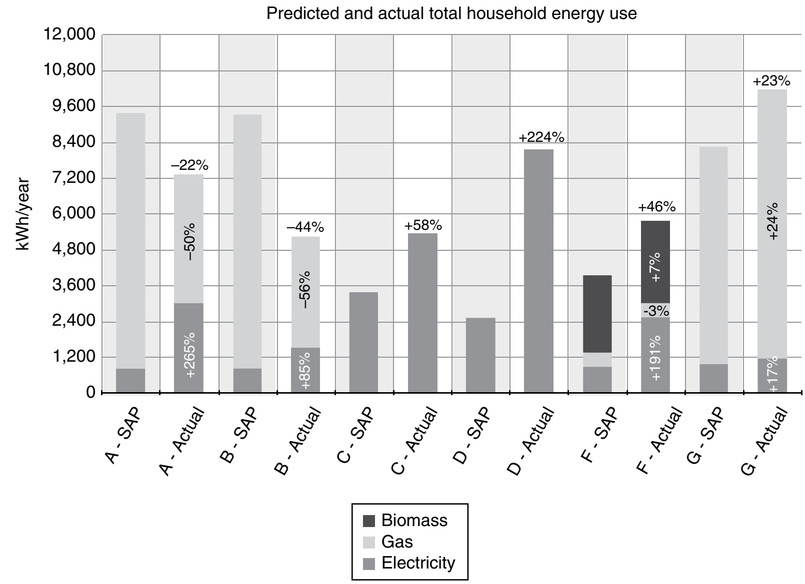



**Figure 15.2** Household energy use – predicted versus actual. *Notes:* Gas and Electricity meter readings from onsite monitoring by BSRIA from March 2011 – March 2012. Biomass use recorded and reported by resident . Total energy use included – 'regulated' and 'unregulated' energy. .

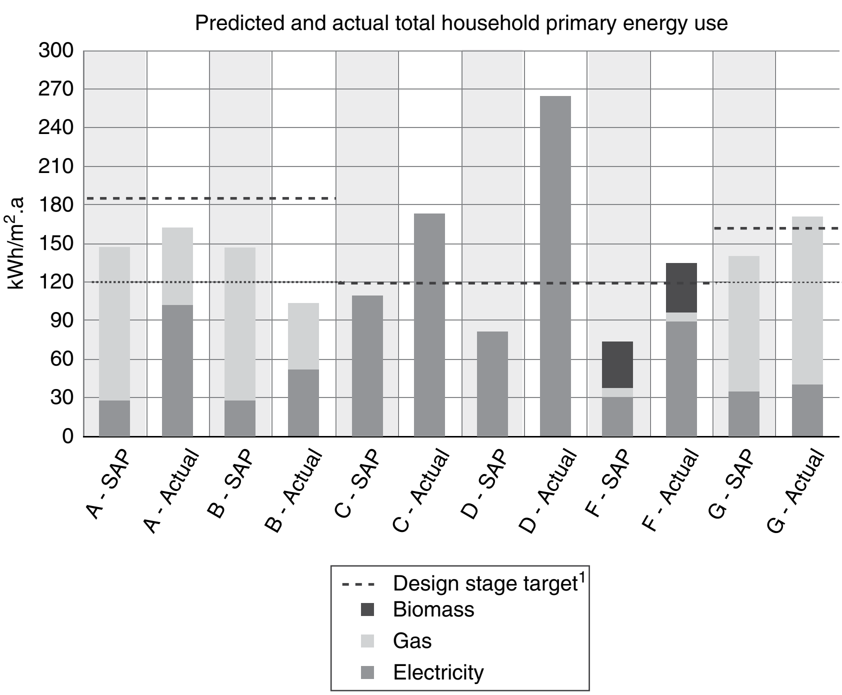



**Figure 15.3** Household primary energy use – predicted versus actual and design target.
*Notes*: 1. Houses A, B and G all have solar photovoltaic panels, which have not been considered or monitored as part of this study as they require little human interaction to function. Increased design stage 'usage' targets here (from 120 kWh/m2.a as required by the competition) are based on design stage SAP calculations and assumptions about PV electricity generation.
2. Primary energy factors as in SAP 2005: electricity 2.8, gas 1.15, biomass 1.1.

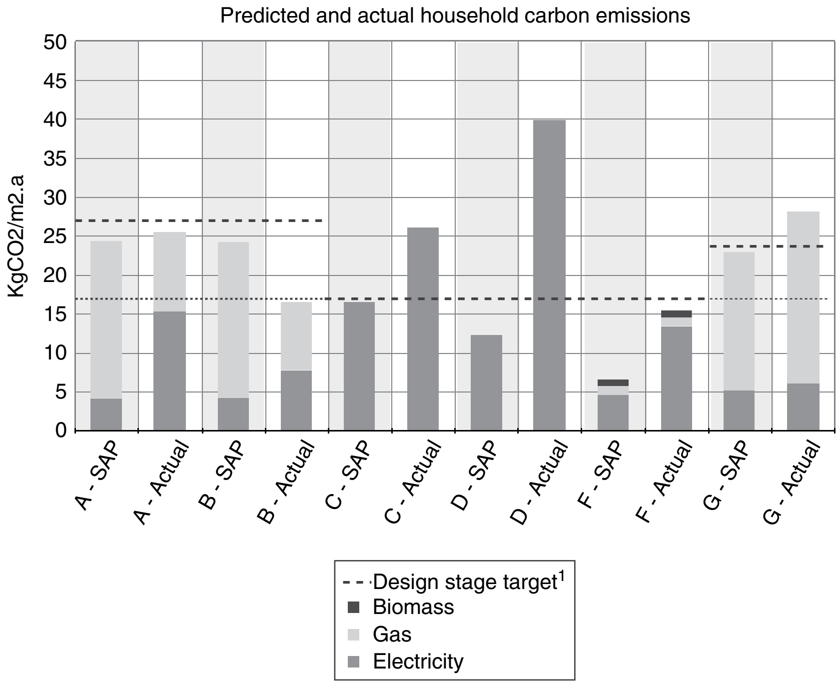



**Figure 15.4** Household carbon emissions – predicted versus actual and design target.
*Notes*: 1. Houses A, B and G all have solar photovoltaic panels, which have not been considered or monitored as part of this study as they require little human interaction to function. Increased design stage 'usage' targets here (from 17 kgCO2/m2.a as required by the competition) are based on design stage SAP calculations and assumptions about PV electricity generation.
2. Emissions factors as follows: electricity 0.422 kg, gas 0.194 kg, biomass 0.025 kg.

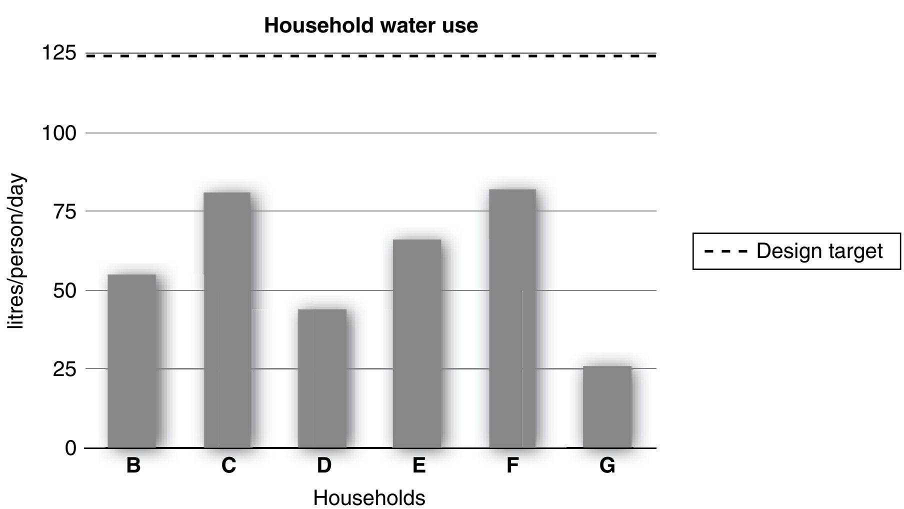
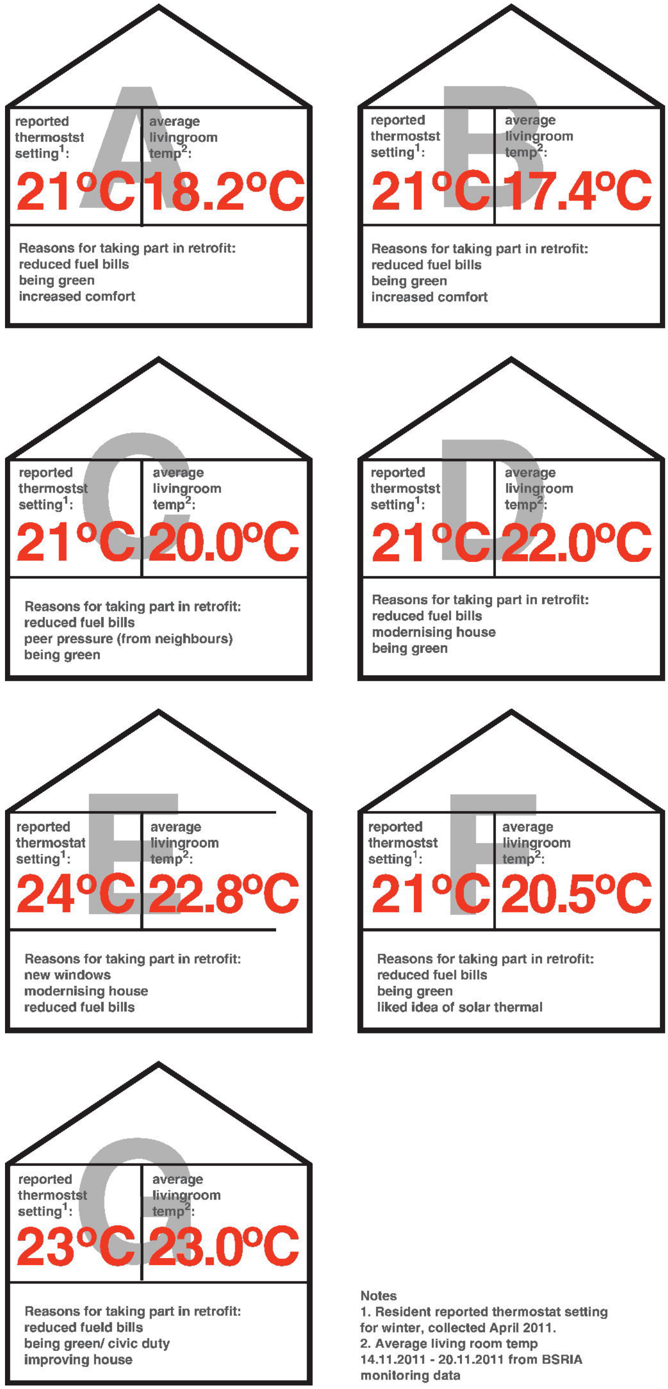


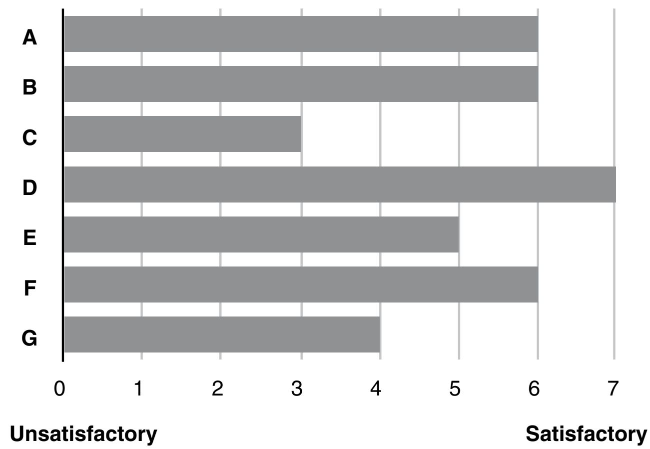

**Figure 15.5** Average household water use.
*Notes*: 1. No data available for household A due to fault with monitoring equipment.
2. In all cases based on actual number of people living in house, rather than SAP assumptions (e.g. In Household B, total water use divided by 3).



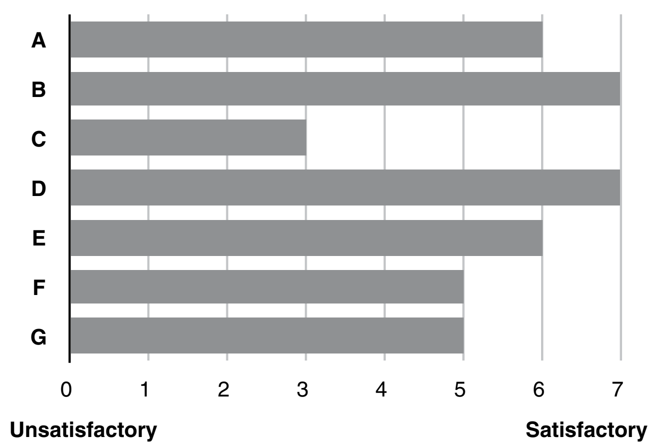

Notes
1. Resident reported thermostat setting for winter, collected April 2011.
2. Average living room temp 14.11.2011 - 20.11.2011 from BSRIA monitoring data

**Figure 15.6** User goals.

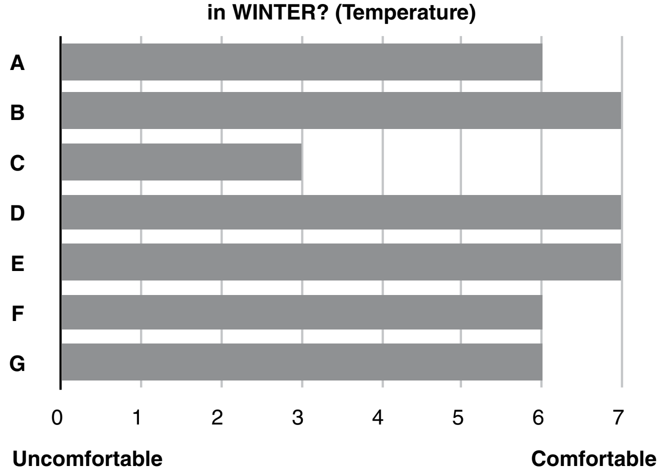
All things considered, how do you rate the design overall?




How would you describe typical conditions in WINTER? (Overall)




How would you describe typical conditions in WINTER? (Temperature)



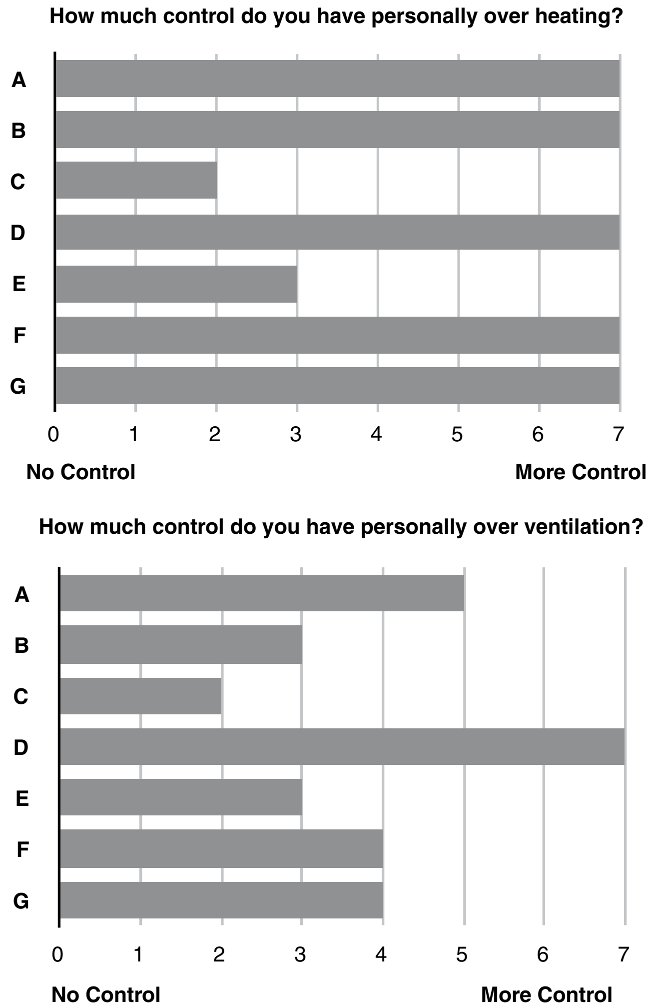



**Figure 15.7** BUS results – user satisfaction.

understanding and abilities of the user. Households C, E and F all had similar heating systems and controls, though with different fuel inputs. Electric, gas and biomass respectively feed into a large stratifying thermal store, alongside 4–8 $m^2$ aperture area of evacuated tube solar thermal collectors. The control for these systems is a small digital screen and push button unit in the hallway connected to a main controller unit next to the thermal store. These controls operate entirely by thermostat, with users required to programme in 'setbacks' for times when the temperature inside the house can be lower, for example at night. All of these residents called this method of operation into question. They pointed out that even in the winter of 2010/2011 it took approximately 24 hours for the internal temperature to drop by 1°C, so the

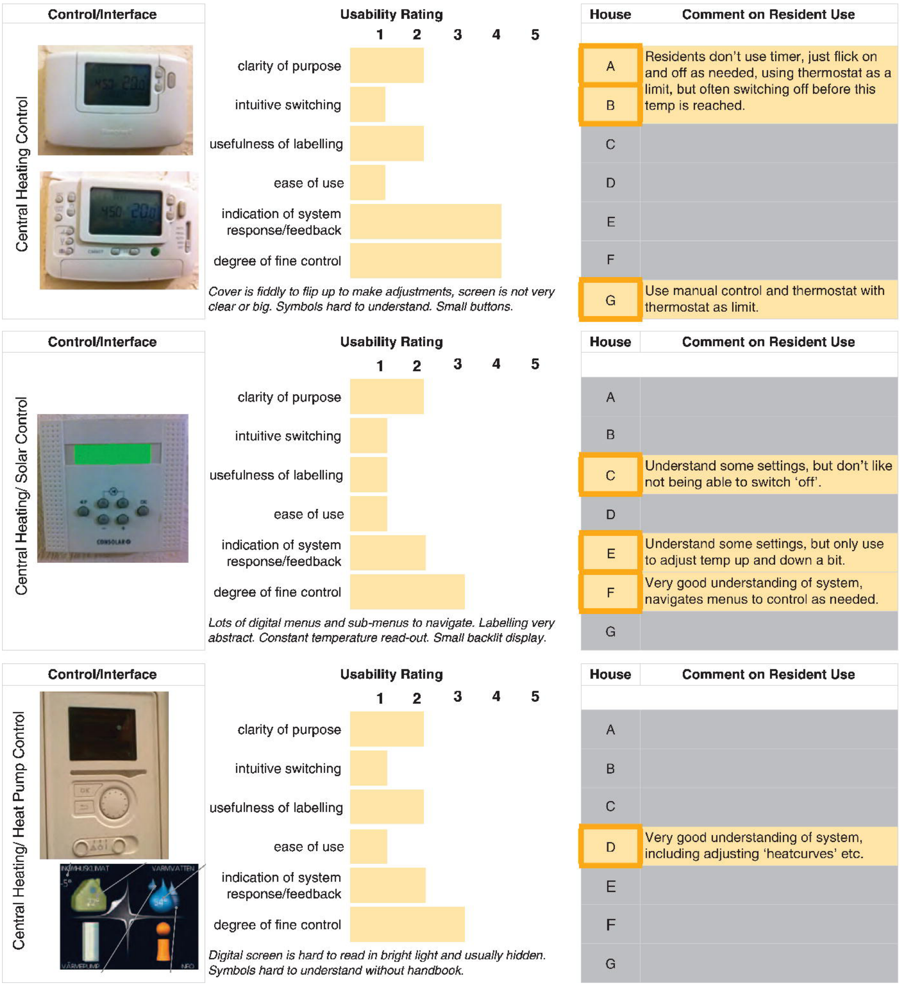



**Figure 15.8** Heating controls and usability ratings.

programming of diurnal 'setbacks' does not give them the responsiveness and degree of fine control they would like (and thereby failing on one of the key parameters of usability as set out by Bordass *et al.* in the PROBE studies).

Households C and E both struggled to understand the system and disliked the multiple digital sub-menus on the control panel (see Figure 15.8). Whilst Household E prioritised comfort over cost, and were satisfied so long as their comfort goals were met, Household C resented the fact that they could not simply switch the system 'off', and felt it was costing them too much because of this (a potential example of a user being 'locked-in' to a higher consumption pattern by automation was suggested by Stevenson and Leaman (2010)). Due to the high level of dissatisfaction expressed, the electric boiler in this household was replaced with a gas system boiler and the control panel changed for one similar to those in Households A, B and G. The resident is now reported to be much happier. This demonstrates the need for a system that provides the user with opportunities to control it effectively to meet their goals. These goals may go beyond simply achieving thermal comfort to include matters such as cost – which a fuel switch here went some way to addressing. There was also a definite sense that this household wanted what they perceived to be a more recognisably 'normal' system, and this supports Shove's suggestion that some needs and wishes in relation to thermal comfort and heating are in fact culturally driven.

Household E likewise demonstrated the need for designers to consider goals other than thermal comfort. This house was fitted with an MVHR unit because of concerns about the poor indoor air quality observed during the pre-works visit, caused by indoor clothes drying whilst all vents were taped up to reduce fuel bills. However, problems with this unit mean it has never functioned to the satisfaction of the resident. Instead they leave upstairs windows open almost all year round to provide fresh air for clothes drying – and can do this at a lower running cost than previously. (Unfortunately, monitoring equipment here proved unreliable, so little good gas use data was available as this chapter was being written.) It is likely that the design targets here are being exceeded by some considerable sum. However, from interviews with the resident it seems these behaviours are unlikely to alter because of the importance for them of what they perceive to be a 'healthy' indoor environment, which is prioritised over cost. Better usability of controls at a tactical level would have made little difference here. However, greater success might have been achieved if more thought had been given to clothes drying as an activity during the design stage. (In some of the other households, this might also have helped reduced the use of electric tumble dryers.)

Household F was amongst the most satisfied in the study and also came close to achieving the design stage energy use targets for heating and hot water. In contrast to households C and E, they reported a very high degree of control over their heating system. This is likely to be due to two factors. First, the fuel for their system is biomass in the form of logs and they therefore have absolute control over the number of logs they burn and when they choose to burn them; thus, as in households A, B and G, this makes using heating fuel an active choice. Second, the members of this household have a high degree of technical understanding, and have a good grasp of the 'conceptual model' of the system. They are confident in making adjustments when needed and have noticed and acted when minor faults have appeared in the early months of the system's operation. This demonstrates, as the definition of usability suggests, that the usability of a system depends on both the attributes of the system and the user. In this case sound understanding of the user and the absolute control offered by the fuel source led to a successful outcome. The residents acknowledge that their technical knowhow and willingness to carry out the small amount of physical labour involved in burning logs, may not be present in all households.

The case of Household D reinforces the suggestion that more advanced systems require more advanced users, and also that automation may lock in higher consumption patterns for even well-meaning and well-informed users. Household D has perhaps the most 'advanced' heating system and controls, consisting of an MVHR unit with a combined exhaust air source heatpump and hot water tank, supplemented by solar thermal collectors. The controls on this system are fully automatic, with user requirements set at installation and small adjustments made on a seasonal basis. Whilst there is a simple front-end menu for the average user, in this case the householder accesses the installer menus. They are unusual in that they take a keen interest in the technology and have a high degree of technical understanding. This was invaluable during commissioning, as even with this enthusiastic response from the resident, it took a lot of effort to get the system set up and working satisfactorily. The heatpump in the MVHR unit only functions when the air it extracts from the house is above 18°C, with the system functioning as an electric immersion below this temperature. Somewhat counter-intuitively, this means the system performs less well when it is most needed. It also limits the possible thermal comfort temperatures of the occupants, meaning that whilst during the night when everyone is in bed a slightly lower internal air temperature may be acceptable for some, the system is working to maintain a higher temperature, which might anyway be achieved when it is needed in the morning by other means such as internal or solar gains. Whilst this work may be minimal, given the highly insulated nature of the fabric, it may still add up over a year to a considerable amount of 'wasted' energy. In fact, this closely controlled and wholly automatically operated system appears to be performing less well than the manually controlled systems in Households A, B and G – something perhaps worthy of further investigation. Despite this, and the apparent complexity of the system, the resident is very satisfied and they report a good degree of control. Their level of satisfaction is likely to be at least in part due to the very great contrast between the house as it is now and the state of the house prior to the retrofit, as the change here has probably been greater than in any other household in the study. However, it also demonstrates that complexity does not automatically lead to user confusion or frustration. Usability can be seen to be dependent on all parts in a system – including the human ones.

## The significance of usability

A focus on usability in the evaluation of case studies above allowed the interactions between people, their attitudes and knowledge, and the technology they use to be examined in depth. This has meant that not only do we know how these houses are performing against their design targets, but also have a fuller picture of why this might be. By focusing on the context as well as the specifics of controls, it has allowed a fuller picture to develop. The level of control that a user feels able to exert over a system and its ability to meet their goals for comfort and cost (and therefore energy use) is a major factor in the level of satisfaction expressed by residents. This is in turn dependent on the nature of the system and the abilities, confidence and interest of the user.

As suggested in the literature, there is a diverse and changing range of goals among residents – even in superficially similar housing. These include not just a range of comfort temperatures, but also concerns about cost, the importance of feelings of control and the need to carry out everyday domestic chores such as drying clothes.

These goals may be influenced by cultural norms and psychological needs rather than simple physical needs, for example the desire for a 'normal' heating system or the understanding of what constitutes a 'healthy' internal environment. Whether each of these goals can be met has a significant impact on the success of a whole house retrofit project.

In a super-insulated home, the requirement for space heating is much reduced as the physical infrastructure of the built fabric provides acceptable background conditions for much greater periods across the daily and annual cycle of changing external conditions. This requires a change in the current assumptions around the design of domestic space heating systems – both in their strategic approach and in the design of controls – for which usability and a user-centred design process is likely to prove an invaluable tool. It provides a potentially exciting opportunity for designers to take advantage of 'interactive adaptivity' and usability to re-think approaches to low-energy design. Whilst it should be acknowledged that this study may be limited because it takes place in social housing, and residents here may be more sensitive to cost than others in more affluent sections of society, this would appear to present opportunities for energy saving that merit further research.

It has also been shown that greater system complexity does not necessarily result in increased dissatisfaction and energy use, though this appears to be very much dependent in these cases on the attributes of the user and other aspects of the system such as fuel cost and control (for example Household C versus Household F). This holds the promise that provided that usability is considered, and the conceptual model is clear, complexity is not necessarily a bar to the success of systems.

A focus on usability highlights the potential for designers to use the diversity of users and their goals to adopt more successful low-energy design strategies, encouraging a questioning of assumptions and standards in the light of effectiveness, efficiency and satisfaction. If a more user-centred design process were to become the norm in retrofit, it might allow a greater understanding of the range of user's needs and responses to technology to be developed, leading to more successful designs. Some may worry that this would lead to a degree of 'tailoring' that would be expensive and difficult to achieve in a mass-market programme. However, by focusing on and designing for the range of user needs for comfort, cost, control and understanding, as suggested by the PROBE studies, and perhaps also taking pointers from inclusive design approaches that consider the full range of abilities of likely users, it may be possible to create more resilient systems that also maximise energy savings and improve satisfaction and usability for all. After all, a relentless focus on the user experience and user needs is a key factor in the mass-market success of many IT companies and car manufacturers. It may yet be possible to achieve similar outcomes in the context of whole house retrofit. This means that we cannot simply rely on energy modelling tools (whatever their disputed merits or otherwise) to deliver retrofit solutions but also need to use our skills as designers to devise strategies that lead to a more comfortable fit between people and technology. The role of the designer is to create the context for successful interactions, with benefits for both environmental performance and resident satisfaction. If whole house retrofit is to work, we cannot adopt a stance that simply blames 'user behaviour' for failures in performance, without questioning why certain behaviours occur in the first place. The consideration of usability – making links between the technological and the social explicit – is key to improving our understanding.

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