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Innovations for Sustainable Building Design and Refurbishment in Scotland

The Outputs of CIC Start Online Project

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Preface

This book has been written to provide an insight into innovations for sustainable building design and refurbishment in Scotland which were developed through collaboration of academics and industry, and supported by the CIC Start Online project. During the project delivery from 1st September 2009 to 28th February 2013, a wide range of innovative construction products and processes were developed or improved in response to the industry requests for assistance. The book provides an overview of the themes that were addressed through the project because they indicate the industry needs and the issues that had to be tackled through planning of the built environment, sustainable building design, low carbon technologies, modern methods of construction, building refurbishment and retrofit, and testing of building performance.

The research outputs were disseminated through interactive webinars and quarterly online magazine Innovation Review. The book authors, who are academics from universities involved in the project delivery, highlight some of the case studies available on the project website www.cicstart.org which remains accessible. The book provides examples of a wide range of innovations and indicates links to research reports, webinars, videos, and articles which provide more information. The project outputs have been and will continue to be used by students, researchers, and professionals interested in developing a more sustainable built environment.

The seven universities involved in the project delivery would like to thank European Regional Development Fund and Scottish Government for the project funding and to Scottish Enterprise for funding of academic consultancies. The assessment of the applications submitted to CIC Start Online would not have been possible without the voluntary work of the members of the independent Assessment Panel. Dissemination of the project outputs would not be as successful without the participation of the businesses engaged in research with academics. We would also like to thank over 2,300 national and international project members whose participation in interactive online webinars contributed to lively discussions and indicated that the project outputs were of interest to the construction sector worldwide.

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Introduction

Branka Dimitrijević

Abstract This chapter provides an overview of the Construction Industry Club (CIC) Start Online project, its context, aims, objectives, partnership, management, outputs, dissemination methods, membership, legacy and beneficiaries. As the project enabled successful collaboration of seven Scottish universities with industry in developing and testing innovations for sustainable building design and refurbishment, attracting 2,385 members (at the time of writing as new members are joining after the end of the project in February 2013 to be able to access all the project outputs), this chapter explains how this was achieved. Various online communication tools were used, not only for dissemination of the project outputs but also for direct engagement with membership nationally and internationally, management of various project activities, co-ordination of the assessment of applications submitted for funding through CIC Start Online and communication with the project partners. This aspect of the project management and delivery was crucial for efficient inter-institutional collaboration, dissemination and creation of the searchable online Knowledge Base which enables easy access to all the project outputs.

1 Context

CIC Start Online project was planned to support academic/industry collaboration in addressing economic, environmental and social challenges in which Scottish construction sector operates with the aim to contribute to sustainable development of Scotland as promoted in key Scottish Government's and industry's policies. The importance of the sustainable built environment for sustainable development of

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Scotland was emphasised in the Scottish Government's strategy for sustainable development 'Choosing Our Future' [28] and 'The Government Economic Strategy' [31]. One of the objectives of the 'Scottish Construction Industry Plan 2007–2012' [24] was to increase good practice in sustainability by sharing best practice and innovation. The Scottish Government's 'Policy on Architecture for Scotland' [29] encouraged the recognition and adaptive re-use of Scotland's historic buildings rather than their replacement to meet the objectives of sustainable development of the built environment. 'Climate Change Adaptation by Design' [25] and 'Sustainable Housing Design for Scotland' [26] point out that it is existing stock which can potentially make the most effective contribution to meeting sustainability objectives and reducing carbon.

The Scottish Government aims to reduce carbon emissions in Scotland by 80 % by 2050 as outlined in the Climate Change (Scotland) Act 2009 [32]. 'A Low Carbon Building Standards Strategy for Scotland–Sullivan Report' [30] recommends future revisions to the CO_2 target reductions within the Building Regulations as follows: 2010–CO_2 savings of 30 % more than 2007 building standards; 2013–CO_2 savings of 60 % more than 2007 building standards; 2016/17–net zero carbon buildings (i.e. space/water heating, lighting and ventilation).

The above targets for carbon reduction cannot be achieved without innovations. The challenge is increased by the risk-averse attitudes of building clients, contractors and building control officers towards innovations. The WWF Scotland report 'Carbon Countdown for Homes: How to make Scotland's existing homes low carbon' points out that sufficient numbers of experienced and knowledgeable building control officers and local authority planners are needed to ensure there are no bottlenecks in obtaining permissions for improvements [2].

The consultations with the industry organised by the Scottish Construction Centre [23], the conference 'Lifting Barriers to the Application of Construction Innovations in Scotland', held at Glasgow Caledonian University on 25 March 2009 [27], and the report 'Developing Scotland's low carbon built environment' undertaken by BRE Scotland on behalf of Scottish Enterprise [21], highlighted that the affordability of research for SMEs, the lack of tested innovative solutions and guidelines on how to apply them in practice are perceived as barriers to the adoption of innovations. This market failure within the above context of policies for creating a more sustainable built environment has been identified as a focus for the CIC Start Online project.

2 Project Aim and Management

The aim of the CIC Start Online project was and remains (through online access to the project outputs) to embed innovations for sustainable building design and refurbishment into practice. The project objective was to support collaboration between academia and Scottish small to medium size enterprises (SMEs) in developing and testing innovations for sustainable building design and refurbishment. The project was led by Glasgow Caledonian University (GCU) in collaboration with Edinburgh Napier University (ENU), Glasgow School of Art (GSA), Heriot-Watt University (HWU), the Robert Gordon University (RGU), University of Edinburgh (UoE) and the University of Strathclyde Glasgow (USG). The project was funded by the European Regional Development Fund and Scottish Government from 1st September 2009 until 28th February 2013. Scottish Enterprise provided funding for academic consultancies.

The project partners were represented in the Steering Group which met quarterly. The project director reported to the Steering Group on the project performance and planning. The project team also included an administrator and a multimedia manager.

Bespoke online management system was developed to monitor and report on the project performance against the agreed targets. The online system also included a communication tool for advising the Steering Group members about the queries received from the industry through the website "assistance request" box. The academics responded within five days if they wished to lead or assist in providing advice to businesses requesting assistance. If more than one academic replied to a query, they agreed who would lead the assistance. The assistance often led to the preparation of a joint application for funding for a feasibility study or an academic consultancy. In total, 244 new links between companies and academics were established and 202 assistances were provided. There were 111 cases of support for energy savings and resource efficiency and 22 renewable projects were supported.

The online management system was also used to co-ordinate the assessment of the applications for funding. This part of the online system was accessible only to the members of an independent Assessment Panel. They were able to download applications, assess them online and provide comments which could be seen by other members of the Assessment Panel. Having seen all the assessment scores and comments, the members of the Assessment Panel were able to discuss and agree the final decision relatively quickly at quarterly meetings.

The online system contained database of the project clients who received monthly e-News and a personal link to each forthcoming webinar. The project had its own equipment for image and sound recording. The webinars were filmed at the premises of GCU, but live conferences and conference videos were filmed at various locations across Scotland.

CIC Start Online run a quarterly competition for feasibility studies (FS) and academic consultancies (AC) on sustainable building design and refurbishment undertaken for the benefit of Scottish SMEs. The joint academic/industry applications were assessed by the independent Assessment Panel whose members were representatives of Buildings Standards Division of the Directorate for the Built Environment of Scottish Government, Scottish Enterprise, the Scottish Association of Building Standards Managers and energy efficiency consultants. When final reports on the completed studies were received, they were uploaded on the online system to enable the Panel to provide comments and indicate whether they were satisfied with each report. If the Panel was not satisfied with a report, the academics were asked to address the Panel's comments and re-submit a report. Only the reports approved by the Panel could claim payment. By the end of the project in February 2013, 48 FS and 13 AC reports were completed and approved by the Assessment Panel, and two AC studies will be completed after the end of the project. In total, 33 academics worked on FS and 18 on AC studies, some of them on multiple studies.

As the Assessment Panel approved only the applications whose outcomes would provide a direct benefit to a business that has applied jointly with academics, the innovations developed through the project were industry driven and indicate areas in which the industry needed assistance. An SME was eligible to apply only for one FS during the project duration and for one AC each calendar year. There were eight SMEs who were successful in applying for both FS and AC (three architectural practices, a software developer, a waste recycling business, a developer and two environmental consultancies).

Studies undertaken through the project were undertaken in collaboration with 23 architectural practices (35 %), eight housing associations (13 %), eight environmental consultancies (13 %), seven manufacturers of technologies for renewables (11 %), five software developers (7 %), two waste recycling businesses (3 %), two timber manufacturers (3 %), one supplier of renewable technologies (1 %), one off-site construction manufacturer (1 %), one contractor (1 %), one insulation manufacturer (1 %) and one supplier of building materials (1 %).

The studies either contributed to the further development of existing products or processes or tested new products or processes, often developed for a specific project with a potential for application in other projects. There were several interdisciplinary studies. Academics who led the studies sometimes collaborated with colleagues from a different department in their institution or with academics from other universities.

Companies which responded to the survey on the project impact reported that their investment increased by £23,261,212. They significantly improved 337 products, processes or services, and introduced 162 new ones. The project also assisted 6 newly established businesses. The companies reported an increase in sales of £8.14 million, and reported that they have created 189 new jobs and safeguarded 828.5 jobs.

The project was listed among top 20 projects on Scottish Green List 2010 by Scottish Sustainable Development Forum. It was also shortlisted for Best Partnership Working and Best Contribution to a "Greener" Scotland by European Structural Funds in the competition for Best Practice Awards 2010.

3 Dissemination and Awareness Raising

The outcomes of FS and AC studies were disseminated through interactive online webinars and/or in the quarterly online magazine Innovation Review [18]. Webinars are increasingly used for the dissemination of knowledge on sustainable

Fig. 1 Webinar screen showing the speaker, the presentation, list of attendees and a box for questions submitted by online viewers by using chat facility. A box with live transcription of the talks and discussions was accessible on demand

building design and refurbishment across the world, e.g. by U.S. Green Building Council [33], American Society of Civil Engineers [1] and Mechanical Contractors Association of America [22]. In comparison to the webinars provided by the above organisations, other professional associations or a range of consultancies and publishers, the CIC Start Online webinars (Fig. 1) disseminated the outcomes of academic/industry collaboration in developing and testing innovations for sustainable building design and refurbishment in Scotland's economic, social and environmental context. Speakers at the webinars were academics and representatives of the businesses which benefited from the studies. Following a request from an online viewer with hearing impairment, live transcription service was provided during webinars and the transcription text published next to video recording of each webinar, available on the project website www.cicstart.org to the project members. Membership is free and open to everyone.

By the end of the project, 2,052 people attended webinars in real time and 1,084 downloaded video recordings of 40 webinars. As the time passes, the number of downloads grows. For instance, the number of downloads of the first webinar is four times higher than the number of viewers during the live transmission. Therefore, the impact of the project will not cease with its end on 28th February 2013 as video recordings will remain available on the website.

All online attendees received continuous professional development (CPD) certificates after each webinar indicating its title and length. When the certificates were sent, the attendees were invited to provide feedback on the contents, management and technical quality of the webinar. Feedback from the members highlighted the convenience of watching webinars in office, and saving time and money related to travel to attend seminars. Online dissemination of the project outcomes also reduced carbon emissions of the continuous professional development of the project members.

The outputs of the studies were sometimes presented as articles in the quarterly online magazine Innovation Review, available at the project website. Access to the magazine is open to everyone. The magazine also published articles on policies on sustainable building design and refurbishment in Scotland, the support offered by various organisations for these activities, current research and best practice. By the end of the project, 14 issues were published, each containing 40–90 pages. The Innovation Review provided the opportunity to architects to write in-depth articles on recently completed projects in Scotland which demonstrated the benefits of sustainable building design and refurbishment.

The project also aimed to raise awareness about various aspects of sustainable building design and refurbishment by organising online conferences and live events. Two whole-day online thematic conferences were held. The first one, on 'Sustainable Refurbishment', was delivered on 4th June 2010 [3]. The seven videos filmed in collaboration with academic partners are available free at the project website following registration. The videos have attracted 1,198 viewers.

The second conference delivered the partners' videos on their research and innovations related to the 'Resilience of Buildings, Neighbourhoods and Cities' [4]. This conference took place online from 14th until 17th June 2011. Each webcast was followed by an interactive online discussion with their authors which was filmed and saved as video recording on the project website. The videos of this online conference were seen by 10,849 viewers. Videos from both online conferences are also available on YouTube. In total, there were over 25,500 viewings of all the project videos on YouTube.

The live conferences explored issues related the following topics:

- Indoor air quality [6]
- Green Deal and ECO incentives for improving energy efficiency in existing buildings at three events [8], [9], [14]
- Re-use of resources [7] and the use of recycled materials in construction [20]
- Design aspects related to building mass [11], water efficiency [15] and lighting [19]
- Sustainable infrastructure systems for electric vehicles [17], security of energy supply, demand side management and smart grids [12] and their integration into the built environment [10]
- Sustainable refurbishment of healthcare estates [13]
- The role of building information modelling (BIM) in the design of more sustainable buildings [5]
- Post occupancy evaluation (POE) of buildings [16].

As almost all conferences were filmed, edited DVDs can be ordered from CIC Start Online.

The project also used Twitter and LinkedIn to inform about forthcoming activities. The use of online communication tools has assisted in attracting membership across Scotland, the United Kingdom and internationally. At the time of writing, CIC Start Online has 2,385 members from 1,612 organisations, of which 1,032 members are from over 769 Scottish SMEs. There are over 200 international members from 53 countries.

4 Project Legacy: Knowledge Base

All project outputs are searchable through Knowledge Base available at the project website. The Knowledge Base is divided into 15 categories as follows:

1. EU, UK and Scottish policies
2. Spatial Issues
3. Building Age
4. Building Use
5. Intervention Approach
6. Resources Management
7. Building Materials
8. Building Components
9. Building Services
10. Decision-Making Tools
11. Energy Management
12. Renewable Energy
13. Construction
14. Occupant Behaviour
15. Performance.

Within each category, the search can be refined by selecting keywords. The search enables identifying relevant reports on FS and AC studies, recordings of webinars, videos of online conferences and articles in Innovation Review. The Knowledge Base is useful to students and practitioners who wish to learn about recent research and practice in sustainable building design and refurbishment in Scotland.

The chapters that follow provide an overview and analysis of the project outputs. As the assistance provided by the universities responded to the requests from the industry, the texts provide an insight into the needs of the industry with regard to sustainable design and refurbishment and how they were addressed through collaboration with researchers. The conclusions include information on the follow-on project which has a larger consortium of Scottish universities and provides assistance for a wider scope of innovations for sustainable built environment.

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Towards More Sustainable Built Environments

Richard Laing

Abstract The built environment in Europe accounts for around half of all energy use across the community. Therefore, drives to improve the sustainability of Europe and its member states have contained numerous initiatives and mechanisms through which energy use and carbon emissions can be reduced. It is important to remember that the built environment is far from homogenous, though, and that the buildings and structures already existing require a variety of approaches. It can also be argued that energy used through the constructed environment is driven by the people inhabiting and using buildings. Therefore, significant efforts have been made to explore and influence human behaviour with regard to sustainable lifestyles. It is also true that buildings exist as part of a wider landscape, rather than in detached isolation. Therefore, various initiatives have attempted to identify such connectivity, and to explore how emerging technologies can begin to drive sustainable changes. This chapter presents an overview of strategies which have developed across Europe, and discusses the responses which can be witnessed at the national and local levels.

1 Introduction

There has been a growing acceptance of the need to change both technologies and behaviour in response to climate change over a period of many years. Buildings account for somewhere between 40 and 60 % of energy use across Europe, with variations due to climate, location, use and design. Therefore, at a policy level, there have been a series of strategies and policies developed to address the

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possibility of increasing energy scarcity, with those often having a direct effect on the way in which we plan for, design, build and use the built environment.

CIC Start Online is an excellent example of an initiative which managed to apply technical expertise in sustainable design to help improve the industry, and the way in which building users can be helped to use buildings in an environmentally positive manner.

In this opening chapter, we will consider a range of initiatives which have been developed and implemented at the European level. They provide a useful context within which it is possible to appreciate the importance of CIC Start Online as a mechanism to demonstrate cutting edge, yet achievable and accessible, ways in which the environmental impact of the built environment can be significantly improved.

2 A European Context

The European Community has developed its responses to energy scarcity and climate change through a series of treaties and strategic plans. Each is of interest in that they at once help us to trace the development of knowledge, and help us to place the importance of applied work (as seen through CIC Start) within a wider context.

Recent studies [1] have identified that certain barriers need to be overcome in order to facilitate significant environmental improvements in buildings, including financial, institutional, awareness and cost/benefit calculation and separation. To some extent, these can be regarded as essential components of sustainable development, and align with the generally accepted 'pillars', being economic growth, environmental protection and social equality (UN [2], paragraph 48). These can be readily recognised through specific studies within CIC Start, including studies of institutional awareness, human behaviour and the impact of building standards on environmental performance.

It is perhaps worth mentioning that a major aspect of energy use is that of user behaviour. This topic has been studied extensively in recent years [3, 4], yet often tends to find itself sidelined within European strategies. Whilst the reasons for this might be obvious (e.g. lack of directly attributable economic benefit, or difficulties in addressing the subject), the CIC Start project was laudable in that a series of studies tackled the area directly. These include a detailed study of the effects of occupant behaviour on energy use (as opposed to theoretically predicted levels) within Scotland's first Passivehaus homes (Fig. 1) [5], and a study of the extent to which occupant behaviour can be altered through the effective use of environmental communication strategies [6].

Fig. 1 Scotland's first certified Passivehaus development © Professor Gokay Deveci

2.1 SET Plan

The European strategic energy technology (SET) plan was launched in 2010, and brings together a series of strands, which collectively aim to address European energy and carbon reduction targets. The plan recognises that in order to meet targets for reductions in energy use, and to address the future challenges of climate change, that the community needs to recognise the importance of both policy and technology. The plan extends the already heavy involvement of industry in European research and development (already very apparent in Framework 7), with the intention of accelerating the uptake of innovative technological solutions within practice.

As mentioned, the SET plan contains a series of 11 initiatives and groupings, dealing with aspects of energy use, energy production carbon capture and the development of renewable energy sources. Of particular relevance to CIC Start is the 'Smart Cities' initiative, which aims to improve energy efficiency in our major cities through the development and adoption of new technologies. Enshrined within the SET Plan, the Smart Cities initiative aims to step up the deployment of renewable energy in large cities and to exceed targets set in EU energy and climate change policy. Major challenges facing European cities in the coming years, and as enshrined within European and national policies, include a need to recognise challenges which will emerge from scarcity of energy sources, natural resources (including water), need for sustainable transport systems, and often radical solutions to waste management and recycling. Indeed, other associated programmes including the CIVITAS initiative and Interreg have supported innovative and ground breaking work in the fields of sustainable transport and sustainable energy use. Smart cities projects awarded within the European research 'framework' have dealt with technological and planning issues, and have tended to concentrate on applied (city led) research.

The smart cities initiative has included the establishment of a stakeholder platform, which itself deals with a range of issues, supported by finance and 'roadmap' steering groups:

- Energy efficiency and buildings
- Energy supply and networks
- Mobility and transport.

As Europe becomes increasingly urbanised (Fig. 2), in terms of demographic location, the importance of cities and the manner in which they are able to respond to climate change, to some extent dictates whether efficiency targets can be met. Strategic sustainable planning of our cities requires an approach to urban planning which is at once innovative, yet also in full recognition of lessons which may be learned by working across geographical and political boundaries. As cities in Europe begin to address the challenges of peak oil, the manner in which European, national and local policies reflect and respond to the challenges will be crucial.

Fig. 2 Successful integrated urban design in Copenhagen © Professor Richard Laing

2.2 European to National to Local

Of course, Scotland itself has been one of the most urbanised countries in Europe since the 1800s, with two-thirds of the current population living in the five major cities and a heavy concentration in the central belt ([7], Sect. 2.4.1). Therefore, the implications of EU agendas for smarter cities are of particular relevance to Scotland. The announcement of Glasgow as the first of the UK 'smart cities' will support the demonstration of technology aimed at improving efficiencies, as well as theoretically helping to reduce emissions and fossil fuel use.

Aspects which were dealt with specifically within CIC Start include responses at both city and building scales. The project considered in some depth the complex relationships between legislation, community engagement and citizen action and responsibility. This included, for example, efforts undertaken by Aberdeen City Council to deal with alternative transport methods, and the use of digital communication to empower households and individuals across the city [8]. In turn, this connects well with initiatives across the North Sea Region, including attempts to address the issues of sustainable urban transport (http://www.care-north.eu) and low carbon buildings (http://www.buildwithcare.eu). What perhaps sets such initiatives apart from many research and development projects is the central involvement and leadership of local authorities. This enables transnational debate and transfer of best practice, including the development of environmental policies (related, in the case of Build with CaRe to issues of environmental issues, economics, technology and human-centred design). Many of these issues were addressed directly through the series of CIC Start webcasts [9] (Fig. 3).

At the national level, it is also important to address building standards, and the manner in which they can be used to drive change [10], including the application of technological solutions including air tightness [11] and the suggested implementation of sustainability labelling [12]. Dodds [13] noted the importance of existing buildings in the drive to meet carbon emission targets, and specifically identified that nondomestic buildings could be targeted. One presumes that this must take place alongside economic incentives, or perhaps be driven by publicly owned buildings in the first instance.

3 Building Specific Initiatives and Drivers

Other initiatives which are having a direct bearing on the topics covered within CIC Start have emerged through industry led and industry supported activities. For example, the European Construction Technology Platform (ECTP) gave rise directly to the energy efficient buildings initiative, in addition to giving direction to wider European R&D expenditure.

The energy efficient buildings initiative (http://www.e2b-ei.eu) was founded in 2008, and aims to address the energy use and carbon emissions emanating from

Fig. 3 Sustainable urban mobility integrated in the urban fabric (example from Bremen in association with CARE North/Interreg IVB) Image © Richard Laing

construction. The initiative is directly managing €2bn of R&D expenditure (between 2009 and 2019), with specific calls dealing with material, technology and both new and existing (heritage) buildings. Given that there have been a plethora of energy-related plans across the community, the E2B initiative serves a useful purpose as a focus for built environment activity. Associated with the E2Bi, of course, is the application of building and energy performance standards.

The European Energy Performance of Buildings Directive [14] has provided the basis for community wide responses to energy use within the built environment. The implications for member states extend to the energy performance of both new and existing buildings, and the standardisation of the manner in which energy performance is measured and certified. As is noted below, though, a major challenge lies in addressing the performance of existing buildings. The energy performance of buildings directive (EPBD) set out standards within the context of building refurbishment, along with direction for the assessment of efficiency in installed equipment (for example, water heating).

The EPBD was effectively 'recast' in 2010, to address a number of specific issues [15], with particular emphasis on a need for the EC to move towards zero energy or nearly zero energy buildings. The revision also greatly increased the requirement to assess the performance of existing buildings undergoing 'major' refurbishment, regardless of their size. Within the UK, there is currently a requirement to deliver zero carbon homes from 2016. Scotland currently has ambitious and specific targets, including an aspiration for all new buildings to be zero carbon by 2016/17 ([16], Sect. 2.3).

4 Building Typologies

The vast majority of buildings and infrastructure which will be in place of 20 years time have already been built, and thus the manner in which we deal with them in relation to energy efficiency at local, city and regional levels is of paramount concern. Particular challenges relate to the balance between spatial planning, energy consumption and behaviour and the development of new and extended urban centres. With such challenges comes a need to also address the appropriate retro-fitting of buildings. This has been recognised within international and national policies and agendas, yet the routes which can be followed by building owners are often not clear. Recent examples of innovative refurbishment projects have demonstrated how modern technology can be used to upgrade the environmental performance of buildings in such a way that is harmonious with the need to respect the built heritage [17].

CIC Start has addressed the issue of sustainable refurbishment through a series of key feasibility studies, many of which are outlined in the following chapters. What is apparent is that there are clear issues to be addressed regarding the relationships between financing [18], design, monitoring [19] and occupancy [20], which may be specific to older properties, and which require distinct solution when compared to new build.

An important feature of the initiatives described, and of the activities within CIC Start, is the importance of the existing building stock. Although figures vary across Europe as a whole, recent estimates have suggested that around 90 % of the UK built environment was constructed prior to 1990 [1], and under building regulations requiring far less attention to insulation, carbon emissions and energy use. Indeed, more than 50 % of buildings currently standing in the UK were constructed prior to 1960, which also opens a natural discussion regarding changing practices in terms of materials use and the availability of appropriate craftsmanship.

5 Summary and Key Points

This chapter provides an overview of some of the international drivers for change within the built environment. Although these can often appear to exist at an intangible level, their effect in terms of driving investment in sustainable technology has been significant.

CIC Start Online has successfully demonstrated how many of the concepts, including the innovative use of design, materials, emerging technology and a knowledge of energy use, can be applied at the project level. Indeed, the knowledge base created can be regarded as a basis from which wider adoption of visionary ideas can begin within the mainstream construction industry.

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Planning for Resilience

Sue Roaf, Branka Dimitrijević and Rohinton Emmanuel

Abstract We live in a rapidly changing world characterised by increasing unpredictability and its associated risks. Many forces combine to add complexity to our once ordinary twentieth century pathways. Extremes of weather, climate change, costs of food, raw materials and energy and a destabilised global economy pile unprecedented pressures onto our lives. A plethora of factors affect the ways in which plan, design and build buildings and cities in a multiply-changing climate. Scotland is leading in many aspects of climate change research and this chapter on Planning for Climate Change is very timely, reflecting rapid changes in the field, in pace with the changing climate and the knock-on socio-economic impacts. Never since the emergence of the UK Planning Profession has there been a time when so much change has been imposed on the profession. The lessons contained in this chapter are key to the evolution of Planning here and around the world. The chapter starts with a brief overview of the background science of climate change and touch on the impacts of a warming world and more extreme weather on the following topics:

- Planning to reduce Flood Blight and building exposure
- Planning to reduce Fuel Poverty with solar buildings and cities
- Planning to reduce the impact of Urban Heat Islands in cities
- Reducing Vulnerability by ensuring smooth transitions between buildings
- Master Planning of Sustainable Communities.

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1 The Need for Resilience: Sue Roaf

The world around us is changing rapidly. Many forces combine to add complexity to our once simpler lives. Extremes of weather, climate change, costs of food, raw materials and energy and a destabilised global economy all introduce unprecedented pressures onto our ways of 'getting-by'. The impacts of such factors individually may not pose a dangerous threat but in conjunction they act to undermine the ability of ordinary families, across social scales, to afford not just to prosper or improve their own condition, but to maintain their customary standards of living and in extreme cases simply to survive. About one-third of people in the UK today suffer significant difficulties in paying their bills and about a quarter have an unacceptably low standard of living. Gordon et al. [30] show that 33 % of the UK population suffered from multiple deprivation in 2012, while in 1983 this figure was only 14 %.

In April 2013, the UK energy regulator OFGEM accused the big six energy firms of profiteering. They predicted that households in 2013 will pay £100 profit per household a year on dual fuel bills, a profit margin of 7 %, over twice the 2011 margin which was only 3.2 % (Fig. 1). These figures are disputed by these utilities who regularly issue warnings that 'there is a very real risk of lights going out in Britain' if their advice on investment in new generation capacity is not followed.

In fact, the lights have been regularly going out across Britain since the turn of this century and are increasingly doing so as a result of extreme weather trends and events across the UK. On 28th August, in the heatwave summer of 2003, 500,000 people suffered from power outages when the grid system failed in the heat island conditions of London and north-west Kent in the largest blackout since the Great Storm of 1987. Part of the problem in 2003 was that France was desperate for electricity as their nuclear power stations overheated due to lack of cooling water in the rivers and three were shut down. The main supplier of nuclear power in France is EDF. EDF had the choice of letting France suffer meltdowns or transferring power from England [65]. For a company owned by the French Government it was no choice at all really. EDF now controls all England's nuclear power supplies. With another heatwave we can expect the same to happen again, and next time the urban heat islands will be greater, as more shiny, air-conditioned buildings fill the city centres in a warmer world.

The planning system has in part exacerbated the energy supply problem by not taking excess demand in the energy supply system capacity into account at all. Since 2003, the soaring demand of computer servers in whole new suburbs of energy guzzling glass skyscrapers in the financial districts of London now result in far more extreme 'peak' energy demand patterns further threatening the already fragile energy supply margins. There is no clear process in the planning system for additional energy demand to be taken into account when buildings such as the tallest building in London, the Shard, were given permission. This glass walled monster is predicted to need four times more energy than the entire town of Colchester with a population of 104,000 people [35]. It is capable of single-

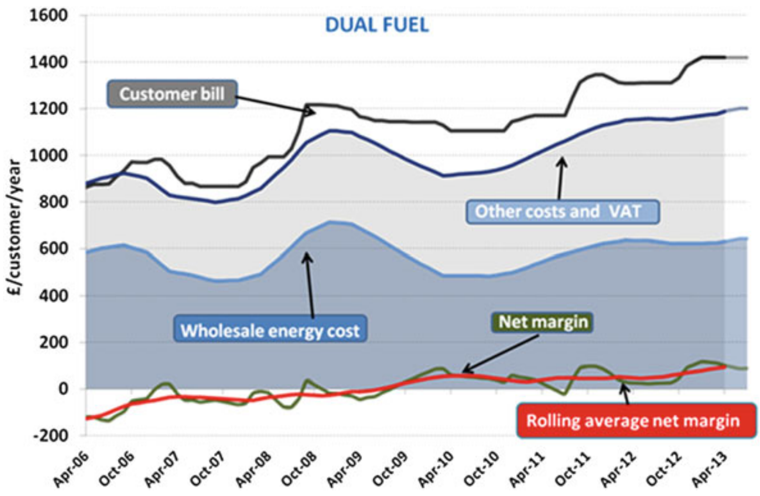

Fig. 1 Typical dual fuel customer bill, costs and total indicative net margin for the next 12 months [54]

handedly turning out the lights in London, yet the utility companies did not object to it on energy security grounds during its planning phase. There is in our planning system one unwritten rule for the glass sky scrapers and one for the rest which is why these environmentally catastrophic buildings are allowed at all [65]. Similarly in England and Wales, water companies are not able to object to new buildings on the grounds that they do not have adequate infrastructure capacity for water supply and sewage to service the building. As a result, there is a huge problem in both countries with sewage overflows. The law is different in Scotland.

Extreme cold periods are also increasingly causing widespread blackouts. In March 2013, the bitter winter weather across Britain put the lights out for 6,000 homes in Wales, 29,000 in Northern Ireland and more than 20,000 properties suffered power cuts in Scotland. Thousands of homes across England also had power cuts, some for over a week and in these storms several people died, mainly the elderly in their homes and one 27-year-old man who tried to walk home in the snow after a night out.

Never since the emergence of the UK Planning Profession has there been a time when so many different changes of such a scale have had to be incorporated into its thinking and operations at such speed. It is inevitable that Planning Profession should now be refocusing its vision, practice, education system and statutes to cope with these unprecedented levels of change. But where should their new foci lie? The CIC Start Online projects dealt with, and shed light on, four key planning issues that are indisputably central to planning for a more resilient Britain:

- Planning to reduce Flood Blight and building exposure
- Planning to reduce Fuel Poverty with solar buildings and cities
- Planning to reduce the impact of Urban Heat Islands in cities

- Reducing Vulnerability by ensuring smooth transitions between buildings
- Master Planning of Sustainable Communities.

In order to future-proof our populations against risks, we must first understand the nature of those risks and how exposed and how vulnerable we are to them [65] (Fig. 2).

The idea of Resilience is now vital for the way we think about both planning and designing buildings and settlements. Resilience is a concept that relates to the fracturing of systems under pressure and their inherent capacity to 'bounce back' [80]. Resilience is a measure of how likely, in the face of extreme change, a population or system is to survive with its customary modus operandi intact. Three properties of a material or system are: (a) how much stress it can take before it changes form, (b) how much capacity it has to absorb strain when it does deform and (c) when it fractures and collapses (Fig. 3). Stress here is the pressure on a system, and the strain is the pain.

For Fuel Poverty, the pressure being applied to a community may be the cost of energy, measured as the percentage increase in energy costs over time. The amount of stress a family can absorb (rise in cost) is a function of their income. The 'strain' a family can take for a given increase in an energy price rise stress is, in part, a function of how big the gap, or safety-net, is between income and outgoings. A family on the bread-line already cannot cope with even moderate stress, while families who earn significantly more than they spend can take considerable stress by using the wider range of 'adaptive opportunities and behaviours' they can afford to absorb the resulting strain and maintain their customary comfort conditions [49].

Ways in which people adapt their lifestyles to absorb the stress of rising energy prices were detailed by Anderson and White [6] who conducted in-depth interviews about real energy habits and found that fuel poverty is already widely pervasive. As household budgets are squeezed, people actively engage in reducing their outgoings with behaviours such as looking for bargains, comparing prices and

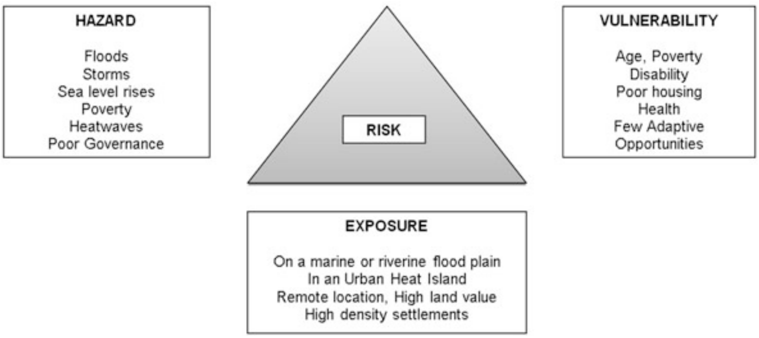

Fig. 2 The Crichton Risk Triangle. Risk has three vectors: Hazards, Exposures and Vulnerabilities that vary for every different population but should be understood by local planners (adapted from [22])

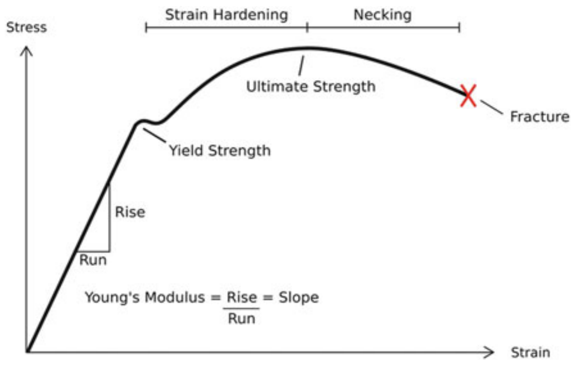

Fig. 3 The characteristics that are involved in the engineering definition of the nature of resilience in metals. With a metal, as with socio-economic systems, the fracture points also changes with the temperature of the material [18]

making their budgets go as far as possible by cutting back on quantity and turning the heating down or off. Behaviours varied according to whether the energy was paid for by a coin-fed metre, direct debit or quarterly. Nearly half (47 %) of low-income households surveyed said their homes had been colder than they wanted during the previous winter, including 18 % who said their homes had been much colder than they wanted with various consequences with problems controlling systems, damp or condensation which would have knock-on effects to health. They employed strategies such as wearing more clothes, wrapping up in blankets, staying in one room, going to bed early and having hot drinks. The most income-constrained households, many of whom are not able to access free insulation, were adept at juggling these options as part of their wider strategies for coping on a low income. The low-income households who experienced cold homes reported adverse impacts on their mental health, physical health and social lives. Nearly half (47 %) said the cold had made them feel anxious or depressed, 30 % said an existing health problem had got worse and 17 % did not feel able to invite friends or family to the house. These families were reaching the end of their 'Adaptive Opportunities and Capacity' and approaching breaking point. The majority could, but did no, switch to cheaper suppliers because of ignorance or fear of consequences if it did not turn out well for them. Such families have no tolerance when things to go wrong. If all of their actions failed to keep them safe and warm in their own homes, then some have one further conscious action available—to move, but most people do not. They default on their utility bills or mortgages and if enough households do so, then whole communities can become blighted [59].

The rate at which stress is applied to an inert metal does not affect the strain at which it fractures because the metal simply mechanically performs to its limits. In 'learning', 'intelligent' ecological systems, the *rate* of change fundamentally affects whether the systems can adapt in time to avoid collapse, or not, and in nature many species and systems do not survive [10]. The rate at which systems around us collapse is escalating, driven on by rising resource costs, particularly fossil fuel and nuclear energy costs, and by increasingly extreme weather events. Yet we, as an intelligent species, are able to anticipate the impacts of such events and design our world to adapt to them. That is the theory we were looking at through CIC Start Online projects and their developments. The planning system is key to the way we are able to adapt our buildings and cities in a rapidly changing world but in some cases, the planning systems appear to be part of the problem, not the solution. In others cases, the planning system cannot act with due diligence to protect the interests of local systems because it is, itself, under enormous stress from a top down and developer driven government.

2 CIC Start Online Insights into Building Resilience to Flooding in Scotland: Sue Roaf

Fundamental to the actual, as well as the perceived, health and well-being of citizens is that they should be able to remain safe in their own homes. Surface water flooding is a significant problem in Scotland with around 125,000 properties or 4 % of Scottish homes and 8 % Scottish businesses at risk from flooding, nearly 40 % being from surface water sources [67]. Flooding not only causes physical damage but can also have huge health and mental impacts [23]. On the 1st July 2013, the Statement of Principles on the Provision of Flood Insurance issued by the Association of British Insurers (ABI) in July 2008 [2] will come to an end. This Statement contains an agreement with the Government that the ABI will continue, until June 30th 2013, to make flood insurance for domestic properties and small businesses available as a feature of standard household and small business policies if the flood risk is not significant, being no worse than a one in 75 risk of return. It should be noted that this commitment does not apply to any new property built after 1 January 2009, after which date the ABI encourages developers and customers purchasing a property in a new development to ensure that it is insurable for flooding. After 30th June, flood insurance is currently set to revert to a free market which means that many householders will find themselves unable to obtain home insurance.

England and Wales. Concern about the human dimensions of the increasing numbers of households exposed to flood impacts and their increasing vulnerability to them led a CIC Start Online team to make an investigative and intentionally balanced film in one flood town in Scotland [58]. The film can also be used to shed light onto some of the potential consequences of England's national planning policy framework (NPPF2) that was published on 27th March [53]. NPPF2 no longer provides any clear guidance on restricting new developments in flood plains or any indication of the need to work with building insurers to reduce the risk of owners no longer being able to insure their own homes. NPPF2 replaces the Framework Planning Policy Statement 25 (PPS25) on Development and Flood Risk brought out on the 29th March 2010, in which all forms of flooding and their impacts on the natural and built environment were considered as material planning considerations, requiring flood risk to be taken into account at all stages of the planning process to avoid inappropriate development. This is no longer the case under NPPF2 which makes no specifications for such requirements.

The Westminster Government is additionally using the New Homes Bonus UK Gov [72] to incentivise the English 353 councils to the tune of £668 million to build thousands of new homes, of which over 150,000 now await planning permission on flood plains. With heavier rainfall now resulting in more intense inundation events, one would expect planning departments to be focussing less on maximising their planning gain and bonus incomes and more upon ensuring that their council tax payers are not exposed to flood hazards. For many councils, those who pay little or no council tax can be sacrificed for the sake of profit and the meeting of government targets. Thus, flood hazard areas are used for schools, hospitals, children's homes, sheltered housing and social housing, in short, properties which do not need mortgages or private insurance. This does of course mean that the very young, the very old, the sick and the poor are being increasingly forced to live in the most hazardous areas, but they are the ones least likely to complain. Planning departments are only sued for flooding in Scotland. They are immune under English Law [21].

The Scottish Government's approach to development on flood plains is more responsible in discouraging flood plain development than English planning law, where south of the border in 2010 some 9,254 new homes were built on flood plains. In England, roughly 10 % of applications are approved against the Environment Agency's advice [31]. In order to explore the nature and scale of current attitudes of a local planning authority and its community to flood alleviation strategies in a flooding district, we made an hour-long CIC Start Online documentary in Elgin in Moray, North Eastern Scotland [58]. Elgin had catastrophic floods in 1997, 2002 and 2009. Against that background, they are now building an £86 million flood alleviation scheme through the centre of town to manage flood water during extreme rain events [43].

For the film, we interviewed a broad range of the stakeholders on the issue of flooding in the town. Positions of the different actors interviewed often appeared entrenched and polarised. This film powerfully illustrates the concerns of the local community that planning permission is still being given on the Elgin flood plain (e.g. [44]) so (a) increasing flood risk of existing properties on and around that flood plain and (b) decreasing the ability of getting flood insurance for those properties.

The most poignant voice was of the home-owner, Mr. McKenzie, whose house had been flooded four times. His insurers have told him that if his house is flooded again, he will no longer be eligible for insurance from them or, consequentially, anyone else. A core issue here is becoming one of community fracture, where one section of the community, or one end of a street in Mr. McKenzie's case, becomes blighted by their inability to get flood insurance at all or afford to reinstate their properties after the next flood event, a fact that potentially renders their buildings worthless and their lives ruined. One business owner describes how his building may be reinstated to its previous condition after a flood by his insurer after which he is no longer insurable. The reinstatements will eventually become unaffordable. Elgin requires new developments in the flood plain to be built with [44]:

(a) Flood-resistant construction: showing that planners envisage that not only the new buildings will flood but consequentially will add to the height of flood water across the plain, exposing more properties to flood risk.
(b) Sustainable urban drainage systems (SUDS) that do not prevent flooding on flood plain during an inundation, yet their specification continues to provide an apparently credible rationale for allowing development on flood plains.

The Planning system in Elgin thus appears to be geared to actually increasing numbers in Flood Poverty and driving up the potential for real Flood Blight in areas of the community, despite the new flood alleviation scheme, simply because of the insurance issue. The Moray Council follows the English system more closely than the Scottish Planning Guidance with its more trenchant restrictions on flood plain development. Twenty-eight out of thirty-two planning authorities across Scotland, representing 94 % of the Scottish Population, have been working with the insurance industry to better understand and design for flood risks but Elgin refused to take up this opportunity. Flood risk management is increasingly a vital tool for good local governance and must be fully understood by planners so such interaction with the insurance industry should provide vital insights into flood prevention [24]. Elgin is one of the few communities that have not established a community forum to discuss flood issues. They have established a group which consists of the council and their advisers along with a major house builder developer, coincidentally the same company which was given the contract to build the flood defences. Insurers, SEPA and community groups are not represented. Flood Liaison and Advice Groups exist in most Scottish authorities representing 94 % of the Scottish population and local authorities (e.g. [1]). The polarisation of the Elgin flood planning landscape into the planners and engineers on one side and the sad, angry, un-listened to community voices, is starkly portrayed in the film. The Planning system, as applied by particular local authorities, will have to evolve to enable closer co-operation between all members of such challenged communities to avoid the pitfall of a planning system that favours the interest of the few at the expense of the many. At a time when the Westminster Government appears to be removing the stops on development in exposed sites and the battle between top down and bottom up government rages, at stake is not only the social and economic resilience of the flooding communities in question in a changing climate, but their long-term survival as well.

3 Planning for Solar Cities and Settlements: Sue Roaf

Planners play a vital role in reducing Fuel Poverty in settlements by promoting the use of solar energy to provide heat and power to buildings. Solar energy is the key source of energy that once installed in homes in cities, can actually take families out of fuel poverty. All other sources of BIG, imported, energy cost more every year, but solar energy is free, forever. Across Britain it is increasingly common to see solar panels on the roofs of homes in towns, cities and rural areas alike. Many of these are photovoltaic (PV), solar electric, panels installed under the UK government's effective Feed in Tariff [29], a generous rate-based incentive scheme that paid people who installed systems up to 41.5 p/kW generated by their systems. Over one GW of PV installations were installed in the UK in a couple of years as a result of that FIT in 2009–2011 alone. The success of the programme was responsible for its own demise. Politicians no doubt took stock of the fact that as more people generated their own energy, the need for major new investment in large-scale nuclear and gas plants diminished and the FIT was consequently slashed. The current rate for PV systems under 4 kWp has been reduced to 15.44 pence per kWh.

A similar hiatus in governance has retarded the advent of the much anticipated Renewable Heat Incentive [73] scheme that promised to similarly pay building owners for the heat they generate. The RHI, once promised for 2010 will now, possibly, start from Spring 2014 [73]. This should result in a significant increase in solar hot water (SHW) panels on roofs, as occurred for the PVs with FITs. Not only must planners get used to and encourage solar panels on roofs but they should also understand that by simply orienting a house towards the south to gather free solar energy, heating bills can be reduced by 30 % [60]. All settlements from now on should try and optimise this solar premium by being planned to face south.

At the turn of the millennium a new movement grew to promote the idea of city level integration of solar energy systems. The importance of the Solar Cities idea lies not only in reducing fossil fuel energy use in cities, and carbon emissions from them, but in stimulating the local solar economy and its businesses while also improving the lot of the ordinary citizen. The cost of so doing is relatively modest. [61] demonstrated that with energy saving measures and PV and SHW technologies on buildings, around 70 % of domestic emissions from heating, lighting and hot water could be eliminated from UK homes at a cost of round £100 billion in 2007. The cost of solar technologies have more than halved since then. The UK Government in 2013 proposed subsidising the nuclear industry by £250 billion over the next 40 years [36].

Scotland has a fantastic solar resource, and one that is particularly valuable in terms of passive solar heating and solar hot water contributions to domestic supplies because of the longer heating season that exists in the higher latitudes [56]. A series of CIC Start Online videos showed how both modern and existing buildings, and even city centre historic sites, proved suitable for the installation of solar systems [58]. Research work on improving the efficiency of solar hot water panels and pioneering work on the storage of solar energy in the fabric of traditional tenement buildings were also financed through the CIC Start Online project and covered in films and webinars.

To optimise the solar contribution to energy demand in buildings, it is necessary to have a low carbon building first. Heriot-Watt University, using IES's Virtual Environment software performed range of predictions of carbon emissions for low, medium and high mass buildings of the same design [62, 63]. The study showed that with a 4 kWp PV array over 3,500 kWh of electricity can be generated in

Edinburgh and over 50 % of the solar hot water demand for an ordinary terraced house.

Two ways of increasing the value of the solar systems were to improve the efficiency of the solar panel and its robustness. Heriot-Watt University tested the performance improvements designed and built into the flat plate solar hot water collectors of AES Solar in Forres [64]. The primary objective of the project was to improve the basic design of the AES solar thermal collector to make it more efficient, lighter, robust and generally a more fit for purpose and a greener product [3]. Taking into account that solar gains and heat losses are linked to conditions of operation and the design of the collector, it was necessary to focus on analysing the mechanism of energy gains and losses from the collector. A total of four sample units, each with a surface area of 1175 × 1175 mm, were manufactured by AES and supplied to Heriot-Watt University for thermal performance testing and the research results led to reductions in the costs for production, the environment, end-users and installer. Building integrated solar technologies are, like wind generators, one of the many renewable energy technologies that are getting substantially cheaper over time, not more expensive as is the case with nuclear and gas-powered generation. Across Scotland industry and academia are working together to ensure such economies of scale and innovations are fostered [70].

But innovation in the solar field is not simply about improving the efficiency of the technologies but also integrating 'out of the box' thinking into products, in terms of optimising the value of the technology to local building users and locals societies. As around 25 % of Scottish homes are in tenement blocks, the idea of storing excess solar energy in the walls of tenements was explored by Fan Wang in another CIC Start Online project. A solar wall heating (SWH) system was developed to provide low cost space heating in traditional solid stone-walled tenement buildings in Scotland using the internal solid walls to store the solar heat collected during the day and to heat the bedrooms at night. To explore the potential for such a system, a computational model was tested in a physical laboratory test rig model and the temperatures throughout the wall structure were measured under the variant solar input of a 24 h cycle [77, 78]. An unsteady state CFD model was developed and validated using the measured data and set up to test a number of key variables of the solar wall heating system in use [75]. These included optimisation control strategies and maximisation strategies for the collection and storage of solar heat under various conditions in on-going research designed not only to assess how much solar benefit could be gained in relation to real tenement occupants but also to build a dynamic model of the system that can inform future system designs. The study showed that current solar hot water systems can be improved upon to harvest more of the available solar power over a year and stored in the heavy thermal mass walls of buildings in Scotland. A preliminary cost analysis of the system in use suggested a 16-year payback period for such a system for a tenement flat [76]. What is so exciting about the solar energy charging of thermal mass in buildings is that it means when the lights do go off you have several days of heat stored in the fabric of the building to tide you over till the lights go back on and also, if you simply cannot pay for imported energy, the building itself has the capacity to stay warm enough to avoid excessively cold indoor conditions.

Roof-mounted solar technologies are thus a vital part of the future landscapes of cities, to provide heat, hot water, electricity and light for free. Solar energy is vital for improving lives in cities, and yet roof-top panels are often sources of concern for Planners who have the reputation for holding entrenched views of what looks ‘in keeping’ with a neighbourhood. This term is used as a ‘material consideration’ in the planning process, driving planning decisions. By necessity, ‘in keeping’ harks back to what a city looked like before, rather than what it will look like in the future. We need more visionary planning for towns and cities. The film undertaken with CIC Start Online on the solar hot water industry in Scotland [66] clearly shows that even in the historic centre of Edinburgh, under the castle itself, it is possible to install roof-top solar systems that comply with planning requirements and make a huge difference to the energy bills of tenement occupants. In the Lister Housing Case study [19], the introduction of energy efficiency measures and solar hot water systems had differing impacts on the household energy bills, with one tenant recording a halving of their energy bills and greater comfort as well. This begs the question of whether the Planning system has to date come to terms with the potential for solar energy to play a major part in building resilient cities and adjusted their ‘material considerations’ accordingly.

A forward-looking research project looked at the costs and benefits of city-scale solar implementation, for the city of Dundee. Fuel poverty across Scotland is rising and is currently experienced in one in four households with over 40 % of rural households finding it difficult to pay their energy bills. While ‘Big Energy’ is increasingly moving into large-scale renewable generation, the resulting electricity it supplies to consumers costs the same amount as any other form of fossil fuel imported energy. A calculation of the potential for using building integrated solar energy systems on all suitable roofs in Dundee was undertaken, a city with higher than average levels of fuel poverty. An estimation of the total roof area practically available for solar integration was carried out using RoofRay software and a mixture of energy efficiency measures and solar systems were costed. It was shown that for around £67 million it would be possible to virtually eliminate fuel poverty in central Dundee [7]. This is roughly a tenth of the soaring costs of the new Aberdeen ring road [9], getting on for half the eventual cost of the new Dundee Waterfront development [25] and one twelfth of the £776 million cost of the Edinburgh Tram [68]. It is all a matter of priorities!

A forward thinking and citizen-focussed planning system is vital for building social and economic resilience in a rapidly changing world, in fact for our long-term survival. The planning system is a key tool for reducing both the exposure and vulnerability of populations to the growing hazard of both Flood Poverty and Fuel Poverty and as we see in the following section, to the overheating of cities in a warming world (exposure) and the accessibility of buildings and open urban spaces (vulnerability).

4 Guidance and Studies on the Use of Solar Power to Reduce Fuel Poverty: Branka Dimitrijević

The resilience of buildings, neighbourhoods and cities in the context of climate change as well as their adaptability to the changing users' needs were the themes of the second online conference organised by CIC Start Online [20]. The online conference videos, guidance and studies for installing solar photovoltaic and hot water panels delivered through CIC Start Online project inform planners, developers and everyone interested in using these technologies on existing and new buildings about the available tools, support and best practice. As CIC Start Online closely collaborated with Scottish Association of Building Standards Managers (three were members of the Assessment Panel which reviewed the applications for funding) and has members in almost all Scottish local authorities, the project outputs have contributed to their continuous professional development in planning of a more sustainable and resilient built environment. Other CIC Start Online outputs on planning of sustainable settlements and the application of solar photovoltaic and hot water panels in Scotland are presented in this section.

The theory of self-organising built environments as a response to carbon levels [42], presented in a conference video produced in collaboration with Robert Gordon University, has provided an insight into alternative approaches to the reduction of carbon emissions by using planning policies and practice in Aberdeen as one of the examples. Low carbon regeneration of existing settlements was proposed in the study undertaken by The Glasgow School of Art for a rural estate in the North of Scotland [69]. Planning aspects were also addressed in the feasibility study about the development of a hybrid solar thermal mass (HSTM) system for the application in new housing [51]. This study, undertaken by The Glasgow School of Art, proposed alterations to an existing masterplan to enhance the HSTM system's performance as well as communal functions [8]. Through the analyses of the site and the discussions with housing representatives, some problems in the existing plan were highlighted and key guidelines for the alternative design proposal drawn up (Fig. 4).

The video filmed in collaboration with Edinburgh Napier University [45] for the CIC Start Online conference 'Sustainable Refurbishment' gives a thorough overview of how to calculate the size of PV systems and the financial payback period. This research informed the feasibility study undertaken for Solas Scotland, a community initiative created over 20 years ago in Dumbarton to assist vulnerable households in fuel poverty [33, 48]. The study includes 'Solar photovoltaic design guide for Scotland' which has also informed the joint study of The Glasgow School of Art and Edinburgh Napier University on PV facilities on existing buildings [52] and new housing developments [4] for Fairfield Housing Co-operative, and other feasibility studies by Edinburgh Napier University on installation of PVs on existing housing in Scotland for several housing associations [13–17].

Fig. 4 Alterations to an existing masterplan (*left*) to enhance the HSTM system's performance as well as communal functions (*right*) [51]

Adequate planning for optimal installation of PVs and thermal solar panels can also contribute to better performance of other low carbon building services which are integrated with them. The benefits of integration of PVs with thermal recovery systems have been reported in three studies delivered by The Glasgow School of Art [50]. The use of thermal solar collectors to enhance the performance of heat pumps was the focus of a study undertaken by Edinburgh Napier University [46, 47]. Potential generation of energy from PVs installed on street lamp posts, the focus of a study undertaken by [41] of Heriot-Watt University, is also of interest in planning and regeneration of settlements to enable greater reliance on locally available sources of renewable energy and to benefit from the export of energy to the grid.

As the costs can be reduced through the procurement and installation of large quantities of photovoltaic panels, the video 'Energy co-operatives as a means of achieving sustainability' [11], produced in collaboration with Edinburgh Napier University, informs on the range of models and benefits of energy co-operatives, and includes the interview with Sarah Deas, COE of Co-operative Development Scotland, a subsidiary of Scottish Enterprise, which provides advice and assistance for establishing energy co-operatives in Scotland. This video has attracted over 4,600 viewers on YouTube at the time of writing, indicating growing interest in alternative models of energy generation from renewables that can be owned by communities, reduce fuel poverty and provide employment.

As most of the reports on the above studies are available on the CIC Start Online website as well as the recordings of interactive webinars at which they were presented, they will contribute to continuous professional development of planners and other professionals involved in improving the resilience of the built environment.

5 Adapting to Urban Overheating in a Warming World: Rohinton Emmanuel

Given the small fraction of land occupied by cities (all urban sites including green as well as built-up areas cover only 2.8 % of the Earth's land area, UNFPA [74], it is unlikely that cities have a direct bearing on global climate change. However, cities indirectly drive global climate change on account of their insatiable appetite for energy and material (and associated waste and pollution). Furthermore, local urban warming (the so-called urban heat island—UHI effect) is a pressing current problem throughout the world. In London, the UHI effect leads to 15–35 % reduction in the heating load while cooling energy consumption is 32–42 % higher in the city [38]. Given the fuel mix for heating and cooling (gas for heating and coal for electricity), the overall carbon implications of UHI in London is negative. UHIs delay night-time cooling and create cool and warm islands during the day, some of which lead to increased thermal discomfort, distress and, in heatwaves, increased excess heat deaths. As this effect is likely to be augmented by the changing climate, it is increasingly important that both planners and building designers understand issues of overheating in both buildings and cities and the fundamental mechanics of UHIs if cities are to build resilience to the impacts of extreme heat events.

One of the earliest works on the urban overheating issue in Glasgow was presented in two CIC Start Online [27, 28]. This work is now well publicised: historic climate trends in the city [28]; fixed weather station data in and around the city [39]; microclimate variations at the street canyon level within the city core [26]; and thermal perception of street users in the city centre [40]. Our work leads to the following key points:

1. Even when urban growth has subsided, the local warming that result from urban morphology (increased built cover, lack of vegetation, pollution, anthropogenic heat generation) continue to generate local heat islands;
2. Such heat islands are of the same order of magnitude as the predicted warming due to climate change to 2050;
3. Substantial variations within city neighbourhoods exist (see Fig. 5 for an example of a 'hot spot') and these relate to land use/land cover attributes, pointing to planning possibilities to locally mitigate the negative consequences of overheating;
4. Strategies to tackle local overheating can lead to less carbon intensive enhancement of comfort, health and quality of life both within and outside buildings.

The planning and energy implications of these findings to 'shrinking cities' are intriguing. 'Shrinking cities', a concept initially theorised in the wake of German unification [57] is an increasingly common reality in many parts of the world. Over the last 50 years, 370 cities throughout the world with populations over 100,000 have shrunk by at least 10 % [55]. These are more common in the industrial

Fig. 5 Local variations in air temperature during daytime in Glasgow city centre (*Note* Contour lines are 0.10 °C apart. Data was collected using a bicycle-mounted instrument (fan aspirated and placed in a protective shield). Data shown as the difference in temperature between field measurements and a reference station (Glasgow International Airport))

heartlands of the USA (59 cities), Britain (27), Germany (26), Italy (23), Russia (13), South Africa (17) and Japan (12). They are also common in other parts of the world, even as growing cities continue to dominate the discourse. A typical planning approach to this crisis is to reconceptualise decline as shrinkage and to explore creative and innovative ways for cities to successfully shrink. Such approaches have usually taken the form of land for recreation, urban agriculture, green infrastructure and non-traditional land uses beneficial to existing residents and leave room for future development [32].

In their drive towards sustainable and ecologically sound places shrinking cities will need to consider the local climate implications of their current urban trajectories. While population may decline the underlying urban morphology largely remains in place, leading to the continuation of the urban climate anomaly. A particularly useful planning implication of such overheating in shrinking cities is to explore the role of green infrastructure in mitigating the change.

A recent work in Glasgow classified the built-up area of the Glasgow Clyde Valley region into 'Local Climate Zones' [71] that exhibit similar warming trends locally (Fig. 6). This helped to identify likely problem areas, a sub-set of which were then modelled for the effect of green cover options (both increase and

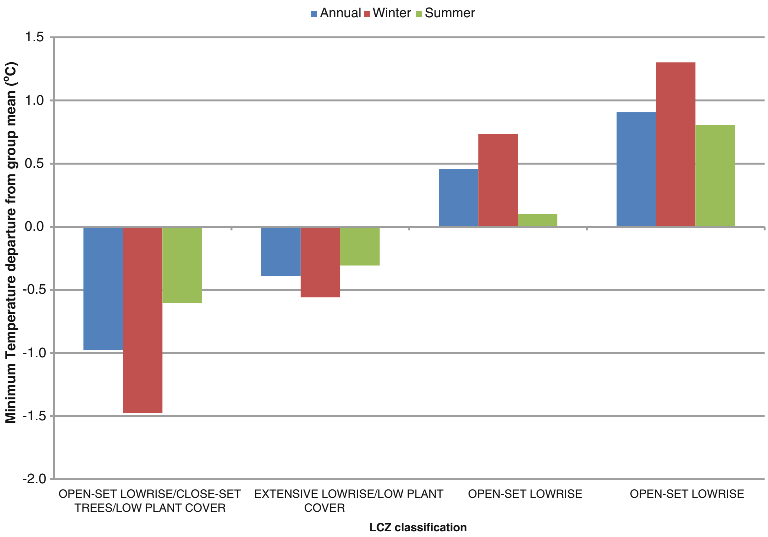

Fig. 6 Influence of land cover/land use classes on annual, winter and summer temperature variations in the Glasgow Clyde Valley [28]

reduction in green cover). We found a green cover increase of approximately 20 % over the present level could eliminate a third to a half of the expected extra urban heat island effect in 2050. Over half of the street users would consider a 20 % increase in green cover in the city centre to be thermally acceptable, even under a warm 2050 scenario.

5.1 *Achieving Green Cover Increase: An Example*

In practical terms a 20 % increase in green cover could be achieved in a number of different ways: mini-parks, street trees, grass areas, roof gardens, green walls or even urban forests. Not all green areas contribute equally to local cooling nor are they equal in their other environmental and sustainability benefits. Recognising this, planners have begun to develop weighting systems that capture the relative environmental performance of different types of green cover. The most widely used among these is the Green Area Ratio (GAR) method [37]. GAR is currently implemented in Berlin and has been adapted in Malmö (Sweden), several cities in South Korea and Seattle (USA). Table 1 shows alternative approaches to a 20 % increase in green cover in Glasgow city centre. All of these are feasible even in the city centre which contains many derelict sites and empty lots.

The green cover increase could thus play a vital role in partially eliminating the expected urban overheating problem, even in shrinking cities. The extent of green cover necessary to make a cooling impact is modest, and there are several options

Table 1 Alternative approaches to increasing green cover by 20 % in Glasgow city centre [26]

Scenario	Permeable vegetated area (m^2)	Street trees (no.)	Intensive roof garden (m^2)	Extensive roof garden (m^2)	Green façade
1. A large park only	1,056				
2. Street trees only		528			
3. 50 % of additional greenery in street trees, balance intensive roof garden		264	755		
4. 50 % of additional greenery in street trees, balance extensive roof garden		264		1,056	
5. Mix of intensive (50 %) and extensive (50 %) roof gardens			755	1,056	
6. 50 % of all 'sun facing' (i.e. South & West) green covered façades					1,268

to achieve this. More work will be needed to evaluate the relative merits of specific green infrastructure interventions at specific urban sites, however, our work indicates green cover could be a future adaptation strategy to at least partially overcome the urban overheating problem.

6 Accessibility of the Built Environment: Branka Dimitrijević

The UK demography demonstrates a major surge in the percentage of elderly, particularly in the proportion of people over 80 years old, a result of the baby boom generation of the post 2nd World War era. In the face also of (a) the rising costs of food and energy prices and growing levels of fuel poverty, particularly amongst the elderly, and (b) more extreme weather, the need to ensure accessibility for disabled and particularly the visually impaired is key to maintaining a safe, usable and sustainable environment.

The research undertaken at the University of Strathclyde Glasgow between 2006 and 2010 on the accessibility of cities for visually impaired users was presented in an hour-long video 'Towards a Visible City for Visually Impaired Users' [79]. The authors highlight that there are around 2.3 million visually impaired people living in the UK (2.2 million aged 65 and over, 47,000 adults and 30,000 children). It is expected that visually impaired population will rise to 4 million by 2030 in the UK due to ageing population and eye conditions associated with obesity (around 25 % of population in the UK is obese and this could rise to 50 % by 2050). The key question is whether our built environment is designed to accommodate the needs of an increasing number of visually impaired people.

Disability Discrimination Act, introduced in 1995 and extended in 2005, aims to promote civil rights and prevent discrimination. The act makes it unlawful to discriminate against an individual or a group due to disability. Building Regulations are in place to provide architects and designers with mandatory minimum standards for the design of the elements in domestic and non-domestic buildings. Design standards for external environments are limited to the design of access routes between a road and the principle building entrance and the access routes to any accessible car parking available within the curtilage of the building. The regulations fail to provide any mandatory standards for the design of spaces and routes between buildings in the built environment on a wider scale. Designers have to source additional guidance from BS8300 and Inclusive Mobility, which are only advisory. However, BS300 fails to provide comprehensive guidance regarding the design of exterior public spaces located beyond the immediate proximity of a building and public transport nodes.

As the visually impaired people are reluctant to venture out due to panic associated with being lost, the research aimed to establish what other mandatory regulations are required to create a more accessible environment to cater for the needs of all visually impaired pedestrians. A nation-wide survey of the visually impaired users of the built environment was undertaken. The survey was followed by an access audit which aimed to quantify the number and type of hazards present within a typical city centre, using Glasgow as the test case. This was complemented by a series of user-based navigational experiments which situate the problem through a comparison of experiences between visually impaired and fully sighted cases.

As the guidelines fail to address accessibility of external spaces, this leads to situations where accessible buildings are located in inaccessible places. The research identified the features in the built environment which present most difficulties to visually impaired people such as pavements, pedestrian precincts, level changes and controlled or uncontrolled crossing points over major or minor roads. Certain features within the built environment can be potentially hazardous to pedestrians of all abilities. However, the risk to individuals with sensory or mobility impairment can be much greater and occur more frequently.

The main topics of investigation related to independent travel behaviour, psychological and physical barriers to access, pavement design, street furniture, colour and contrast combinations, daylight and weather conditions that affect navigation. Over 200 responses were received from across the UK, 44 % from men and 56 % from women. The age of respondents ranged from 18 to 85 years with the highest proportion of respondents from the age group 65 and over. The survey indicated that 30 % of the respondents make no independent visits to the nearest town or the city centre, but 50 % indicated that they wish to make more independent visits. The investigation demonstrates that visually impaired people are less disabled by personal factors such as fear, stress and level of confidence, and are more disabled by the design and physical influence of features within the built environment.

The hazardous nature of items of street furniture was also investigated. Bollards were highlighted as the most hazardous (Fig. 7) followed by litter bins, outside dining areas, signage, lam posts, seating, bus stops, railings, trees and telephone boxes. With respect to colour and contrast combinations within the built environment, the survey responses show a general trend favouring the visibility of warm, bright, vibrant colours and also established silver as the most difficult colour to identify. The three least visible colours—silver, green and blue—were identical for each field loss category. As the most suitable colour contrast combinations for use in three scenarios of stair and edge strip, pavement and bollard, and pavement, kerb and road, the four main colours to be used were black or grey in combination with yellow or white in any of these scenarios.

Uneven paving, location and presence of street furniture, and unexpected level changes were highlighted as the most problematic features associated with the pavement design. The research produced a set of recommendations which augment current building regulations and best practice documents. They relate to the pavement design, level changes, street furniture and pedestrian crossings. It is envisaged that the enhanced guidelines should not be treated as an optional extra but rather be incorporated in mandatory building regulations to provide equal access opportunities to pedestrians regardless of ability or location either internal or external.

Fig. 7 Bollards in silver colour which is one of the least visible colours for visually impaired people, from the video ‘Towards a Visible City for Visually Impaired Users’ [79]

7 Master Planning of Sustainable Communities: Branka Dimitrijević

The rapid rise in the cost of energy, the reduced availability of investment capital, the need to increasingly run our cities on clear, renewable energy while at the same time dealing with waste, transport, security and social equity have been addressed in several articles published in Innovation Review and in feasibility studies.

Scottish Government supported Scotland's Housing Expo 2010 to enable practical and innovative demonstration of its policies on sustainable communities, planning and building design. The interview with John Cadell of Cadell2, the author of the masterplan for the Housing Expo in Inverness, shows how the inspiration for the plan was sought in the settlements across Highlands and how the site specific features such as patterns of tree-belts, forest woodlands, water channels, park lands and existing pathways were considered in the masterplan. The video which includes this interview was filmed in collaboration with the University of Edinburgh for the CIC Start Online conference 'Resilience of Buildings, Neighbourhoods and Cities' [12].

Scottish Government also run ideas competition for the Scottish Sustainable Communities Initiative, which looked at one housing plot within a larger Cadell2 masterplan for the proposed development of Whitecross Village near Linlithgow [5]. The winning project by Malcolm Fraser Architects and Stewart Milne Homes successfully addressed the critical question posed by the competition brief to design a sustainable housing scheme and to examine how the principles of low carbon development might fit with ideas about good 'place making'. The authors' thinking about the sustainability as more than the sum of the components is explained as follows:

> The skills required to create environments where people feel happy, secure and content are less tangible concepts than photovoltaics and wind turbines. They do not form part of any BREEAM checklist. They are often not integrated as part of the teaching of sustainable design in schools of architecture. In short, they are too subjective. Yet, if we are going to invest resources and energy into making any built environment, good design and place-making must be at the core of what we do. It should not be enough to simply fulfil the requirements of the end-users and environmental checklists, we have also to make something beautiful, and for an environment to be truly sustainable it should still be functioning as an attractive place to live or work in hundreds of years from now.

The core ideas that influenced the discussions and development of a site strategy were to minimise the intrusion of cars on the site to create secure, family focused places at the heart of the site; maximise the efficiency of passive solar design strategy for each house type (and minimise the use of gadgetry) and give every house a south facing garden; and create a landscaped pedestrian route through the heart of the site (the green spine) (Figs. 8 and 9).

Decision making tools for planners can assist in the appraisal of the sustainability of planning options and provide visual demonstration that enables stakeholders' engagement. Isaacs et al. [34] highlight that sustainable development can be

Fig. 8 Site layout diagram, Whitecross Village near Linlithgow [5]

considered as a common sense approach to balancing the social, economic, environmental and ethical aspects of proposed developments. However, as traditional participatory methods often fail in communicating these complicated and interconnected issues, researchers at the University of Abertay Dundee have developed

Fig. 9 View of the 'Green Spine', Whitecross Village near Linlithgow [5]

3D virtual worlds for designing and monitoring the sustainability of urban and rural developments. From a simple 2D designer view that allows users to select, drag and drop features in order to spatially organise urban and rural components, a 3D immersive, navigable world is created.

The platform allows for real-time moving of buildings, alteration of features or changing management options. The effect on sustainability is immediately realised via underlying computational models and novel visualisation techniques. The platform contextualises the area being designed in the wider landscape and shows impact on water quality and biodiversity. For the rural catchment model (Phiz), there are a set number of water treatment management options explored (to reduce level of pollutant) informed by water authorities; however, for the urban visual simulation (S-City-VT), there are no set scenarios and the users can investigate a large number of user defined scenarios. Currently, this type of scenario comparison cannot be done using any other software in real time, i.e. results of computational models transformed into textures and rendered as soon as they are computed.

Research undertaken through CIC Start Online and best practice examples presented in the online magazine Innovation Review, indicate expertise available at Scottish universities in developing tools and guidance for creating a more resilient built environment as well as the capabilities of architectural and planning practices to deliver projects which will enable communities to be more resilient against environmental, economic and social challenges.

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Building Design

John Brennan

Abstract This chapter distills the work undertaken by CIC Start Online in respect of building design. It examines how environmental control systems and sustainable construction strategies work in conjunction with the social, economic and spatial needs of buildings. The chapter asks how renewable and low carbon systems can integrate successfully both inside and outside the construction envelope. This section compares different approaches to sustainable buildings. Sustainable design strategies often have quite different characteristics. Some buildings feature sophisticated technical systems and rigorous performance metrics to produce sustainable and low carbon solutions; key examples being those with comprehensive renewables generation and Passivhaus methodologies. On the other hand, an alternative design approach emphasises simple and robust construction and environmental control systems, often utilising low impact building materials and components. The chapter also looks ahead to future scenarios beyond simply looking to reduce carbon. Some design practices advocate tightly defined solutions, tailored to projected use whilst others suggest looser, more flexible and adaptable interpretations. The chapter illustrates these issues from a rich collection of feasibility reports and case studies undertaken by the project including the documenting of passive houses in Aberdeenshire, the Healthy House for the BRE Innovation Park, Enkelt Simple Living and Scotland's Housing Expo. These case studies are carefully described and their relevance to the wider themes of the chapter are discussed. These examples and other exemplars found in the CIC Start Online Innovation Review series are used to identify key future trends that will influence building design. This section communicates the wide range of design approaches available and the importance of intelligently deploying technology to ensure the needs of building procurers and users are well served.

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1 Introduction

1.1 Terms of Reference

This chapter examines the diversity and development of sustainable design practices for new building projects in Scotland, as demonstrated in the research and knowledge exchange activity of CIC Start Online. The following text looks not only at exemplar projects, but to locate design practice in a wider context of how we define sustainable development.

Sustainability as a term that engages with social, economic and environmental aspects of the built environment is subject to almost limitless interpretation. It frames so much as to the evolution and transformation of the built environment, yet can be counterintuitive and contradictory. Andrew Blowers in "Environmental policy: ecological modernisation or the risk society" refers to sustainability as a concept 'whose strength lies in its vagueness' [1]. At the heart of sustainable discourses lies the Brundtland definition of 'not compromising the needs of future generations' [2]. However, this imperative eventually manifests itself in legislation and regulation that mostly applies to the regulation of carbon.

The chapter considers a number of salient themes. The first is an overview of current challenges to the adoption of sustainable design strategies in the construction sector. Following this, we examine some key organisational methodologies and how wider theories of sustainable development are subsequently refined into frameworks to aid effective design practice. New strategies for sustainable design are set out, appraising knowledge transfer through research led practice. We survey how architects and designers go about predicting building behaviour and ensuring their projects are robust and adaptable. The very diversity of design strategies is discussed through an examination of varying philosophical approaches to sustainable development. The chapter concludes with a short series of case studies that describe projects that broaden our perceptions of what constitutes sustainable design strategies in the built environment.

2 Sustainable Building Design: Current Challenges

This chapter explores how design practice is changing in a fast evolving environment where statutory regulation demands levels of performance that the construction sector will find testing to deliver. A lack of effective partnership structures in the construction sector can hinder co-operative frameworks required to engage effectively with the integrative nature of sustainable development. This is now explored in the context of discipline boundaries, professional relationships around the building lifecycle and the increasing complexity of stakeholder relationships.

2.1 Discipline Boundaries

As the skills required to executing complex projects require greater specialisation, so there is a push towards strategies that encourage effective understanding and collaboration between built environment disciplines. There is a perception that professional boundaries are too rigid, not reflecting the diverse skill sets to meet the challenges currently facing the building industry [3]. 'Rethinking Construction' identifies building processes as a 'series of sequential and largely separate operations' [4]. Here the implication is that a lack of integration at all levels of the industry embeds low levels of productivity and profitability in comparison with other economic sectors. In respect of the architectural profession, the education of architects is a process that often leads to an 'introverted perspective where architects are often driven by their own achievements and peer group recognition rather than responding to client and market needs' [5]. The complex nature of sustainable development requires that multidisciplinarity, defined as co-contributions between disciplines, is pervasive and ingrained within the procurement process. Within the construction sector, a fragmentation of scientific, cultural and social science expertise has been identified and effective cross-disciplinary methodologies are seen as being vital to producing meaningful interpretations of sustainability [6].

2.2 Lifecycle Matters

The nature of building procurement in the UK has revolved around competition rather than partnership. Levels of risk inherent in the construction process mean that relationships between designers, contractors and client are often adversarial. A result of this is that building projects have quite circumscribed boundaries in terms of tightly defined contractual roles. Sustainable development discourses asks us to look both before and after the design and construction phase of the procurement process in respect to issues such as embodied energy and building adaptation. The continued success of a building project depends as much on its subsequent stewardship as it does on its generative design [7]. In this respect, post occupancy evaluation (POE) methodologies become critical in helping ensure a continued involvement of the designer in the lifecycle of a building. However, the contractual and legal frameworks for this to take place in a non-adversarial environment remain a significant challenge.

2.3 Compliance Obligations

Many delivery strategies for sustainable development depend on quantitative metrics. Assessment systems such as BREEAM use a numeric scoring system to derive a rating. Whilst effective as a benchmarking tool, there is a danger that design practice simply becomes a series of compliance steps that paradoxically discourages innovation and diversity in sustainable design. Donald Schön [8] talks of practitioners allowing themselves 'surprise, puzzlement or confusion' when faced with a new design challenge. He observes that the designer will experiment to 'generate both a new understanding of the phenomenon and a change in the situation' [8]. We will see that in some instances short-term financial yardsticks work against longer term benefit [9]. With the ever growing range and diversity of sustainable approaches, building procurement will become more complex with a wider body of stakeholders—this effect in itself will make funding and procurement more challenging [10].

3 Organisational Methodologies

3.1 Theory Frameworks

A key challenge to forming coherent sustainable strategies in the built environment is the sheer volume and diversity of information and approaches available to the designer. No overall strategy can be privileged over another, but theoretical frameworks have been explored that reflect on natural processes to inform design from the scale of the city to that of the building.

3.1.1 Push Pull

Sustainable development is often characterised as being subject to 'legislative push and ecology pull'. In research conducted by Robert Gordon University into theories of self organising built environments a distinction is made between what are essentially coping strategies to deal with the effects of carbon emission that are regulated through legislative push [11]. In terms of transforming environments, an approach of 'ecology pull' is promoted in respect to transformative strategies in the city. This harnesses the theory and practice contained in 'Self-Organization of the City' [12] to look at carbon not simply as a threat to our current development but also through its inherent flexibility and transformative characteristics as becoming part of any long-term solution. Through working with Aberdeen City Council, there is a realisation that working both with business and grass roots initiatives allow for transformational change to take place without need for regulation. This theoretical framework is important to designers as it facilitates a creative engagement with green agendas. Such a positive approach provides an encouragement to creative design solutions as opposed to demotivating aspects often evident in working exclusively towards regulatory compliance.

3.1.2 Principles and Processes

What constitutes sustainable building design of course encompasses a wide spectrum of ideologies and value systems. Although theoretical frameworks are both varied and widely disseminated, how architects and building designers synthesise these into coherent strategies vary widely. In 'Principles and processes related to sustainable building design' [13], a selection of well-established design methodologies were studied. Key sources included 'Ecological Design' [14], 'Green Architecture' [15], 'Adapting Buildings to Climate Change' [16]. Following this, a matrix was prepared that mapped key sustainable design criteria to the construction plan of work process [17]. From this template, structured interviews were conducted with a selection of architectural practices within Scotland, including Page/Park Architects, Gaia Architects and Archial. What was apparent from the research was a diversity of approaches both in terms of practice policy and design output.

The frameworks adopted by each practice were varied in their relationship to the indicators established by the researchers. The existing strengths and interests of each practice were reinforced and amplified by the sustainable methodologies employed. The following design characteristics could be identified that demonstrate a diversity in current sustainable practice.

Pragmatism. Archial's design intentions for new housing for Craigwood Homes was articulated by the architects as being a process of employing straightforward principles of siting and orientation, combined with robust low energy technologies. The sentiment here was a declared aim of eschewing 'eco-bling' and bringing durable sustainable solutions to the marketplace.

Innovation. Gaia Architects' work for Acharacle Primary School (Fig. 1) demonstrated a strongly held series of values that encompassed indoor air quality and community participation. Here, fundamentals of what is often referred to as 'ecological design' informed a research led practice that seeks to innovate through sustainable design (Fig. 2).

Reinforcement. Page/Park in their design for the Carrochan headquarters building placed emphasis on ensuring long-term social sustainability through careful design of the workspaces and the deployment of sophisticated daylighting strategies. The architects looked at where their existing design principles in making legible and elegant architecture resonated with qualitative sustainable criteria (Fig. 3).

Fig. 1 Craigwood homes by Archial architects [13]

4 New Strategies for Sustainable Design

4.1 Introduction

Many sustainable design guidance documents rely on a ‘checklist’ approach that often encompasses a wide spectrum of indicators to encourage compliance across a diverse set of criteria. These can be effective scoping and benchmarking tools but, as apparent in the previous section, do not necessarily take into account an equally diverse collection of ideologies and value systems held by individual design practices. This section instead identifies operations within the building design process where the work undertaken by CIC Start Online Partners has assisted in forming more effective sustainable design strategies.

A key challenge in formulating sustainable design strategies is a need to navigate an ever-expanding field of knowledge in respect of sustainable design and procurement. An important theme of this chapter as a whole is the importance of seeing sustainable design being embedded in all parts of a building’s lifecycle. Research active, informed practitioners, able to properly brief client bodies and help them make the most effective design decisions are critical to the overall development of the construction sector.

Fig. 2 Acharacle primary school [42]

Fig. 3 Carrochan: Loch Lomond and the Trossachs national park authority [41]

4.2 Research Active Practice

Ever since the Egan Report, the level of research activity and knowledge transfer has been a critical issue for the construction sector. More recent reports such as Constructive Change [5] highlight the need for design practices to acquire and nurture active research cultures. CIC Start Online has worked both to collaborate with design practices as well as disseminate information and many of the case studies referred to in this chapter show how designers can innovate confidently. The Tarryholme Sustainable Healthy House Study [10] conducted with Assist Architects asked two basic questions: ‘What is a sustainable house?’ and ‘How much does it cost to build?’ For affordable housing providers, such fundamental issues are critical to successful option appraisal exercises. The study saw a substantial investment in time and resource, involving visits to 30 exemplar projects followed by an intensive period of design analysis.

The research allowed a much more effective overview of a host of key environmental and sustainable criteria that included costing for innovation and also the health effects of very low energy design solutions. The research investment in interrogating a series of holistic sustainable issues allows for the identification of key issues. In this case, indoor air quality was identified as a critical factor in terms of occupant health. The research also opened the process of building design outwards to engage with a wider constituency of stakeholders. Here, the case was made for low toxicity building materials and effective ventilation as a means of reducing demand on health providers.

4.2.1 Informed Practitioner: Informed Client

Procurement bodies from the scale of the individual client to large public sector and corporate organisations are demanding of designers to deliver environmentally responsive and sustainable buildings. With this has come awareness of the range and scope of the technologies available. Knowledge of the characteristics of micro renewable installations, in particular, is widely disseminated but their financial and functional viability is less easily accessible to the non professional. A rural housing design study undertaken by Robert Gordon University [18] highlighted the susceptibility of client groups to what is often termed ‘greenwash’, a term that refers to the adoption of seemingly sustainable technologies in an ineffective or inappropriate way [19]. In this case, a set of client requirements for ‘technology driven’ solutions such as photovoltaic arrays and ground source heat pumps were seen as essential components of a refurbishment even though set within the confines of a tight budget. In the study, the building designer was seen as a mediating influence, able to recast priorities in terms of cost, environmental impact as well as operating energy.

This entailed the adoption of enhanced insulation, more efficient appliances and passive solar techniques. The fact that this type of project is common, especially in rural areas, points to a need for widespread knowledge transfer to the widest possible constituency of building designers. A key finding was that consideration of orientation, insulation, thermal mass and air tightness are not necessarily privileged by client groups in researching their building project.

Where there is a close relationship between client and designer, as in the case of the new Scottish Environmental Protection Agency Headquarters in Aberdeen, then the specific requirements of the programme can be tailored to the exact needs of the organisation [20]. Although achieving a BREEAM excellent rating, the client organisation and building designers clearly differentiated between an ‘environmental standard’ and an ‘energy standard’. After the initial BREEAM assessment, inclusion of biomass heat generation reduced carbon emissions by a further 30 % on the completed building. This however did not improve its BREEAM classification. In this case, an informed design team and client group set priorities independent of rating systems and as a result enhanced real performance rather than a benchmark score.

4.3 Anticipatory Design Practice

Sustainable development tends to be defined using universal values, taking a cue from the Brundtland definition [2] making the link between our present behaviour and the well-being of future generations. The building design process as outlined earlier in this chapter has been characterised as a discrete series of operations beginning with project inception and ending with completion and a short defects period. A lack of feedback loops to improve embedded knowledge and design practice has always been challenging [4, 5]. They are also philosophically at odds with the core concept of sustainability being a continuous and precautionary process. This section looks at two aspects of how we can incorporate predictive techniques in terms of environmental behaviour, resource consumption and building programme.

4.3.1 Predictive Behaviour: Simulation Modelling

Simulation modelling has reached a stage where applications have developed in all scales of enquiry from the detailed simulation of building components using programmes such as WUFI [21] to the EnTrac package that works at the scale of the city. In ‘Simulation Based Design Tools’, Professor Joe Clarke uses as a starting point, the diversity of sustainable practice [22]. This can be illustrated by extending from modelling operational energy use to predicting overall carbon consumption and resource impacts. A growing recognition of social sustainability criteria is becoming increasingly important with connection formed between thermal comfort and workplace productivity [23]. Simulation modelling has reached a stage where it can be effectively embedded in all stages of design. Instead of being available to specialist users, a key trend is a tendency towards the embedding of sophisticated interrogation tools in mainstream practice. Projects supported by CIC Start Online reflect this trend and we now explore how simulation modelling allows for the predictive benchmarking of various building typologies as well as methodologies to democratise the deployment of such software across the construction and education sectors.

Predictive Benchmarking. For the designer, easy access to the means to benchmark and iterate design options is a significant development. The Riccarton Ecovillage project uses a series of proposed houses to benchmark performance between different building construction systems. In particular, it looks to examine the meaning and implications of the term ‘zero carbon’ and the role of renewables both on- and off-site as a method of reaching such a goal [24]. The project was undertaken in conjunction with IES Ltd whose simulation software was used to model potential building performance using data beyond descriptions of building location, geometry construction and services (see Sect. 6.5.1). Additional data was input for user profiles, occupancy type, appliance and lighting use. The research benchmarked a series of terrace housing of different construction profiles with varying thermal mass characteristics. The project also modelled a range of regulatory scenarios. In current contexts, where the baseline performance of buildings is uniformly high compared to even a decade ago, simulation can highlight significant factors that might change the behaviour of the building. The results gave clear guidance as to the amount of PV panels required to offset operational carbon consumption. In this study, complex interactions between the building envelope, heating technologies such as ground source heat pumps and photovoltaic array were also modelled. The work highlighted the limits inherent in conventional steady state calculation methods to accurately predict renewable electrical energy generation to provide a near zero carbon design. The government regulatory energy prediction tool (SAP) underestimated the amount of PV panels required by over 50 %.

Embedding Ease of Use. For the designer to access and usefully employ sophisticated prediction tools, requires both embedding of simulation modelling at all stages of the design process and also making its operation accessible to as wide as possible constituency within building design professions. In ‘How Designers Think’, the importance of evaluation, reflection and iteration is identified as critical to many processes [8]. There is now a trend towards the democratisation of complex predictive tools. This is explored in ‘Taking Analysis out of the Architects Back Room’ [25] where the facility of simulation software to intervene in all stage of the design process is explored. The complexity encountered in the interaction of consumer choice and regulation means that we need to construct systems that are dynamic, non-linear and systemic. In particular, the realisation that much design practice is either overtly or unconsciously qualitative and subjective in nature makes for a complex relationship between the designer and the data they encounter [26].

CIC Start Online have supported projects in which the decision-making process can be made more accessible. In ‘Options Appraisal Tool for Architects’, a study carried out with the University of Strathclyde and NORD architects [27, 28] sought to prototype a simple options appraisal tool to help make specific decisions such as payback periods for insulation and the use of blinds to avoid overheating.

Design education has a critical role to play in embedding iterative practice in sustainable design practice. The ‘Environmental Design Teaching Model’ (Uduku et al. 2011) enquired how the IES-VE simulation package could be adapted to become an effective undergraduate teaching tool through simplifying and clarifying key processes, such as daylight analysis and building energy demand. The study found that the importance of immersive graphical interfaces and results representation was important in helping users understand simulation data. At the same time, user accessibility was deemed to be relatively straightforward to achieve through an editing of package functionality, although at the potential cost of reducing flexibility and customisation of simulation models in specific contexts.

The CIC Start Online studies that involve simulation packages show how a wider range of sustainable metrics can be usefully processed from building component to the scale of settlements. At the same time, development resources are now being deployed to widen the user base from the specialist to the wider design professions.

4.4 Predictive Behaviour: Another Perspective

Quantitative design practices to reduce carbon and to a lesser extent broader environmental impacts are well documented. More qualitative sustainable criteria and metrics that engage with economic and social sustainability are less developed. We have seen that we can simulate the environmental behaviour in a sophisticated way, but designing buildings that anticipate programmatic change over time is less straightforward. The relationship of sustainable design to adaptability is often raised but rarely investigated in any depth. There are some notable exceptions including research by the Adaptable Futures network who have concentrated primarily on explaining its value in respect of the sustainability of economic capital as well as resource conservation [29].

In 'More Support Less Obstacles, how we need to encourage innovation in housing' [9], the future proofing of new housing is discussed. Straightforward anticipatory decisions such as designing the roof structure to easily convert attic space to living accommodation was proposed for an affordable housing scheme. The architect recounts that inflexible cost yardsticks for affordable housing meant it was difficult to secure funding for an enhancement even at marginal cost but providing excellent long-term benefits.

Post occupancy evaluation (POE) methodologies are well developed and allow for a fine-grained analysis of the quantitative and qualitative performance of a building once realised on site. This is investigated in more depth in Chap. 7, however, a key challenge lies in constructing effective feedback loops from POE analysis to building designers to deploy in subsequent projects. For designers to acquire effective tools and techniques to accurately predict short- and long-term usage patterns is as critical as any mastery of digital technologies. In 'Embedding Simplified POE in the Design Process' [30], an information gathering tool (POET) has been developed to include both quantitative data and user survey. It is intended as a resource for designers to build up a structured knowledge base of post occupancy feedback on a series of construction projects to embed best practice for future projects.

Like building simulation, predicting and designing for the future does not necessarily suffer from a lack of available data for the designer. Instead, accessible and powerful means to access, understand and benchmark both quantitative and qualitative feedback remains a critical area of research.

5 The Role of Technology

5.1 Introduction

Sustainable discourses are diverse and often complex. In ‘Reinterpreting sustainable architecture: the place of technology’ [31], its authors highlight a number of sustainable design ‘logics’. The research is useful in that it moves design debates on from what are often simplistic ‘deep green: light green’ stereotypes. The work refers to an ‘eco-technic’ strand of sustainable design that advocates sophisticated methods for the maintenance of comfort and efficiency in resource use through complex, highly engineered technologies. ‘Eco-centric’ and ‘Eco-cultural’ logics describe strategies formed around modest ecological footprint, simple vernacular technologies and construction practice. The research and consultancy conducted by CIC Start Online reinforces the trend, especially in housing towards robust legible design solutions. This section explores these issues in the context of post occupancy evaluation, the phenomenon of ‘greenwash’ and the appropriate use of technology.

5.2 A Suspicion of Greenwash

Many of the projects undertaken as part of CIC Start Online seek to interrogate processes and building projects for demonstrative sustainable value through measurement, survey, simulation and benchmarking. Many supposed sustainable solutions are often instances of what has become popularly known as ‘greenwash’ [19]. In ‘The problem of rural SME contractors and sustainable technologies’ [18], the research outlines how misleading and inappropriate marketing leads to false expectations, especially in respect of inexperienced clients.

In ‘The Glasgow House: a ‘low-tech’ approach to the problem of fuel poverty’, PRP architects were commissioned by Glasgow Housing Association to design an exemplar house to stringent cost yardsticks that would cost no more than £100/ year to run [32]. The firm had been involved with the Sigma House constructed for the BRE Innovation Park in 2008 [33]. Here, building performance was affected by the complexities of the interface between the building’s micro renewables and

Fig. 4 The Glasgow house [32]

heating systems. After this, the architects were now keen to implement simple construction and servicing concepts, in part to allow construction by trainees and aid employment creation in what are areas of social deprivation.

> We don't want to saddle GHA and their tenants with a house which has an array of eco-friendly gadgets requiring constant maintenance and replacement and which are difficult for the tenants to control unsupervised [32].

The architects therefore provided a design proposal based on good orientation, a compact building envelope, enhanced levels of insulation, solar hot water and simple construction methods (Fig. 4).

5.3 Low-Tech: High-Tech

A continuous strand in many of the CIC Start Online projects is a desire to learn about and deploy building materials with very low environmental impacts. In 'Earthship biotecture, independent off-grid architecture' (Simmonds 2010) describes a building typology that has at its heart the re-use of building materials, employing tyres as retaining walls with bottles and cans acting as bricks. Earthship projects, by their nature, are autonomous with their own water collection, sewerage and power generation resources on site. It is, however, important to note the low impact building materials can be embedded within more conventional building typologies too. The study 'Towards low technology—higher performance architecture: potentials of alternative construction in West Scotland' looks at the potential of the deployment of new and rediscovered building systems, but critically, in existing and localised contexts [21]. The report explains that the very notion of low technology has embedded within it an ease and robustness in manufacture, construction and maintenance. Three different construction system typologies were studied and tested against a timber frame base case:

- thermal mass—rammed earth and cob
- insulation—straw bale hemp lime
- hybrid—light clay and adobe.

The constructions were tested for internal humidity, mould growth, then operational and embodied energy. It was found that rammed earth and cob had significant drawbacks in a Scots context but that straw bale and hemp/lime constructions were found to perform effectively, especially in respect to internal humidity and air quality.

For the building designer, this study suggests that 'low tech', low impact materials can perform effectively in respect to contemporary standards defined in terms of thermal comfort and energy efficiency. Also, it demonstrates that the use of powerful simulation tools such as WUFI are relevant not only to complex and highly engineered construction systems. Simple low environmental impact design strategies can thus be partnered very effectively with powerful simulation and prediction technologies.

5.4 The Limits of Low-Tech?

For the designer, ever more stringent carbon reduction targets have meant that straightforward improvements to the building fabric no longer meet statutory standards. As a result, ventilation losses from the building envelope are investigated intensively to reduce operational energy use. Designers who espouse a simple and robust approach, as in the case of the 'Glasgow House', acknowledge that a point is often reached where mechanical heat recovery and ventilation require consideration to further reduce energy demand. In non-domestic buildings, plan footprints and specialist programmatic requirements for circumscribed temperature and humidity levels often mean the deployment of mechanical ventilation and conditioning of the internal environment. In its own way, an imposition of natural ventilation in all circumstances can be seen as an example of 'greenwash' in itself where it leads to excessive heat loss, especially in winter months.

The issue of mechanical versus natural ventilation remains a point where different ideologies can and do come into conflict. This plays out in publications such as 'Green Building' [34]. The debate is most clearly framed around the Passive House standard. Originating in Germany in 1988, it establishes specific criteria with the aim of reducing space heating energy demand to a very low level of 15 kWh/m^2/year. It achieves this through a prescription of passive solar gain, extremely high levels of insulation, low levels of ventilation and mechanical ventilation and heat recovery [35]. In 'Build with CaRe: A case study of passive houses in Aberdeenshire' [36], the passive house method is carefully explained. In particular, it is suggested that the imperative to meet Scottish Government carbon reduction targets means widespread adoption of the Passive House method. In opposition to this are concerns often cited about complexity, build ability and internal air quality [34].

In the 'Selective Environment' [37], Dean Hawkes and Koen Steemers set out two fundamental typologies. Selective Environments where buildings have an open relationship with their outside environment, for instance in temperate climates, espouse natural ventilation and passive gain. In contrast, they describe Exclusive Environments as essentially closed systems, using technology to control and condition internal environments. In the last decade, this led to assumptions of selective environments being inherently more virtuous than exclusive models that were associated with complex and wasteful air conditioning.

Standards such as PassiveHouse challenge these preconceptions and mean that, for the designer, the field remains complex and sometimes confusing. It suggests that an appropriateness of any design solution depends as much on the needs, means and aspirations of the building user as much as it does on quantitative indicators of environmental performance.

6 Beyond Carbon

6.1 Introduction

The final section of this chapter examines how sustainable design practices are moving beyond carbon reduction strategies. This is in many ways inevitable given the breadth of meaning inherent in the Brundtland definition and its subsequent development in the social and economic as well as environmental realms. This evolution from low energy design as practised 30 years ago is explained well in 'Ecological Design: A new critique' [38], as it documents this shift to more holistic sensibilities. Lately, disenchantment with a perceived over-emphasis on carbon reduction issues has become more widespread [19, 39, 40].

In part, carbon reduction is privileged because it can be straightforward to measure, quantify and predict and therefore easily subject to regulation. Social and economic metrics of sustainability and the benchmarking of more holistic approaches are inevitably less clear-cut. However, many projects documented by CIC Start Online demonstrate a clear commitment to a wider sensibility to sustainable design. In the following case studies, we look to quite different approaches in building design that are broadening our understanding of sustainable architecture.

6.2 Case Study 1: Qualitative Design Practice

Carrochan, located north of Glasgow, acts as the headquarters of the first national park in Scotland and was designed by Page/Park Architects and completed in 2007. It also provides space for partner organisations such as Scottish Natural Heritage and the Scottish Environmental Protection Agency. The building has been part of three CIC Start Online outputs: 'Principles and processes related to sustainable design' [13], 'Embedding simplified post occupancy evaluation within the design process' [30] and a comprehensive description featured in the CIC Innovation Review [41].

Fig. 5 Office space in Carrochan: Loch Lomond and the Trossachs national park authority [41]

The building features, as a matter of course, a low carbon footprint alongside careful siting, a high level of air tightness to the envelope, generous insulation and biomass heat generation. As an office building, some of the design decisions differ from housing strategies. In this case, overheating through excessive solar gain and the provision of good daylighting levels to the workplace mean larger areas of glare-free glazing to the north and limited openings to the south to mediate internal temperatures. A sense of a more holistic approach can be found in the careful selection of low impact building materials. Douglas fir for the main frames is sourced from Scotland and Northern England, Lake District slate is specified alongside Scots larch cladding.

A key intention of the architects was to enhance the workplace and engender a sense of community with an intention to increase productivity. The success of this approach is recorded in the POE surveys. The workplace was thought of by users as ‘light and airy’ with the curved form of the building giving a calming sense of enclosure. The offices were considered to be efficient and adaptable to any workplace reorganisation. Here, the architects’ qualitative ambitions for design quality are clearly articulated through reference to social and economic sustainability of the workplace, and reinforced by Post Occupancy Analysis (Fig. 5).

6.3 Case Study 2: Research Led Design

Acharacle Primary School is located on the Ardamurchan peninsula in North West Scotland and was completed by Gaia Architects in 2009. The building has been part of two CIC Start Online outputs ‘Looking at principles and processes related to sustainable design’ [13] and an article in Innovation Review [42]. Gaia Architects work to a declared set of values that:

- Minimise pollution
- Enhance biodiversity
- Use resources effectively
- Created healthy environments
- Support communities
- Manage the process.

This frames a clear agenda for sustainable design strategies for the firm that are distinctive and embed research lead practice in the procurement of buildings. From the outset, the community and key stakeholders were involved in the briefing process. It informed the design of the building that includes two clearly defined wings programmed for education and communal use. In such a remote location, the building hosts a diverse range of community activities and very much acts as the social heart of the surrounding area.

Gaia Architects have long had an interest in producing healthy internal environments [43]. At Acharacle, the architects are confident that the building interior

Fig. 6 Brettstapel mass timber construction in Acharacle primary school [42]

is free of harmful pollutants. Key to this is the first use in the UK of Brettstapel mass timber construction that uses hardwood dowels rather than glue in its assembly (Fig. 6). Elsewhere, untreated timber, clay plaster and linoleum alongside a natural ventilation design ensure high internal air quality. This preoccupation extended to the manufacturing process of the classroom furniture. In the building, feedback is given to the user in terms of temperature, humidity, carbon dioxide and daylighting levels.

The school is a good example of sustainable design where priorities of the architect and client go further than basic carbon reduction and resource conservation strategies. It also demonstrates the process of building design and procurement as a research process in its own right.

6.4 Case Study 3: Predictive Design

The WholeLife house (Fig. 7) formed part of Scotland's Housing Expo held in Inverness in 2010. This building has been part of two CIC Start Online outputs. 'Learning from Scotland's' Housing Expo: making resilient buildings and neighbourhoods online conference' [44] and 'The WholeLife House' published in Innovation Review [45]. The building engages with best practice in regard to energy use but is focussed on issues of long-term social and economic sustainability. In Scotland, less than 7 % of households are families with more than four members, whilst 40 % of all household relocations are because of dwellings no

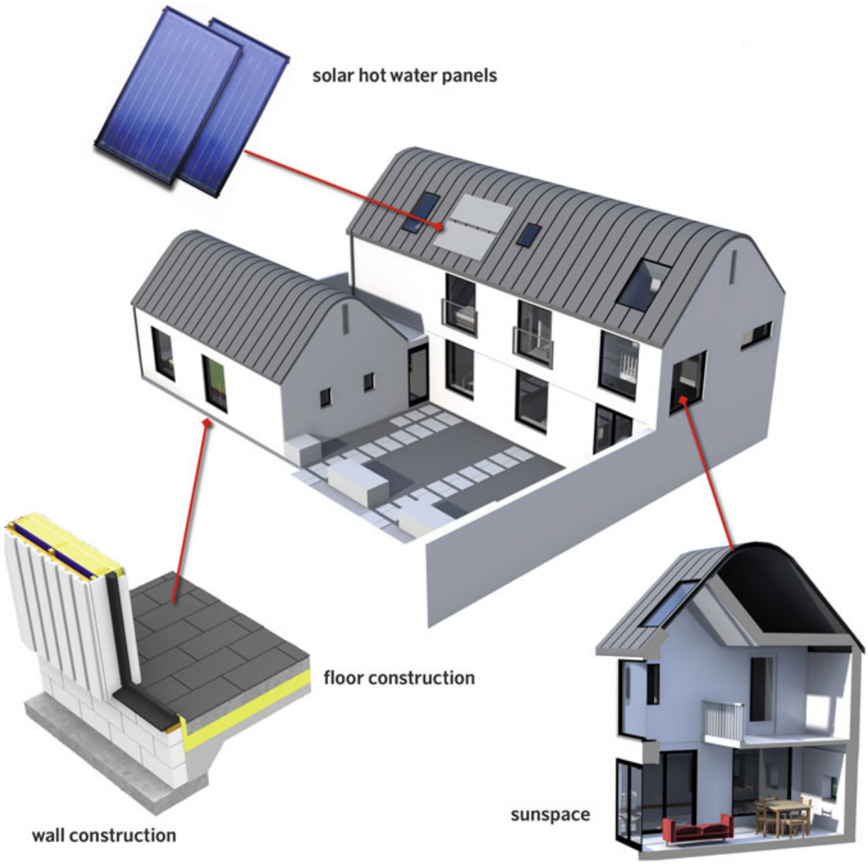

Fig. 7 The wholelife house [45]

longer fulfilling user requirements [46, 47]. If we see the formation of stable communities as a characteristic of sustainable settlements, then the dwellings we design need to become more adaptable.

The WholeLife house by Brennan and Wilson architects is located on the southern suburban edge of Inverness, a city that has undergone in the last 10 years, a population increase of 25 %. Growth has been accommodated in new low density housing estates around the edge of the city, characterised by poor local amenity and public transport provision. The housing typologies overwhelmingly cater to a family market that in reality is not at all significant in terms of any household demand. It is a clear example of the definition of 'soft flexibility' [48].

The building is designed for a wide spectrum of different uses. It achieves this through a multipurpose annex block accessed through a common lobby to allow a degree of separation from the main house. The wing coupled to a more traditionally designed house can function as office, workshop, a self-contained apartment for young and old residents as well as extra bedroom accommodation for larger households. The proposed functions of the building are deliberately loose; the permutations and combinations are complex and intentionally not predicted. The building does endeavour to anticipate demographic change such as shared households and an increasing incidence of live work activities within the home.

7 Conclusions

The knowledge exchange processes at the heart of the CIC Start Online have helped to define and extend the nature of sustainable design practices. It has identified trends and developments that explain how building design and procurement is evolving. The project's focus on knowledge exchange with small and medium enterprises has indicated a clear preference by designers and clients for simple, robust and practical solutions. Fundamental decisions as to building orientation, form and construction continue to be vital in the realisation of environmentally responsive buildings. There is also animated debate as to the role of technology to deliver on government targets for 'zero carbon' building in the coming decades.

As carbon reduction technologies and design practices mature, focus has moved to related issues such as the healthy building environments and social and economic dimensions of sustainable development. Practice is evolving to respond to this, working in harmony with long held values, such as building with daylight and a sensibility towards building materials. We are therefore seeing projects that combine excellence in environmental performance with a high degree of aesthetic value. At the same time, research-driven practice is articulating concerns about material toxicity and indoor air quality and fashioning them into a series of coherent design strategies.

The project has dispelled any myth about sophisticated simulation tools being suitable only for complex, technology-laden projects. Sophisticated interrogation and prediction software validates simple, low impact construction systems and design solutions.

A clear shift in perception has been recognition of the need to fuse sustainable design practice throughout the lifecycle of a building. This anticipates future programmatic change in the function and use of our homes and workplaces but also to methodologies to feed user experience and building performance to the designer. This is perhaps the most complex challenge but one that will reap dividends for this and future generations.

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Technologies

David R. Moore

Abstract The drive for a sustainable built environment is resulting in a greater focus on the range of technologies available and the level of performance that such technologies can achieve. Performance is typically measured across a number of factors but most usually comprises a relationship between cost of purchase and energy saved. The performance levels of renewable technologies can be improved but the improvements are not always financially cost-effective. However, there are other measures of performance that CIC Start Online supported projects have identified. These may be as simple as the manner in which communication about sustainability issues takes place (ineffective communication results in no positive conservation/reduction actions). There may also be a case for changing the measure of performance away from a financial base and towards a base that is focused on reduction of, for example, CO_2 levels. The overall message however seems to be that 'solutions' in the context of technologies should not be evaluated in isolation; the 'big picture' remains important.

1 General

In the context of achieving a future sustainable construction industry and built environment, the demands being placed upon the industry, both directly and indirectly, are increasingly encouraging the industry to look more critically at the technologies it has traditionally made use of. The focus is essentially one of determining if existing technologies are 'fit for purpose' in the context of a future construction procurement process that is constrained by legal, cost, time and societal demands and requirements. For some traditional technologies the situation

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is a relatively clear one; high carbon and high energy-based technologies are coming to be regarded as not acceptable. For other traditional technologies the situation is less clear as there is a degree of interpretation applied to just what is meant by the term 'sustainable'. There is also a level of confusion amongst practitioners and consumers as to what exactly is meant by 'low carbon' and 'zero carbon'. The situation is made more complex again when a technology moves from a new-build context to a 'retrofit' one; technologies that can work well in new-build structures may be less effective in a retrofit context. In such an environment, effective decision-making is of significance, and becomes more so when the problem to be solved is further complicated by the possibility of adding 'emerging' technologies such as micro-generation and the need to conserve vital resources such as water. In such a context the work of CIC Start Online, with its focus on seeking 'real-world' solutions to significant problems facing developers and self-builders alike, has a real value. This is reflected by the number of studies related to the application of renewable building technologies to both existing and new buildings. Much of the work carried out relates to the actual (as opposed to theoretical) performance achieved by the individual technologies. The range of technologies covered include air source heat pumps (ASHP), ground-source heat pumps (GSHP), biomass, flexible solar cells, hybrid solar/thermal mass systems, renewable energy co-operatives, solar hot water, solar photovoltaic and wind turbines (including roof-mounted turbines). In total 21 Feasibility Studies, three Academic Consultancies, 27 Innovation review articles and four Webcasts cover the area of renewable technologies. In terms of expertise centres, the majority of the work was carried out by Edinburgh Napier University and Glasgow School of Art. A full list of studies can be found in an appendix provided at the end of this book.

2 Decision-Making: Renewables for Buildings

There is evidence that the majority of housing developers (housing being one of the main potential contributors to achieving a sustainable built environment through carbon emission reductions, etc.) are averse to one of the two generally recognised strategies for enhancing construction sustainability. The two strategies are essentially those of improving insulation to reduce heat-loss, and adding renewables to cut carbon emissions from the energy generation side of the built environment sustainability formula. The first strategy is typically referred to as a 'fabric first' strategy, in which the emphasis is on 'improving' the fabric of the building so as to reduce energy requirements. Unfortunately, current technologies related to improving the fabric of a structure are reaching the limits of what can realistically be achieved; very few consumers would be happy to accept insulated external walls over 0.5 m thick. Consequently, developers are 'pushed' towards the use of renewable (typically referred to as 'bolt-ons') energy technologies. However, the problem becomes more complex when the range of renewable technologies is considered, and more complex again when the nature of the structure's location is added to the decision; a micro-turbine in a windy coastal environment may work well but what will be the impact of the surrounding houses if that technology is used in the context of a large development?

As with all decisions, there is a need for accurate and relevant information to assist the decision-making process. In the context of traditional and well-established technologies much, if not all, of the required information is readily available and such 'mature' technologies are generally well understood and there is an awareness of their limitations and the appropriate manner in which they can be used. In the context of new and emerging technologies, the situation is much more variable with regard to both the quantity and quality of information that is available for the decision-making process. Perhaps unfortunately, increasingly stringent legal requirements need to be met and the timescale for the selection of technologies is becoming shorter. This is arguably particularly so in the context of a country such as Scotland with its ambitious targets (especially with regard to the timescale) for the reduction of carbon levels. Thus, there is a level of urgency to the identification of technologies that will make a positive contribution to meeting carbon-related targets, and CIC Start Online has supported research relevant to this problem. The following are examples of online resources illustrating research relevant to the making of decisions regarding renewable technologies for buildings.

2.1 Optimization of Economic, Environmental and Energy Savings in Buildings

This feasibility study was carried out by a team from the School of Engineering and Built Environment at Edinburgh Napier University for Eurocapita [2].

Description. The need for an energy modelling and decision-making tool that aims specifically at buildings outside the residential and commercial sectors was identified as a result of the regular project work undertaken by Geocapita Investments Ltd. It is clear that there is a lack of data available in energy intensive industrial sectors such as industrial facilities, transportation projects and research and development complexes. In order to collect this data and to turn it into a usable form, the ENU team was commissioned to undertake research and to develop a design tool for use by a practicing investment company. Innovative features of the research are:

- The tool is specifically intended for project scenarios regularly encountered in design, allowing the early assessment of on-site energy available for a building in the context of its location.
- Provides a decision-making tool for the rapid identification of the most appropriate and cost-effective way of achieving lowest carbon emissions for a specified building.

The developed software allows the selection of low and zero carbon energy sources (LZCES) in buildings (residential and commercial). It allows defining if the optimum combination of LZCES in the building with the three variables to be analysed being: Energy—Environment-Economy (Financial costs). A competitor analysis revealed that the software tool currently has no competitors; it is a unique purpose built software which combines technical and financial analysis and with application not only in UK but worldwide.

Objectives. The project's objectives were to evaluate energy demand versus the energy resource and analyse each building under the three E's performance criteria. The feasibility study addressed all possible combinations of LZCES focusing on three aspects—three Es—of the: energy generation, emissions reductions and economics (i.e. financial feasibility). It provides all possible combinations of energy efficiency improvements and renewable energy retrofit for the building.

The research method provided for renewable energy economic modelling, selection of the optimum combination of the systems based on experimental methodology as well as computational modelling. The project was based on existing research carried out at ENU and aims to extend this to all types of residential, commercial and public buildings, and apply the software to all possible combinations of energy efficiency and renewable energy retrofit following the three E's assessment.

The work investigated the feasibility of the appropriate use of low or zero carbon energy sources (LZCES) within the built environment. A number of different assessments were employed including the collection and analysis of LZCES monitoring data. The tool holds ten different simulations and estimations such as energy demand, solar photovoltaic panels, passive solar air, solar water heating, ground-source heat pump, wind power, solar photovoltaic, rainwater harvesting, biomass, CHP simulation and a combination simulation. It is therefore a versatile tool in the context of decision-making with regard to renewable technologies for use in the built environment.

Outputs. Looking at the number of combinations, designers generally do not have time to do an analysis combining LZCES. Assessments can become complex, with a large number of combinations possible (50 different LZCES and different group sizes were identified during the project). In order to face this dilemma and help the designers, the analysis enables 'designers' to combine rapidly the different options available.

The innovative modelling tool developed can analyse the amount of sun, wind and rain of the LZCES resources for any location in the UK and therefore predict the LZCES performance. Software simulation parameters can be changed by the user for their own research thereby allowing for the evolution of the programme.

Comment. This kind of simulation tool can be regarded as a key facilitator in the rapid development of both sustainable design skills and renewable technologies that can be identified as being viable within specific situations/environments. In terms of design skills, the tool can achieve significant reductions in the timescale of pre-feasibility studies and more fully formed (having considered a range of possibilities) decisions concerning a project prior to its implementation. It is quite possible that such tools can significantly contribute to the development of a sustainable built environment both in the UK and worldwide. As part of that development, the technology of energy micro-generation is increasingly being seen by government as a key contributor, and this aspect of sustainable development has been studied by a number of CIC Start Online funded projects.

3 Technologies for Energy Micro-generation from Renewables

Renewable technologies can, as with most systems, be considered as being appropriate to at least two scales of production (in this case the production of energy), the macro and micro scales. There is also a possible third scale in between the micro and macro scales—the meso scale—but for the purposes of this chapter, there is no real benefit to adding a consideration of meso scale renewable technologies. With regard to the domestic-scale construction product (housing), the macro-scale renewable technologies such as wind-farms, large biomass facilities and, to a currently lesser but increasing degree, solar-farms are all possible additions to a development project. However, at least in the UK context, the scale at which these technologies become commercially viable tends to rule them out for the average development project. The contribution of such macro-scale technologies is usually seen to be in 'topping-up' the existing energy generation infrastructure rather than as servicing a distinct development project. This does not, however, rule out the use of renewable technologies for development projects; by scaling-down to the micro level (the so-called 'bolt-ons'), renewables can contribute to reducing the carbon emissions of individual houses and structures. The problem then becomes one of determining what mix of the available renewable technologies to apply to a specific development project. Again, the decision-making process requires relevant and accurate information if the selected mix of renewable technologies is to be successful. This can be particularly challenging in a 'non-commercial' environment where the client is not a developer or a private individual but a housing association (HA), of which there are a large number in Scotland.

3.1 Solar PV Feasibility Study for Homes in the Greater Easterhouse area of Glasgow

This feasibility study was carried out by a team from the Scottish Energy Centre, Edinburgh Napier University, for Easthall Park Housing Co-operative [1].

Description. Easthall park housing co-operative (EHPH) required to determine the potential for using solar photovoltaic (PV) technology in the Greater Easterhouse

Area of Glasgow (Fig. 5.1a–c). The background to this decision was to address the issues around energy demand versus supply amongst their ever growing housing stock. Issues related to energy conservation had been slowly addressed, and the majority of the housing stock in this area of Glasgow has either undergone refurbishments in the mid-1990s or are newly built houses/apartments that comply with current building regulations. The focus on improving the energy conservation and demand of the properties through energy efficiency continues, but the potential 'gains' in this respect are becoming more difficult to achieve. As energy conservation is tackled, there is also the concern of addressing appropriate methods of energy supply to the housing stock. Scotland has set a number of targets to reduce carbon emissions and buildings account for nearly half of the country's CO_2 emissions.

Following some of the Scottish Government's targets, The Climate Change (Scotland) Act has put in place a legislative framework to pursue a reduction in emissions associated with the unsustainable use of fossil fuels and placed duties on public bodies.

Dependency on global energy supply is a risk, not only the origin of this energy but also its availability in the not so distant future. Finite energy sources will overshadow the housing sector sooner rather than later and it is a wise decision to project towards a non-dependant energy supply.

Objectives. While the overall aim for the client in this study was to determine the technical and financial viability of this kind of technology to the context of HA apartments, there was also an awareness of the issue of fuel poverty (given the circumstances of perhaps the majority of 'users'). The client also expressed a desire to gain a greater understanding of the relationship between carbon reduction and a level of investment over a longer period than may be considered 'normal' for other clients. This challenging set of aims led to some detailed objectives being identified for the feasibility study in relation to issues of understanding both the 'physics' of the technology and how to obtain optimum efficiency. The technical constraints related to identifying what type of PV panel would be optimum for the selected buildings (in terms of efficiencies and production factors) were also to be considered, along with the impact of energy suppliers sizing constraints in terms of the role of the Feed in Tariff (FiT) and sell back to grid economies. This latter item is typically of concern to all users of this type of technology with regard to understanding the issues surrounding the economical payback of all equipment of a particular size. Finally, the client needed an articulation of the role of the location and orientation of the properties in the performance of the installed system (for which 'best practice' case studies of renewable energy usage and application were deemed desirable).

The feasibility, economic and technical results in the study report were calculated and produced by using one of the leading design software tools on the market for European photovoltaic systems (PVSyst). In order to obtain valid and reliable results the software requires the following information:

Fig. 5.1 **a**–**c** Types of houses in Easterhouse, Glasgow [1]

- Tilt of pitched roof (if flat roof an ideal and on optimum tilt can be suggested)
- Orientation of roof (southern orientations)
- The amount of power required, in order to size the system
- Type of modules specified—monocrystalline (typically 15 % efficiency) or polycrystalline (typically 8–12 % efficiency), for example.

In addition, to make sense of the results obtained by the software, it is essential to know the following:

- The initial demand of energy
- Cost of the panels and equipment
- Funding mechanisms—government or other
- Cost of the price per kWh by the energy providers.

The above provided the tools to conduct an economic feasibility framework which would determine whether the installation was feasible both technically and economically.

Outputs. The study report points out the essential constraints that a solar PV design should focus on. It is important to note, for example, that the PV sizing of a roof depends on many aspects of the building. The limitations relate to the type of technology and the number of inverters which influence the FiT constraints and also the grid connection constraints. They all have an influence on the economic and energy output, and a balance between them is preferred.

Overall, the site constraints are found to be the most demanding factor when designing an efficient and economically productive PV system. It is pointed out throughout the case studies that the site where more dwellings are eligible for PV modules is the site located in the Easterhouse area, as the urban setting of the dwellings favours (in many occasions) a southern orientation.

A particularly useful output of the study is a table that allows for some prediction (without having to carry out the full calculations every time) of both energy generated and tonnes of carbon saved for roofs of a similar area, overall dimensions, orientation and degree of tilt. This represents an important guide for producing estimates of the total output of energy from specific PV modules in relation to dwelling type and roof orientation. However, the study does stress that all buildings will have their own specific constraints and although they could be orientated similarly to buildings within the case studies, there may be particular issues to be considered in terms of the overall performance of any installation. An issue that may be significant is suggested as the relationship between the extent of shade and building design. Some dwellings, for example, may be located at the edge of a row of houses with odd roof angles. Others may be located where adjacent roofs meet each other.

Comment. In analysing the interaction of PV module performance and factors such as roof orientation, etc. the study leads to an interesting possibility to ‘sidestep’ the initial cost of such installations (something that may be particularly attractive to organisations with a non-profit ethos). The study suggests the use of schemes that involve “rent a roof” which will include the collaboration of a third party organisation (many times an energy supplier or an external company) which will be able to fund the capital cost of installation and maintenance of the PV panels. This company in many occasions will benefit from the FiT's over the total 25 year period but will supply the dwelling occupier with the generated electricity. This scheme would bring advantages to the tenant as their electricity bill can be reduced or abolished completely depending on the dwelling type. This in turn can reduce fuel poverty and take off the pressure of investing in such a big initial capital cost (and also has implications for on-going and uncertain maintenance costs that may act as a disincentive to HAs).

On a wider front, the study contributes to improving the quality of the decision-making of all organisations and individuals by providing an overview of some possible alternatives of sizing for the diverse housing stock that the EHPH has in their two main sites, Easthall and Kildermorie. In supplying performance data for up to four options per building studied, the study facilitates decision-making with regard to factors such as the PV technology (monocrystalline or polycrystalline), phase (single or triple) and size and tilt of roof. This kind of support for decision-making has considerable value but there is a slight caution to be considered in that the data needs to be updated as the technology improves and becomes more efficient and economies of scale enable prices to drop as the technology becomes more widely adopted. Therefore, there is a need to be aware of on-going developments that improve existing renewable technologies. CIC Start Online has funded studies in this area.

4 Improving Renewable Technologies

Renewable technologies can be regarded, to varying extents, as essentially immature technologies in that they are relatively new resources in the context of construction procurement. Consequently, these technologies have only recently begun to be incorporated into 'mainstream' development projects and thereby allow for a wider base of information and data regarding their 'real-world' performance to be gathered. While there is no doubt that some of the renewable technologies currently available have been available for use by the construction industry in some form for decades, most have been used on the fringes of the industry and in relatively small numbers. In many respects, it can be argued that some renewables suffered in terms of adoption by the mainstream through their association with what were perceived as the extremes of society—the so-called 'tree-huggers'. While these early adopters should be praised for their vision, the majority of society did not regard them positively and the adopted technologies suffered by association. It is thus only relatively recently that serious research has been carried out on the performance achievable by such renewable technologies as solar thermal collectors, wood pellet stoves and the various forms of heat pump. Such research is beginning to identify areas where true performance improvements can be achieved and both decrease the cost and increase the output of what were previously regarded by many as fringe technologies.

4.1 *Achieving Higher Heat Pump COP Through the Use of Roof-Top Thermal Solar Collectors*

This feasibility study was carried out by a team from the School of Engineering and Built Environment, Edinburgh Napier University, for European Energy Centre [5].

Description. The adoption of ground-source heat pumps (GSHP) is dependent upon a number of factors, key among which is the performance level of such pumps. The manufacturers' claimed performance levels (coefficient of performance or COP) are not always achieved in 'real-world' situations. This dearth of in situ measured data on COP of GSHP and their equivalent performance may be a factor in the relatively low level of adoption of this technology but there is sufficient data to conclude that a further factor is the need for a performance improvement. This seems to be particularly the case if the technology is to achieve wider adoption in the residential and commercial sectors. In order to achieve higher heat pump COP the research team studied the possibility of 'assisting' GSHP technology through the use of roof-top thermal solar collectors (referred to by the study team as 'solar-assisted ground-source heat pumps' (SGSHP).

Objectives. A key objective of this work was to determine the threshold coefficient of performance required to achieve the financial and environmental break-even point, compared to a conventional heating system. This was to be determined for two scenarios, i.e. (a) space heating only and (b) space heating combined with hot water heating. Additionally, the performance of three systems (gas boiler based space heating systems for buildings, electrically operated GSHP and SGSHP) was to be compared using the criteria of energy use, emissions and financial cost.

Outputs. The key result of the study was the conclusion that the use of solar collectors combined with ground-source heat pump helps in achieving only marginally higher COP. Put simply, based on the cost of installing solar collectors (in this case 63 m^2 at approximately £1,000/m^2) to supplement the GSHP, the performance gain (approximately 0.06 %) is not commercially viable in the Scottish environment. However, it is also worth noting that the combined technology may have a more favourable outcome in cold regions that have a higher irradiance over all heating seasons than is typical in Scotland.

Key cost-related conclusions are that a heat pump is a third cheaper to run than a gas boiler when only counting the cost of energy, but when counting all the costs through the lifetime of each system, a heat pump's overall running cost is nearly 50 % higher than that of a gas boiler.

A final output of the study is particularly interesting when the focus is solely on the issue of carbon levels; decarbonising the grid will make heat pump a very attractive low- carbon solution compared to the other presently popular sources of heating.

Comment. The study made useful contributions to the manner in which one particular renewable technology may develop in the short-to-medium term. In evaluating an innovative idea (combining solar collectors with GSHP) and producing 'real-world' in situ measured data, the study clearly demonstrated that the performance gains are simply not financially viable in environments such as

Scotland but may move closer to being financially viable in other environments (cold but having higher solar irradiance values than Scotland). Thus, it is possible for developers and individuals to examine the data produced and make an informed decision before investing a considerable amount of money on what would otherwise be an untried technology.

There is also a value to the data produced with regard to informing decisions where perhaps financial viability is not the key factor; for those who are seeking a low-carbon solution to their heating requirements the heating system comparison data clearly shows that a GSHP system has a significant advantage over a gas system (CO_2 levels are approximately 44 % lower). However, while a further gain in reducing CO_2 levels can be achieved through the use of a SGSHP system, this is minimal (approximately 0.05 %). The study clearly evidences that in both financial and CO_2 reduction terms the SGSHP concept is not viable for environments such as Scotland. Future development aimed at performance improvement of the GSHP technology should therefore be focused elsewhere.

The concept of 'performance improvement' is not always just about issues of how much energy can be generated; in the case of biomass systems, for example, there is an aspect of 'performance' that is regarded as a barrier to the wider adoption of this renewable technology; the problem of biomass 'fuel' storage. External storage of biomass fuel and in many cases heating appliances is essential for significant deployment of biomass-based heating installations in the UK. Most installations are in areas which are distant from the mains gas network and therefore offer significant CO_2 savings given the 'displacement' of oil, LPG, electricity or coal. However, there is frequently a problem regarding the storage of the biomass fuel; a lack of suitable space prevents the adoption of the technology. If potential users are discouraged by poorly performing storage solutions they will simply not invest in the biomass technology. Key issues relevant to the performance of the storage component have been identified as:

- Choice of material suitable for various climatic conditions to ensure condensation free storage for pellets and quick drying times for logs.
- Mechanical testing of storage unit designs regarding various types of loading, including temperature fluctuations, wind and snow loading.

For some users the 'solution' will be to use biomass while for others the storage problem for this technology will remain a barrier. For many users, solar technology arguably remains the most accessible of the renewable technologies.

5 Use of Solar Energy for Buildings

Perhaps one of the great ironies of solar energy is that mankind has tended to focus on viewing it as a problem rather than as a benefit, in that the perceived need to cool buildings has arguably received greater emphasis than has finding ways in which to make use of this abundant ‘free’ resource. The perception of solar energy as being problematic is, fortunately, becoming increasingly outdated as a range of solar strategies are developed and made use of as a means of reducing energy consumption and displacing carbon from the energy supply chain. Such strategies can be placed under a few broad headings such as solar gain (directly by the building fabric), solar heating (of water) and solar generation (of electricity). There is, of course, no reason (other than purchase cost for the hardware) why any building located within a suitable part of the world cannot make use of all three strategies in combination and buildings are increasingly being designed to do precisely that. As with renewables in general, the basis of much current solar technology has been around for a very long time, albeit in a relatively basic form. However, the development of increasingly efficient materials (such as in the production of photovoltaic cells) is improving the performance of individual technologies. This in turn leads to a widening of the range of locations and structures within which they are regarded as viable alternatives to more traditional technologies. As such technologies develop further it may well become realistic to talk in terms of a solar economy, with a carbon-free energy supply chain that may even be specific to a single building.

5.1 Solar Wall Systems for Domestic Heating: An Affordable Solution for Fuel Poverty

This feasibility study was carried out by a team from the School of the Built Environment, Heriot-Watt University [6] in conjunction with Changeworks.

Description. The study focused on developing earlier work on the concept of a Solar Wall Heating System. This system uses the thermal mass of the building (the internal solid walls) to store solar heat collected during the day when solar heat is available. The heat is released throughout the day and night to heat internal spaces. As the walls are used for storing heat (thus performing a similar function to a conventional hot water tank), the heat exchange efficiency of the system is improved and the walls act as a warm core, providing better heating quality. As the heating panels are thin, attaching them to the wall presents no restrictions that a normal radiator would not do in terms of interior design and furniture arrangement.

The key device is the heating panel, which comprises a row of thin pipes embedded in the internal walls. Water heated in the solar collector during the day flows through the pipes and transfers heat to the solid walls, allowing the walls to release the heat during the night.

The solar warm wall system is expected to be a novel and effective solution for heating buildings with solid internal walls, particularly tenement dwellings. These buildings have been identified, in terms of improving energy efficiency, as hard to treat due to their construction features which include uninsulated stone walls, etc.

Objectives. The study had a main objective of developing a computational fluid dynamics (CFD) model and a mock-up lab-based system. The value of this objective was that it would provide a platform for various tests to develop optimised operation and controls to maximise solar heat collection. More specifically, the study, using both computer and lab models, would test the new heating system under representative conditions: namely those of a Scottish tenement flat in March. Three specific objectives were identified for the study:

- Quantify the thermal effect of internal solid walls used as thermal storage for solar heat in tenement flats for all-day usage;
- Optimise the device to maximise heat exchange between the wall and hot water from the solar panel;
- Provide a modelling tool to enable a Solar Warm Wall system to be designed to suit individual buildings (either new or retrofit).

In order to achieve the objectives, the study was structured into three areas of research:

1. Analysing the solar availability and heat demands in two typical Scottish properties, using Edinburgh as an example.
2. Developing the CFD model for various modelling studies examining the various key controls.
3. Setting up of the mock-up in the Lab and collection of data for model validation.

The study was recognised as having two technical challenges regarding the system development. First, to optimise the technical and operational parameters for the system, and second to estimate the total life costs of implementing this system in real buildings, both of these being key to the possible future adoption of such a system.

Outputs. In terms of moving forward the development of this particular renewable technology, the study produced three key outputs:

1. The solar energy collectable is more than is currently used (primarily for domestic hot water); increased solar collection is possible if the heat store capacity is increased, and this can lead to further cuts in energy bills.
2. The heat store is effective in the panel wall structure; it both stores the solar heat and improves heating quality (in the study two rooms of different occupancy patterns were used).
3. The computer model developed is robust and sensitive enough to reveal changes in heat transfer due to subtle variations in input variables, such as thermal properties of the wall layers, panel configurations and so on (relevant to future studies to develop an optimal operation system that integrates water cylinders and wall panels to maximise heat harvesting).

On a financial basis, the study's basic cost analysis suggests a 16 years payback period for such a system in a tenement flat. However, in a different situation the payback could be shortened (a larger solar collector in houses and bungalows would have a positive effect on the payback period).

The study also identified two parallel 'development' tasks regarding the production of a 'market-ready' system. One task would be to integrate the wall panel with a cylinder and develop an optimised control algorithm. The other would be to carry out a parametric study, comprising a series of modelling tests, to enable better control of the temperatures and flow rates both at the solar panel and the heating panel. This should also include the primary heat store (the hot water cylinder) when it is integrated with the existing setting. Along with these larger activities, the study has identified a number of minor improvements that could also be made. These would include tests on another type of wall heating panel, which is thinner as it uses a network of capillary tubes for hot water.

Comment. The study is another good example of an innovative renewable product that, with further development, has the potential to be applicable to a range of common scenarios. The potential of such a system is not constrained by the context of its current development activity (Scottish tenement buildings) and it could have a wide applicability within the built environment.

The study also shows that the solar collection of current solar hot water systems can be improved upon so that, even in Scotland, more solar power can be harvested to contribute not only to domestic hot water but also domestic space heating, particularly in those 24 hours per day occupied buildings with heavy thermal mass. However, not all solar projects are reliant upon being of a large scale; relatively small items within the built environment can, with a little innovation, make a contribution to the production of renewable energy. Another feasibility study focused on the humble lamp post.

5.2 Exploration of the Creation of PV Renewable Energy from Lamp Posts by Direct Delivery into the National Grid

The feasibility study 'Exploration of the creation of PV Renewable Energy from Lamp Posts by direct delivery into the National Grid' was carried out by a team from Heriot-Watt University in conjunction with Grid Post Ltd [4].

Description. Grid Post Ltd. aims to explore the options that exist to design, develop and implement a direct delivery solution for PV generated electricity directly into the grid from various social infrastructure, focused initially on lamp posts and other lighting solutions.

The aim of the study is to evaluate a system utilising the available infrastructure of the lamp post which is already well connected to the national grid, while also using it as a structural element for placing the PV panels. The system differs from the traditional PV system as it does not have any storage system. All the energy generated is directly fed into the grid.

Four different cities were selected across the UK to have a preliminary analysis of the available solar radiation. They were Birmingham, Edinburgh, Glasgow and London. The case of placing a multi-crystalline PV panel at an angle of 30° with the horizontal is analysed for these four locations. The analysis was conducted using the commercial PV system design software, PVSYST. This is a preliminary analysis to give an idea of the net solar electricity production and its variation across different places and variation in energy production over the whole year.

Objectives. The study sought to determine the cost reduction achievable in local authority energy bills by utilising the available infrastructure of the lamp post which is already well connected to the National Grid while also using it as a structural element for placing PV panels. The structural element of the lamp post gives a high altitude to the solar panel. The system differs from the traditional PV system as it does not have any storage system. All the energy generated is directly fed into the grid.

In order to find the optimum angle for placement, a series of calculations were performed to find out what angle would give the highest amount of incident solar radiation. The simulation included that the PV panel is mounted towards south facing. In addition, incidence angle, day length and albedo factor of 0.2 was considered.

Outcomes. The study determined that Glasgow achieved the lowest solar radiation of 949 kWh/m^2/year, whereas, the highest global radiation of 1,022 kWh/m^2/year was achieved in London. The average yearly global solar radiation on a tilted surface of 31° placed in Edinburgh is 985 kWh/m^2/year. However, the global solar radiation on the horizontal surface placed in Edinburgh is 876 kWh/m^2/year. The simulations indicated that an average energy collection improvement of 12.5 % can be made with an appropriate choice of inclination angle of the solar collector.

In order to have an optimum design of the system, the material choice is important in selecting the type of PV panel and the inverter. Proper matching of the output DC voltage from the solar panel needs to be done for the input DC voltage of the inverter.

Based on the available quotations of component costs and solar data from the modelling carried out for the study the indication is that the highest financial benefit of £303/per system will be achieved in London. In comparison the lowest financial benefit of £275 will be achieved for the same system installed in Glasgow.

Finally, it should be noted that inverter design plays an important role in determining the viability of the Grid Post. Suitable inverters need to be designed and connected to the grid. Likewise, suitable electrical, thermal and testing requirements need to be met for the system.

Comment. The assessment of available solar energy is a common theme across work carried out within the context of sustainable development of the built environment, and understandably so; energy conservation and generation is a key concern in the context of both energy security at the national level and also for the reduction of CO_2 levels. This study evidences that the development of technology continues to present new possibilities for energy production and thereby bring about a reduction of costs. The need for local authorities to do more with less money gets plenty of attention from the media and study FS-36 highlights one possible contribution to achieving that. However, there are other aspects to sustainable development that do not get a great deal of coverage but nonetheless make a considerable contribution. One such aspect is the conservation of water.

6 Water Saving

It is perhaps understandable that for certain parts of the UK the concept of needing to save water is regarded as an unnecessary constraint—when the problems that you are experiencing actually relate to having too much water, it can be difficult to appreciate that it is, overall, a relatively scarce resource. Under such circumstances the proposal of a ‘national grid’ for water distribution is something that can be regarded as inevitable, albeit one that is considered by many experts in the area as being too technically demanding to be realistic. Nonetheless, the temptation to those parts of the UK that regard themselves as having a plentiful supply of water (typically a relatively high rainfall) of being able to sell a surplus of a resource to those areas in which it is in short supply will always lead to a consideration of how it may be achieved. Whilst such a development may prove to be a possibility in the long-term (possibly the very long-term!), a more productive perspective would be to focus on water conservation generally. This is not simply a matter of considering the availability of water—irrespective of factors such as high rainfall levels, water is an expensive product that should not be wasted; the processing and distribution of the ‘raw’ resource are relatively expensive activities. Research directed at how water can be used more effectively and how consumption-related behaviours can be modified for the better is therefore both relevant to achieving a sustainable built environment and, for those whose water supply is metered, a possible means of reducing costs.

6.1 Identifying Effective Communication Strategies to Minimise Water Consumption in Social Housing Through Interaction With Tenants

The feasibility study ‘Identifying effective communication strategies to minimise water consumption in social housing through interaction with tenants ‘was carried out by a team from the School of the Built Environment, Heriot-Watt University [3] in conjunction with Home Log Book Solutions Ltd.

Description. While Scotland is a water-rich country, this does not mean that unlimited water is available for treatment and supply. There are regional variations in the capability and flexibility of the water supply systems. This study funded by CIC Start Online was commissioned by Home Log Book and performed by Heriot-Watt University with the specific aim to elicit and understand the attitudes of HA tenants towards water use in their homes.

Water is currently un-metered at an individual dwelling level in Scotland; a temperate climate and ample rainfall might lead to an impression of water abundance. There is no perceived need to conserve water in Scotland, but use leads directly to energy consumption—mostly to heat the water. Generating energy produces carbon dioxide (CO_2), one of the main greenhouse gases which causes climate change. In addition, there is a link between domestic hot water use and fuel poverty which is not yet fully measured by industry professionals, or understood by domestic home owners and tenants. This raises issues of communication concerning factors such as the perceived value of water, its relation to energy use, and so on. Determining the reasons for communicating and understanding what is to be achieved are best done in consultation with intermediate and end users. It is also important in determining which communication pathways and media products are most suitable to develop.

Objectives. The study focused on three key objectives:

- Understand the attitudes of HA tenants towards water use in their homes.
- Elicit tenants' preferred media for communicating water conservation messages.
- Recommend communication strategies to encourage tenants to participate in a programme of widespread water metering in HA dwellings.

In achieving these objectives, the researchers took the approach of a qualitative study, for which 10 individual interviews were initially (later reduced to eight due to various problems) agreed to be conducted to examine the current trends, needs and preferences of Link HA tenants in Falkirk. All discussions were taped, fully transcribed, in addition to notes being taken during the meetings. The approach adopted to analyse the contents of focus groups and interviews was based on 'content analysis' methodology, thereby allowing data to be reduced to manageable representations.

Outputs. The results of the study should be considered in the context of the sample of tenants representing a specific user group (predominantly consisting of the elderly and people with disabilities) that is more likely to represent the 'users' of social housing. Interpretation of the study's results was carried out under the following headings:

Water conservation information. Tenants who participated in this investigation, unanimously agreed that they were never provided with any kind of information regarding water efficiency or water conservation. Furthermore, they were unaware of the need to conserve water and therefore did not think about saving water. Tenants agreed that information on current issues is generally provided to them by their HA through general meetings and as long as the message is clear and effective (providing them with information on the importance of water conservation based on facts and figures), it is likely to have an impact.

Water as a precious resource. Respondents regard water as a key resource for survival necessary for carrying out daily routines such as drinking, cleaning, washing, watering plants. A majority of the respondents regard water as the most important resource when comparing with energy, pollution, transport and recycling.

Motivations for water savings. When tenants were asked about what encourages them to think about their use of water and to value it as a precious resource, the respondents could not come up with a particular reason other than (the majority) just think that wasting water is silly and not the right thing to do. However, a minority does not believe in saving water at all.

Personal actions to reduce water wastage. Respondents in general do not think that they waste water. The majority confirmed that taking a shower is better than having a bath. A number of tenants believe that dish washers are the most economical device as long as it is used to its full potential when it is completely filled up. For a minority the incentive for not wasting water is to recycle water after washing dishes to be used for growing their own vegetables.

Views on an effective and memorable campaign. The most effective campaigns were suggested as the ones that are presented on television (TV). This may lead to the conclusion that TV is the most popular medium for respondents. For a minority (partially sighted and blind) radio campaigns are the only preferred option.

Overall, an effective campaign is suggested as being not just figures and numbers but explaining the causes, preventions and actions that can help to bring about a change. For example, telling people that they are using a hundred gallons of water a week which can be reduced by 50 % by not having so many baths but having showers instead, would be effective.

Trustworthy members of the community. A majority of respondents have shown confidence in the water companies as they provide water and have all the necessary information about supply, demand, how much water is used and how much it costs. Respondents have mixed views about the way their HA provides information to them. 20 % of respondents voted for government organisations. A minority also voted for religious leaders who should be explaining to people the importance of water conservation in their own way.

Actions influencing water efficiency. A majority of respondents deem media as the most effective way of promoting water efficiency messages. According to them this would work if there are advertisements which actually mean something rather than the ones that are aimed only at selling. Some respondents suggested that it should be a slow but persistent process as sometimes people don't get the message the first time so it should be followed by a reminder.

Effective medium for communication. TV is the popular choice followed by eye catching posters, direct mailing and radio. TV is deemed the best way to get a message across to all generations; direct mailing and newsletters are the preferred choice for older generations. Tenants strongly prefer to have information pasted on the noticeboards in their sheltered housing accommodation.

Information on utility bills. 80 % of respondents do not think that the information provided on the back of a utility bill is important and therefore they don't read it. They believe that the information provided on utility bills is not user friendly, the typeface is far too small, and that it is unintelligible.

Barriers to adopting conservation measures. The major barrier perceived by tenants in Scotland is the fact that people have a set amount to pay no matter how much water is used. It is said that in England people are more aware of their water use as they have water meters and they know it is going to cost them money.

There was a perception that leaks are a major problem, especially in England, which are not always fixed right away and lose hundreds of gallons of water. This puts people off from doing any savings.

Comment. Given that the respondents were not especially diverse in terms of social class, income, etc. the results of the study could be treated with some caution in terms of forming the basis of an effective water conservation/consumption reduction strategy. However, the results do have a value in terms of the overall consistency of opinions expressed. Arguably the key result is that the majority does not have awareness of water conservation and do not have any connection between the need for conservation and climate change. In terms of formulating a campaign to achieve water conservation in Scotland (or countries where similar beliefs are held) it seems that the first step has to be one of providing factual evidence that there is indeed a need to conserve water.

In terms of 'delivering the message' the most effective medium appears to be TV (other than for the blind community, for whom radio is most effective), while the least effective is adding information to utility bills. Overall, the study indicates that the message must be factual, clearly communicated, and make use of more than one medium (in response to the needs of different groups).

7 Conclusion

The role of technology within the production of the built environment has always been a central one. However, in the traditional context the important technologies have always been those related to the efficient production of materials and components, and those that have enabled the completion of increasingly large and complex structures. These can collectively be regarded as the 'production' technologies. However, as the nature of the political and natural environment has undergone changes, the emphasis has moved to a different range of technologies; those related to achieving targets relevant to a sustainable way of living while retaining a level of comfort and quality of life that has, for many, come to be regarded as the norm. Construction development projects are therefore adopting more and more renewable technologies such as micro-generation of electricity.

There is also a drive to use technology to enable waste-reduction and conservation of resources other than energy; water conservation and reduction of biomass disposal are both part of the renewable ‘revolution’ that is changing the built environment for the better.

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Construction

David R. Moore

Abstract The construction phase of a building project is where the theory applied at the design stage starts to become reality. This reality is formed in an environment of regulation and cultural expectation of how the industry should practise its skills. Traditionally, these skills have been strongly aligned with criteria such as cost, time and quality. Organisations such as CIC Start Online are increasingly widening this traditional expectation to include new expectations that require the industry to develop new materials, technologies and management skills. Along with new materials and technologies come new possibilities to build in novel ways that have not previously been attempted. In order to maximise the probability of achieving a successful outcome (such as being zero carbon) for the project, the managers of the construction process have to be open to developing new skills (such as carbon accounting and management). However, these new skills, materials and technologies are not always going to be applied in the context of a new-build project; the built environment across Europe comprises many old buildings. Construction managers and designers will need to develop a further skill—treating old buildings sympathetically when adding new materials and technologies in the search for improved carbon-related performance.

1 General

The construction phase of the building procurement process can be argued to be the point at which reality begins to take hold, and success or failure (with regard to achieving a sustainable building) begins to emerge from the ideas of all those involved in the design of that specific building. At this point, all the claims and promises start to be tested; issues of time and cost are traditional concerns but other

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success criteria are increasingly being added and given emphasis as sustainability moves from being a peripheral concern to a core one. The boundaries of the construction phase are becoming more frequently set by wider concerns than local or even national issues with regard to planning, finance, etc. The construction environment has become more complex in terms of European legislation and requirements, decision-making in a context of unknowns regarding actual performance of retro-fitted technologies, the emergence of new materials and components the real-world performance of which may be largely uncertain, the need to take in broader concerns at the design stage, and emerging evaluation criteria such as carbon accounting. Such an environment requires a relevant base of research to provide reliable data and information to support those responsible for successfully navigating the construction phase of a built environment project. The sections within this chapter will provide examples of how CIC Start Online research projects have contributed to meeting that requirement. Further studies, consultancies, etc. are listed in an annexe at the end of this book; within the construction section of the Knowledge Base pages of the CIC Start Online website there are five feasibility studies, one academic consultancy, 11 'Innovation Review' articles and two webcasts.

2 European Context for a Sustainable Built Environment

In recognition of the fact that the sustainability agenda is of relevance at a transnational level, individual countries are increasingly becoming involved in projects that pool resources and ideas across national boundaries so as to more effectively address areas of concern to all involved. The EU has supported and encouraged many relevant projects that act as examples of this transnational co-operation. Of these, one of the most appropriate for consideration at this point is the Build with CaRe (Carbon Reduction) project, which commenced in 2008.

The project comprised local and regional authorities, universities and institutes from ten regions in five countries in the North Sea Region, all of whom came together with the objective of making energy-efficient building design the mainstream as a response to the prioritisation by the EU of reducing human impact on climate change. Since buildings structures account for around 40 % of EU energy consumption, achieving energy-efficient building is a key factor in achieving wider EU goals regarding sustainability.

Despite tested and available technologies and 'incentivised' energy pricing strategies, energy use in the built environment continues to exceed the level that is theoretically possible. Build with CaRe was focused on taking the necessary steps, in collaboration with the building sector, to develop a transnational strategy for increasing energy efficiency in building. Through providing a forum for interested parties, along with tools for importing and exchanging knowledge and experiences, Build with CaRe provides professionals with the latest ideas and insights, best practices and critical reviews of local actions relevant to a sustainable built environment [2].

2.1 *Build with CaRe Conference*

The Build with CaRe (BwC) conference was held at Robert Gordon University (RGU) in Aberdeen on 2 June 2010. The conference was part of a wider BwC project which aims to support and promote energy-efficient building design and construction in the North Sea Region in Europe.

The aim of the conference was to discuss the planning and policy issues related to supporting the implementation of energy efficiency practices in buildings. The conference focused on European policy and how this translates into both UK and local legislation, whilst also looking at the policy issues in other EU countries such as Germany, Sweden and France. Not only was the conference an opportunity for dialogue between policy makers, planners and the construction industry at an EU-level, also it provided insights into how some of the policy issues may be addressed in practice [1].

3 Innovative Building Materials and Components

The traditional perspective on the construction industry that is typically applied by stakeholders having little direct experience of the industry's operation is one in which relatively few materials and components figure. Timber, concrete, steel, glass and so on will usually be mentioned, but the more exotic materials in use will rarely be mentioned. Those stakeholders with a focus on, and awareness of, sustainability issues will be aware of the 'natural' products such as wool that are used as insulation materials but may be less knowledgeable with regard to the various forms of composite materials that are in use and being developed for future use. Such a situation is simply a reflection of the complexity of the modern construction industry, which is such that even some professionals within the industry struggle to be aware of the full range of innovative materials and components available to the industry.

3.1 *Testing of a Method for Insulation of Masonry and Lath Walls in Existing Domestic Scottish Construction*

This feasibility study was carried out by a team from the Scott Sutherland School of Architecture and the Built Environment, RGU [3] for Craigie Levie in conjunction with KDL.

Description The method involved using water-blown foam, developed by Canadian company Icynene Inc (see Sects. 7.4.1 and 8.5). This is the first time such insulation has been used in an historic building in Scotland. The water-blown foam was created specifically for injecting into delicate structures. The foam expands slowly putting little pressure on the fragile inner wall and, as it is 100 % water blown, it contains no harmful blowing agents. Additionally, through its open cell structure, the foam will allow the wall to breathe which will assist in controlling moisture movement. A method was discussed and developed remotely, then further on-site between all partners to come up with an appropriate "harm-free" method adapted to this specific building.

Prior to the trial, considerable discussion took place between the researchers, local architects/SME and the company who agreed to supply the insulation material and implement it by using the proposed method agreed by the team. The agreed method was tested in a workshop by KDL before its application on the real wall. This trial involved the construction of a wall representing the same characteristics of the real wall in terms of cavity dimension. The spray foam sealed the area behind, where the skirting boards would be fixed, resulting in no loss of pour material. The pour material was capable of being injected down a 2,800 mm pipe and expanded vertically between and behind the vertical studs, leaving no voids. No deflection in the hardboard was detected. This trial was deemed to be successful, and a decision was made to adopt this method for the field-trial.

Objectives The presence of an existing building stock and its relatively poor energy performance puts great emphasis on the upgrading of existing buildings. The basic fabric of these buildings: walls, roofs, floors and services require upgrading to reach present and future increasing standards of thermal performance. For the Scottish context, this research focused on existing load-bearing masonry construction with internal plastered lath lining.

The main aim of this research project is to develop and test the feasibility of a method of insulating an existing house whilst maintaining its original architecture features. The project comprised of the following phases: Phase 1 (Building selection and site surveying); Phase 2 (Testing method preparation); Phase 3 (Site preparation); Phase 4 (Application); and Phase 5 (Remedial work).

Outcomes In transferring theory to practice, there are always 'real-world' problems of a practical nature to be resolved and, in terms of the wider adoption of this particular method of retrofitting, the study had several outcomes of value:

- During the trial, it was discovered that the PVC pipe was not capable of more than one injection without blocking, and therefore not suitable for this application.
- The debris behind the lath and plaster should have been cleaned of debris before the draw strings and pipes were installed. This would have made installing the pipes much quicker and easier.
- It was determined that in some locations the draw cords for the delivery pipe were not required and the pipe could be inserted, positioned and withdrawn while attached to the fibreglass probes. This would make the process quicker in certain circumstances.
- It was found that the Icynene insulation added rigidity to the wall.

Arguably, one of the key outcomes of the study was that, while the installation was deemed successful, it was determined that this was dependent upon a high level of skill, along with an understanding of the construction of the building to ensure that no damage is caused; trained installers with a joinery background would be suitable. The process needs to be executed unhurriedly and methodically with no time constraints placed on the operatives.

Comment In terms of reducing the uncertainty attributable to a new material being applied in an existing context, the study has potentially significant value. The team established, for example, that the target buildings for the application of this novel material require the installers to have an existing level of expertise and understanding with regard to the morphology of such buildings. They would also need to develop expertise concerning the use of the Icynene material. The more usual context for the application of such a material is new-build construction and in such a context the installer would not require to have the same level of understanding of the building's morphology.

Obviously, such a finding is important in terms of future issues of who is 'allowed' to instal the material; use by naïve, inexperienced individuals could lead to significant damage to a property. This study provides an excellent example of the need to consistently be aware of the training needs attendant to the adoption of any new construction material or techniques. Arguably, this understanding of material properties and context-specific requirements also applies to achieving successful innovations with regard to new markets for old materials, as was found in a study investigating new markets for recycled plasterboard.

3.2 Investigating New Markets for Recycled Plasterboard

This feasibility study was carried out by a team from Glasgow Caledonian University in conjunction with First Options Services Ltd [5].

Description Plasterboard waste arises primarily through construction and demolition activities. Waste from new construction arises during installation through wasteful design, off-cuts, damaged boards and over-ordering. Plasterboard waste is also generated from demolition and refurbishment activities, such as from removing partitions, refurbishing wall and ceiling linings, repairing damaged linings, and from complete soft-strip before demolition of a building.

Recovered gypsum is recycled to manufacture new plasterboard. However, in order to maximise environmental benefits, income streams and diversity of outlets, the company in addition to supplying gypsum to plasterboard manufacturing is also seeking to identify and exploit new alternate markets.

Objectives The objectives of the project are to assist First Options to identify and exploit a new and emerging agricultural market for odour control. The project will build on existing academic research within the university and through a programme of farm trials and laboratory testing will assist First Options to assess the viability of the use of gypsum for odour control in the Scottish agricultural sector.

Outcomes The study is yet to report outcomes. However, there is no reason to expect that the outcomes will not be favourable as research elsewhere has indicated that recycled plasterboard (unless heavily contaminated during its original use) can prove effective in an agriculture context; as a replacement for sawdust in animal bedding, mopping-up of spillages, soil improver, fertiliser and in the treatment of animal manure (Nature's Way Resources, no date).

Comment Plasterboard is arguably one of the more problematic building materials, in that its success as a material has resulted in it becoming near-ubiquitous (particularly in the new-build sector) but also in that there can frequently be a high level of waste in terms of off-cuts (to accommodate window and door openings, etc.). In the context of seeking to discourage the 'landfilling' of this waste, SEPA, the Environment Agency and WRAP have worked together to develop a protocol (PAS 109) to encourage the recycling of gypsum. In working with First Options to produce quality assured products, the GCU team are in a position to contribute to one of the more troublesome (from a sustainable development perspective) construction materials being seen in a more positive light. Through projects such as this, the industry can evidence its willingness to adopt a more sustainable approach to the construction activity.

3.3 The Use of Cross-Laminated Timber in High Density Affordable Housing

Placed within Edinburgh Napier University's Forest Products Research Institute, the Wood Studio's focus is on innovation in the use of timber in architecture and construction.

Description One of the projects at the Wood Studio is this feasibility study, focused on examining the economic viability of domestically produced cross-laminated timber (CLT) panels in the construction of high density affordable housing projects [10]. The study represents a development of advanced work on commercial production in Scotland of CLT manufactured from Scottish grown timber (carried out through the involvement of the Scottish government, Scottish Enterprise and Forestry Commission Scotland).

Objectives The study aims first to examine the benefits of cross-laminated timber construction in high density affordable housing in three ways:

- Bespoke panel production related to specific project designs;
- Standardised panel sizes used to determine repetitive construction parameters conforming to current housing standards;
- Off-site assembly of cross-laminated timber elements into modular units that can be delivered fully fitted to site.

- Each of these approaches presumes parametric design linked to off-site manufacture to ensure high manufacturing standards and optimised modern methods of construction (MMC).

Outcomes The second part of the study explored the manufacturing technology, the local resource (forest and sawmill) demands and the potential for localised CLT production in the Dumfries and Galloway region. Each of these points will be examined within the wider context of the resources, economic viability, investment capacity and strategic disposition of future CLT manufacturing facilities in Scotland.

The feasibility study does not aim to deal with the specifics of the housing design included in the initial proposal to CIC Start Online.

Comment Timber is a traditional construction material and it would therefore be reasonable to assume that it is a well-understood material in terms of its properties and characteristics. While this is true in the context of traditional forms of construction, the extent of innovation within this sector of the materials supply chain is such that studies of this kind make a valuable contribution to understanding how materials such as timber can be used efficiently in non-traditional ways. The study also makes a contribution to the development of sustainable construction systems in the context of its examination of the interaction of economic viability, manufacturing technologies and locally available resources.

4 Sustainable Construction Systems

The issue of the complexity of the modern construction industry (in terms of the extent of innovative materials and products) referred to in the previous section is also of relevance when considering how to achieve sustainable construction systems. The simplest representation of a system is: Import(s) + Conversion = Export(s).

In the context of a sustainable construction system, the ‘export’ would be a construction ‘product’ (house, office building, etc.) that meets all relevant sustainability criteria at (or above) the required levels. While those required levels for the relevant criteria may be relatively easy to determine, the manner in which they are to be achieved may be less clear, particularly when the factor of innovation (with its attendant level of uncertainty re performance of innovative materials in ‘real-world’ use) is added. Consequently, the conversion component of the system model can be regarded as being concerned with both the design and construction activities in that both of these activities represent a conversion of a variety of imports into the required end product. Both the design and construction activities will have an acquaintance with a range of materials and components, and this will be based on a relationship in which materials are brought together to form components. Thus, materials are selected on the appropriateness of their performance to the objectives of a specific component. Therefore, it may be appropriate to consider the durability of materials when producing one component, whereas for a second component materials with a high level of sound insulation may be most appropriate. In this manner, construction systems are increasingly being required to move beyond relatively simple and well-understood criteria such as cost, and address more complex and less well-understood criteria such as carbon management. In such a situation, even an apparently simple tool such as a carbon reduction 'shopping list' can be of value in navigating the apparent complexity.

4.1 Tenement Flat Carbon Reduction Shopping List

This feasibility study was carried out by a team from Energy Systems Research Unit (ESRU) at Department of Mechanical Engineering, University of Strathclyde Glasgow, in conjunction with Holmes Partnership (architects) and Doig + Smith (cost consultants) [6].

Description The study focused on the problem of how an individual home-owner could be supported in the decision-making process with regard to the overall objective of reducing carbon levels on a day-to-day basis (see Sect. 7.2.1). Given the range of technologies and materials available to the home-owner (and the considerable financial cost that can be accumulated when multiple technologies are selected) a 'shopping list' based on performance and cost of specific technologies was thought to be a useful (and possibly valuable) tool to develop.

Objectives The study aimed to provide typical Glasgow sandstone tenement flat dwellers with a guide as to the most suitable carbon reduction measures to apply to their dwelling. In particular, it was intended to provide a cost per tonne of carbon dioxide saved comparison to demonstrate value for money for various retrofit options.

A particular tenement flat was selected and surveyed (Figs. 1, 2). It is a corner flat on the second floor of a four storey block. The flat is accessed via an unheated entrance stair, but the stair has doors to both the street and the rear court. The dimensions and conditions were passed to ESRU who prepared a dynamic thermal model. Various retrofit options were agreed and applied to the model and the outcomes recorded in terms of tonnes of carbon dioxide emissions saved.

The shopping list itself was structured around five typical technologies available to the retrofit 'upgrader' seeking to reduce carbon levels: windows, general draft sealing, wall insulation, heating system, and renewables. In addition, the study examined the impact of alternative flat positions (located elsewhere in the building). This latter item may initially seem a slightly strange one to include but the logic of considering the impact on, for example, heat gained or lost through either being in a mid-floor location as opposed to a top floor location is valid.

A final point to note is that a number of renewable technologies were rejected as part of the study:

Fig. 1 External image of tenement and the selected flat [6]

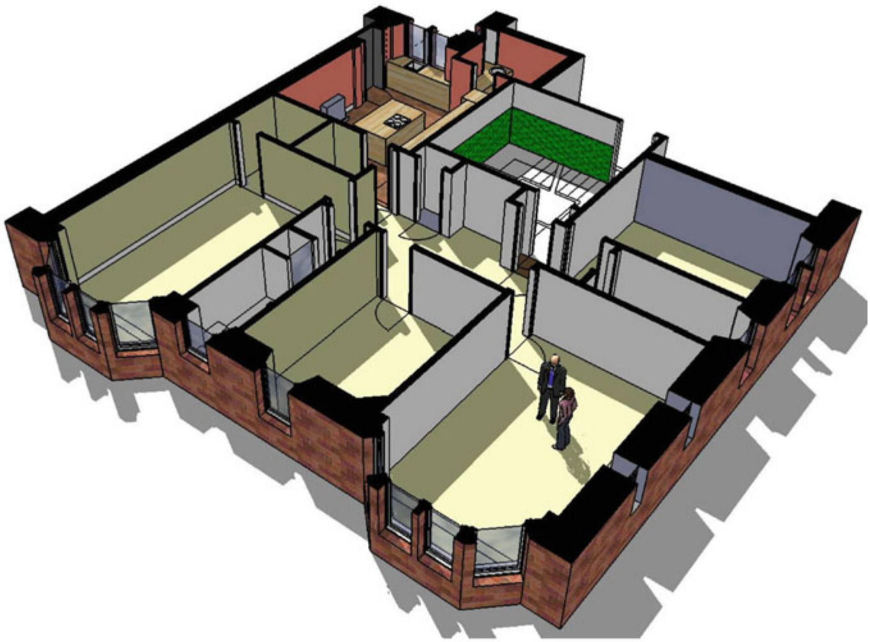

Fig. 2 The selected tenement flat [6]

- Wind turbine thought to be too inefficient and very difficult to justify the consistent wind speeds in the urban landscape. Also noisy with annoying vibrations.
- Air sourced heat pump—thought to bring in complications of size of intake/extract holes in possible sandstone walls. Could be seen as a possible source of heat in particular situations.
- Ground source heat pump—thought to be too difficult to resolve legal ownership issues and very expensive.
- Biomass—Although all flats will have access to chimneys, it is thought that the pollution created by individual stoves would be unacceptable in the inner parts of the city.

Outcomes Outcomes for the study could be considered in a variety of formats but, given the objectives of the study, the team made use of the following:

1. Order of cost, lowest to highest.
2. Amount of carbon saved, highest to lowest.
3. Value for money—most carbon saved per £ spent.

In presenting the outcomes in this manner, the shopping list becomes more useful with regard to quickly accessing key results relevant to the various options within the study. For example, in terms of cost, the least expensive option was a new boiler (£3,000), while the most expensive was replacement of double-glazed sash windows (£10,000). In terms of the amount of carbon saved, the most effective option was the application of wall insulation (fitted after a strip out) at 3.7 T of CO_2, and the least effective option was solar thermal panels (0.6 T of CO_2). In terms of the overall balance between carbon reduction and cost, the most cost-effective option was the new boiler (£1,154/T) and the least cost-effective was the solar thermal panel option (£6,667/T).

The team did, however, provide a note of caution with regard to the results; the boiler in this particular flat was old and inefficient—this would not always be the case in every flat. On that basis, it was felt to be important to note that the most effective technology in terms of CO_2 reduction (wall insulation) was also the second least expensive of the options studied.

Comment The team provided a commentary on the study within the work and a shortened version is included here as the issues raised are relevant to any consideration of installing any of the options studied:

- The amount of carbon saved has to be considered carefully as with the high ceilings in tenement flats, most of the heat will rise above head height; the improvements could therefore simply increase the temperature in the flat rather than reducing the fuel used (as heat will be 'located' where the tenant will not initially feel the benefit).
- The analysis only measures the space and water heating and as such electrical use for white goods, lighting and entertainment (TV, music players, phone charging, etc.) is not measured; lifestyle choices will be an important input into the total household carbon emissions.

- The non-strip out wall insulation performs poorly in the cost/tonne saved table and this may be partly due to the ventilation allowed for behind the lath and plaster. Removing the ventilation could create timber decay problems. Similarly, with loft insulation, the roof ventilation should be checked to ensure that enough air is circulating.
- The whole issue of interstitial condensation has to be monitored closely. This is particularly relevant to the double glazing of the windows which removes the previously coldest part of the internal fabric face; vapour will seek to condense on the coldest face it may be that this is now a hidden face of stone behind the plaster and lath.
- Interesting to note that draft sealing is more efficient in the cost/tonne saved measure than new windows.
- Installing insulation above the ceiling, where the flat is on the top floor, is by far the most efficient way of saving carbon. This is of course dependant on the position of the existing flat.
- The issue of the high ceilings in typical tenement flats is worth further consideration. Investigations into measures which will bring the high level heat down to a useable level in the flat, such as simple ceiling mounted fans, could be explored.

Overall, the study makes a useful contribution to the making of decisions in the context of factors such as carbon reduction and cost effectiveness with regard to improving the performance of existing, traditional forms of construction. As such, the study takes a specific and focused perspective on sustainable construction systems. Another CIC Start Online resource took a somewhat wider perspective on the carbon problem in that the focus was on the concept of self-organising built environments.

4.2 The Theory of Self-Organising Built Environments as a Response to Carbon Levels

This webcast was presented as part of the CIC Start Online 2011 conference dealing with the resilience of cities [7].

Summary The relationship between a modern, industrialised society and carbon is one of threats and opportunities. The threats and opportunities can be argued to flow from the versatile nature of carbon—it almost seems as though it would be difficult to develop a more versatile element even if you wanted to. Current estimates place the number of carbon compounds at over 5 million, within which organic compounds are particularly well represented. A very small number of these (such as CO_2) have been given a great deal of attention (such as through legislation and regulation—the ‘push’ approach), solely because of the threat they are seen to represent.

Given the possibility that legislative push will not fully achieve targets such as zero carbon by 2020, perhaps at least some of the training effort could be focused on ecology, with a particular focus on using the ecology of carbon as a means of ‘pulling’ CO_2 levels downward. Such an approach is not be to be confused with expressions such as ‘greening’ the industry—carbon ecology is focused on the interactions that are possible between carbon compounds (particularly organic compounds) within the boundaries of the built environment.

The natural environment contains many autopoietic (biologically self-organising) systems and, if a truly sustainable built environment is to be achieved, it is arguable that it must become either a single autopoietic system or a grouping of interacting autopoietic systems. In other words, it should become biologically self-organising. One model of this general nature that has been proposed in the context of cities is the Portugali model. A key feature of the Portugali model is the concept of cities as an inter-representational network or IRN for which a form of self-organisation is claimed.

Cities are complex entities that have a life-cycle, and are therefore similar in many respects to biological systems, and throughout history it seems that differing approaches have been applied to the management of that life-cycle. In the modern context, the emphasis may be changing to one of eliminating the climate change related disbenefits, such as pollution, energy use, CO_2 emissions and so on, while mitigating any resultant negative impact on related benefits, such as wealth generation through economic activity.

The usual interpretation of biological systems is that the more complex they are, the more open they can become and, potentially, the more intelligent. As any system becomes more open, it has an increasing potential to select amongst a number of possibly effective responses to perturbations within its environment. Given the complexity of even a present-day city system, as opposed to the possible complexity of a mega-city system of the future, it may be too ambitious to think in terms of a single autopoietic system that can deal with all of the problems. IBM have the belief that future cities will naturally become more networked environments; a future city could be regarded as an ecology based on applications—in the same manner as you may now buy apps for your smart-phone, future city building owners may buy apps for their buildings.

By more fully understanding both the ecology of carbon and the requirements for city-based autopoietic systems, future cities might become sustainable by not only reducing their output of problem forms of carbon such as CO_2, but by also converting CO_2 to an economically valuable form such as carbon monoxide. This compound can be used as a source of energy and biomass for microbes (which may themselves be of ecological value elsewhere in the city’s systems) and, because of carbon’s versatility and tetravalent nature, it can quite easily be converted into hydrocarbons or methane which can then be used as a fuel by the city’s housing, etc.

As technologies such as CO_2 to CO conversion emerge, the concept of a sustainable city ecology arguably becomes more realistic. It seems possible for the growth of future cities to become sustainable to the point where mega-cities or even hyperstructure arcologies[1] can seriously be envisaged. For such ecologies to be sustainable in the long term, however, the technologies will need to be managed by biologically open and self-organising systems. Such systems will need 'rules' to govern their decision-making and no doubt some of those rules will relate to the activities of carbon accounting and management.

5 Carbon Accounting and Management

As the focus of the construction industry is increasingly encouraged to move toward a more sustainable model of operation, the consideration of resources begins to move away from a simple use of cost and quality criteria. As additional criteria are added to the materials and components selection process, the requirement for information and knowledge regarding both traditional and innovative materials and components is becoming wider. A perspective on a sustainable society that is becoming the norm is one in which carbon effectively becomes a form of currency, and thereby allows the possibility that 'expensive' (high carbon levels) materials, components and construction processes are to be discouraged through a variety of strategies and mechanisms. However, for such an approach to be successful, there is a need to obtain accurate figures for the carbon used in the production of individual materials and components, and also the level of carbon produced by particular methods of construction. As the carbon 'issue' becomes more and more central to the operation of the construction industry, a new skill is evolving; accounting and managing carbon levels to evidence performance in achieving objectives such as zero carbon construction.

5.1 Assessment and Application of Zero Carbon Building in Scotland

This feasibility study was carried out by a team from Heriot-Watt University's School of the Built Environment in conjunction with integrated environmental solutions (IES) Ltd [9].

Description The feasibility study involved investigation of recently published guidelines into the definition of 'Zero carbon' by the government and a comparison with 'true' zero carbon buildings. The study used the proposed Riccarton Ecovillage on the campus at Heriot-Watt University to provide the sample building used for the detailed analysis and assessment parts of the study. Heriot-Watt University and IES worked together using IES's Virtual Environment software to perform predictions of carbon emissions.

1 http://www.arcology.com

The detailed calculations considered a range of currently available building technologies, and systems that could be used either in isolation, or in conjunction with one another. The analyses were intended to demonstrate the differences between current building standards and the improvements that will be needed in future both to meet the published regulatory guidelines and also to provide a comparison with true zero carbon using representative domestic Scottish buildings as the basis for the analysis.

The methodology employed in this project can be split into two distinct steps:

- Creation of a series of (three) base case models (of different heating options) using the Virtual Environment dynamic thermal modelling software and performing simulations on the models.
- Corresponding SAP calculation for these base case models.

Objectives The study can be regarded as having one key objective: from base case results, determine what improvements will be needed in future to meet the published regulatory guidelines and to achieve a true zero carbon dwelling. A second objective could be regarded as being to determine if the results of both a design tool such as Virtual Environment and a compliance tool such as SAP were broadly in agreement.

Outcomes The key outcome from the study was the conclusion that SAP calculations were in the order of 60 % adrift of the actual photovoltaic (PV) areas required to achieve zero carbon levels in all of the three heating options.

Comment The study raises the intriguing prospect of the construction industry using a compliance tool (SAP) that appears to consistently under-estimate the area of PV panels required in order to achieve a zero carbon building. However, the important word in this context is 'compliance'—SAP is a relatively simple tool that is not intended to be used to 'guide' the design process. Using SAP, in such a manner raises the prospect of supposed zero carbon buildings being around 60 % 'short' of actually achieving zero carbon levels. The study therefore rightly emphasises that:

> "…building designers, housebuilders, owners and occupiers are also made aware of this difference and that they should adopt more rigorous forms of calculation if they wish a more accurate result in addition to the basic compliance calculation. Equally, legislators and those setting standards need to be aware that the tools they specify for use with building regulations can have a significant effect both on the requirements placed on house builders but also on the effect the standards will have on the ability of the resulting buildings to meet their declared objectives."

In terms of the procurement of buildings, there is arguably a case for the development of skills specific to the achievement of products that are actually zero carbon.

6 Skills Development and Construction Management

The previous sections of the chapter (and also the other chapters within the book) have focused on various aspects of achieving a sustainable construction industry. However, in doing so, they have also, either explicitly or implicitly, touched upon the need for the industry to develop new skills. Construction management is, at least in terms of research activity related to the development of expertise and understanding, a relatively new 'science'. Nonetheless, the management of construction projects is something that humans have practised for several 1,000 years, during which time new skills have had time to evolve as the pace of development was, for a large part of the industry's history, painfully slow. The builders of Europe's great cathedrals, for example, had plenty of time to hone their skills with increasingly massive forms of construction as each 'product' typically took decades to complete. Increasing levels of mechanisation have speeded-up the act of construction, as have developments such as prefabrication. However, the political, technical and financial environments in which the act of construction takes place do not remain static, with one consequence being that the construction management role has also been unable to remain static; new skills have been required and will continue to be required in response to the demands of achieving a sustainable built environment.

6.1 Developing a Process to Improve Productivity and Competitiveness

This feasibility study was carried out by a team from the Construction Management Research Unit, University of Dundee, in conjunction with Pert Bruce Construction Ltd [4].

Description This feasibility study was a collaboration between the University of Dundee and Pert Bruce Construction Limited. The study explored the opportunities to develop a process to improve productivity and competitiveness. Pert Bruce Construction Ltd is a North East of Scotland Construction Company based in Montrose, Angus, with an annual turnover of around £6 million. The Company was formed in 2005 from the merger between James Bruce and Son (est. 1871) and WWP (est. 1965). One of the key challenges associated with the work that Pert Bruce undertakes is that it is highly specialised and bespoke. As a result, there are very few standard processes which can be measured and benchmarked as would be the standard approach using such tools as the Productivity Benchmarking Tool (PBT) and applying the principles of cost-significance.

Labour accounts for some 30 % of typical construction costs. An increase in productivity of 30 % would therefore reduce construction costs by 10 %. In days when contractors' margins were 4 %, this would represent a 250 % increase in profits. Equally, it could represent an 8 % cut in costs to the client and a 50 % increase in profit to the contractor. In an environment where contactors' margins are zero or even negative, improvements of this magnitude potentially represent the difference between survival and extinction.

Objectives The team established a key objective as being to undertake a study of the existing processes used within Pert Bruce to determine how these were aligned with the Construction Management Research Unit's background research. A second objective was to then identify opportunities which might exist for improving these processes.

Outcomes At the conclusion of their research, the study team were of the opinion that Pert Bruce Ltd. was significantly more advanced than many other contractors. On that basis, the recommendations made by the study were focused in scope on a number of key areas that, if addressed, were expected to add to the company's competitiveness and productivity in the medium to long term:

- There is no feedback loop between what happens on-site with the monitoring of the programme and the estimating process. As everything that is undertaken is dependent upon the bill of quantities and the hours that are allocated by the estimator, this needs to be influenced by the actual production rates that are taking place on-site.
- The focus on the implementation to date has been within the directly employed staff of Pert Bruce. Whilst controlling the productivity of sub-contractors is not the immediate requirement of the company there would be significant benefits to the company in engaging their supply chain in this process.
- There is a focus on recording what has happened and the reasons for less than expected productivity. However, this does not necessarily explain the root cause of the delays. Therefore suggest that the causes of delays are explored in more detail.
- One of the challenges in measuring productivity on projects is when the tasks are very specialised and bespoke. One approach to overcoming this, which is closely aligned with the approach used by Pert Bruce, is Earned Value.

Comment The study may initially appear to have little direct relevance to sustainable development. However, a focus on the skills of both management and labour with regard to issues of productivity, while obviously being linked to levels of competitiveness, are also linked to key aspects of the sustainable development agenda. Possibly paramount amongst these is the management of waste that comes along with productivity gains. In an earlier section of this chapter (see Sect. 6.5.3), a study focused on the recycling of plasterboard waste was introduced which, laudable as recycling is, is always going to be a reaction to waste rather than a prevention of waste. On that basis, any research that indicates a means of increasing productivity through the reduction of waste can be argued to also represent a development of carbon management skills!

7 Conclusion

The construction of buildings has traditionally occupied the middle-ground between the design activity and the occupation by the end-users. In this model, the design activity has not usually placed a great deal of emphasis on research and development of new materials and components. Whilst it is true to say that a minority of cutting-edge structures have pushed along the research and development activities in terms of new products, the majority of research has been confined to the finding of the most appropriate means of incorporating traditional and new products into a design. Such an approach has resulted in buildings that met the regulations of their time but have resulted in a legacy that is of increasing concern with regard to meeting the broader objectives of achieving a sustainable built environment into the future. Designers are increasingly responding to this situation by becoming more involved in the research and development of new products, components and, in some cases, systems of building, that are intended to be suitable for a not-too-distant future that is carbon neutral, if not zero carbon. This response has involved the learning of new knowledge and skills in terms of product development and post-occupancy evaluation (performance) of the completed buildings. In such a manner, the construction phase is less clearly bounded by discrete activities of design and occupancy, with issues such as the need to refurbish existing buildings and develop new technologies that will strive to achieve the increasing demands for a level of performance that leads to a sustainable built environment.

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Refurbishment

Paul Baker

Abstract The current perception is that options for upgrading the thermal performance of pre-1919 dwellings with solid wall constructions are particularly limited and are considered as 'hard to treat'. This chapter reviews research projects which challenge the assumption that there are only limited options for reducing the carbon emissions of older buildings by taking a holistic approach which balances conservation needs with energy efficiency measures, and considers the risks and impacts on other aspects of building performance. The results are generally applicable to devising refurbishment strategies for the pre-1919 housing stock in Scotland. Building simulation software can aid in ranking solutions on the basis of energy efficiency saving by CO_2 reduction coupled with cost-benefit analysis of appropriate measures. Addressing maintenance and repair issues, with comparatively low cost, can also have important consequences on improving energy efficiency. Post-intervention assessments are advisable both as a check of the actual thermal performance and the important impact of occupancy. These should be addressed in live projects, for example, where new technical solutions are implemented. Whilst consideration is given to minimum intervention strategies to conserve traditional or historic features, risks assessments should be carried out at an early stage before the final decision on the refurbishment package is made.

1 Introduction

How can we conserve our architectural heritage whilst improving the existing housing stock in response to climate change and the urgent need to reduce carbon emissions? In 2004, the UK's carbon emissions were 559 million tonnes per year,

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with 27 % attributed to the energy used in people's homes. Approximately a third of the emissions from the average home could be saved by adopting simple energy saving measures. However, achieving further reductions in emissions from households to meet the Government's 80 % target is a major challenge. Some hold the opinion that older buildings are energy inefficient and should be replaced with new build rather than refurbished. However, whilst the operational carbon emissions of new buildings are often lower than traditional buildings, the latter already embody carbon. Existing buildings have cultural and societal value.

The current perception is that options for upgrading the thermal performance of pre-1919 dwellings with solid wall constructions are particularly limited and are considered as 'hard to treat'. Clearly, restrictions apply to upgrading the insulation of walls in listed buildings, etc. Conversely, investigations for Historic Scotland, English Heritage and the Society for the Protection of Ancient Buildings (SPAB) indicate that the actual thermal performance of solid walls is often better than assumed for energy performance assessments [3, 16]. It is also questionable whether it is necessary or desirable to replace traditional windows although these are considered as perhaps the easiest option for replacement with modern double glazing: simple measures, such as shutters, can reduce heat loss and modern secondary glazing and slimline glazing technology can offer comparable performance [1, 2, 10].

Recent research projects have challenged the assumption that there are only limited options for reducing the carbon emissions of older buildings by taking a holistic approach which balances conservation needs with energy efficiency measures, and considers the risks and impacts on other aspects of building performance, particularly the risk of moisture problems post-intervention. For example, for solid wall constructions upgraded with internal wall insulation, calculations of heat and moisture transfer through the walls indicate that the greatest risk of condensation occurs at the interface between the cold face of the insulation and the masonry. Pilot studies carried out with various insulation solutions indicate that the risk is low compared with predictions.

Advice concerning insulation systems and moisture vapour control in refurbishments can be contradictory. The Energy Saving Trust's Good Practice Guide 138 "Internal wall insulation in existing housing—a guide for specifiers and contractors" [9] recommends vapour checks to reduce condensation risk whilst solutions using vapour permeable material represent an approach which some perceive as being more 'sympathetic' for use in traditional buildings, benefiting the transport and absorption and release of moisture through the use of hygroscopic materials.

Concerns are also expressed over air-tightness and indoor air quality post-intervention. Reducing unwanted air leakage is important and can be achieved during refurbishment, both in terms of reducing air infiltration through insulation systems and 'leaky' windows, etc. However, an appropriate ventilation strategy should be considered as part of the refurbishment.

The chapter reviews studies carried for CIC Start Online with an emphasis on the refurbishment of pre-1919 buildings (traditional construction), which make up about 19 % of the Scottish housing stock and are considered as challenging to upgrade. However, the studies show that there is a developing understanding of the requirements for upgrading the traditional housing stock in Scotland. Broadly there are five main interlinking factors in refurbishment:

1. Technical solution
2. Energy efficiency/CO_2 saving
3. Cost
4. Conservation
5. Risk.

Selecting a solution for improving the energy efficiency and effecting CO_2 savings should be seen as cost effective, however, the impact on conservation issues in buildings should also be considered for historic and listed buildings, those in conservation areas, and those which generally have some architectural merit (design, decorative features) and contribute to the built environment. The important fifth factor is risk: will the refurbishment solution impact negatively on the building? For example, moisture problems are considered the biggest risk when improving insulation; improving air-tightness may have the consequence that indoor air quality is compromised unless an appropriate ventilation strategy is considered.

The CIC Start Online studies have gone some way in addressing the relationship between the above factors. The studies can be divided into two categories:

1. Studies which consider the refurbishment of the complete dwelling including methodologies for assessment, decision making and management of retrofit. A number of the studies concerned with the first category were investigations of tenements which form an important part of the urban housing stock in Scotland. Other studies were carried out on refurbishment options for traditional housing, including applying the German Passivhaus standard.
2. Investigations of practical technical solutions, which included injecting insulation behind lath and plaster walls and a study of the impact of improving air-tightness on the overall thermal performance of a hard-to-treat crofter's cottage on Uist.

2 Refurbishment of Tenements

Tenement flats constitute 35 % of pre-1919 dwellings [19]. Roaf et al. (15) state:

> Tenements pose some of the most complex problems for reducing the energy consumption of Scottish homes, however their preponderance in Scotland's housing stock and the range of cost efficient savings that can be made from treating them mean that they are a strategically important cohort for consideration when policies and schemes for refurbishment of hard-to-treat stock are developed.

Three of the projects considered the available options for refurbishment in specific case study dwellings and using simulation software estimated the energy efficiency benefits and CO_2 savings, and conducted cost-benefit assessments.

2.1 Tenement Flat, Hyndland, Glasgow

Energy Systems Research Unit (ESRU) at the University of Strathclyde Glasgow in collaboration with Holmes Partnership [11] conducted a study, which aimed to provide typical Glasgow sandstone tenement flat dwellers with a guide as to the most suitable carbon reduction measures to apply to their dwelling. In particular, it was intended to provide a cost per tonne of carbon dioxide saved comparison to demonstrate value for money for various retrofit options.

A typical tenement flat, located in Hyndland in Glasgow, was surveyed and the geometry, construction and services specification modelled in the dynamic computer model ESP-r by ESRU (www.esru.strath.ac.uk/Programs/ESP-r.htm). ESP-r is an integrated energy modelling tool for the simulation of the thermal, visual and acoustic performance of buildings and the energy use and gaseous emissions associated with environmental control systems. Various carbon reduction upgrades were proposed and modelled. These upgrades were costed and the results combined to provide a shopping list of cost per tonne of carbon saved.

Upgrade options considered were as follows:

- Windows—The existing windows are single glazed, timber, sash and case. Replace single glazing with new sealed double glazed sash frames installed into the existing box casement and apply draugh sealing.
- General draught sealing.
- Insulation of external walls and walls to common stair—The existing external walls are constructed of sandstone external face with plaster on lath internally. Two options were proposed:

  Option 1. Retain original cornice and skirting. Apply a 42.5 mm composite insulated plasterboard directly to the existing plaster finish, the existing skirting and below the existing cornice to avoid significant disruption. This approach will allow for the retention of the existing decorative features.

  Option 2. Remove lath and plaster, cornice and skirting and fix 82.5 mm composite plasterboard over timber frame fixed back to existing stone. This approach maximises the insulation thickness.
- Heating—Replace the heating system with new high efficiency condensing boiler connected to the existing radiator and pipework system.
- Renewables—Fit solar thermal panel to south facing roof section. Use hot water produced for heating and domestic hot water. Other renewable options were rejected as inefficient or impractical in the urban environment.

Table 1 Value for money—Carbon saved per £ spent

Description of upgrade	CO_2 savings (tonnes)	Cost (£)	Cost/tonne CO_2 saved (£)
New boiler	2.6	3,000	1,154
Wall insulation (with strip out)	3.7	6,100	1,649
Draught sealing	2.4	5,600	2,333
Double glazed window sash replacement	3.3	10,700	3,242
Wall insulation (non-strip out)	1.3	4,400	3,385
Solar thermal panels	0.6	4,000	6,667

- Alternative flat positions—The flat selected is a mid level flat, but should the flat be either ground floor or top floor then the installation of insulation quilt will be a very cost effective solution to carbon reduction.

The results of the CO_2 savings are given in Table 1 ranked in terms of value for money (cost per tonne of CO_2 saved).

The report concluded that the new boiler was the cheapest measure and the best value for money in terms of carbon saved. The most carbon is saved by the full insulation of the walls and this is also second best value for money (this is important because the boiler in the flat measured was old and inefficient and this will not always be the case with other flats).

2.2 *Garrioch Residents Association Tenement Flats, Glasgow*

ESRU at the University of Strathclyde Glasgow in collaboration with Collective Architecture [21] have investigated strategies to reduce carbon emissions through a comprehensive study of the quadrangle of traditional red sandstone tenement flats in the west end of Glasgow represented by Garrioch Residents Association. Tenant participation was encouraged throughout the process. The study developed an upgrade strategy that can be employed and documented for the wider community, housing associations, public bodies, planners, academics and students.

Initially, a consultation is carried out with the clients to explain the project and get their inputs on the current issues with the building and the range of upgrades of most interest. Following this process the current building performance is established through a physical survey, air-tightness testing (Fig. 1), thermography and smoke analysis, to target air leakage, in representative dwellings. The appropriate upgrade options and best practice examples for the building type are then researched and a reference database created. Both Collective Architecture and the residents association were issued with a copy of the reference database to assist with any future similar projects.

Fig. 1 Air-tightness testing in a tenement flat [21]

The carbon and energy performance of a representative sample of the existing dwellings is then modelled; and the carbon, cost and energy impact of a range of upgrade options quantified. Based on best practice and modelling results some recommendations are provided. A customised version of the modelling tools is made available to the residents association and training offered to allow them to assess further upgrade options on an ongoing basis. The customised tools are similarly available as the starting point for future similar projects. A report of the outcomes of the work is prepared and presented to the clients.

As there are many similar properties in Scotland requiring similar upgrades, the work undertaken in this study can be utilised elsewhere. However, the process is not restricted to these similar properties; it can also be applied to other dwelling types.

2.3 Tenements in Bellshill, North Lanarkshire

The main focus of this study carried out by Edinburgh Napier University in collaboration with North Lanarkshire Housing Association [6] was to explore the possibilities of improving the energy efficiency of housing association tenement buildings in Bellshill, North Lanarkshire. Some refurbishment of the apartments had been carried out during the late 1990s, however the more recent standards expected of social rented housing require that further energy efficiency upgrades are implemented. The study addressed options for improving the thermal performance of various elements, and also explored improvements to heating services, which at present are approaching the end of their life cycle and are costly for the tenants to operate.

The feasibility study addressed all the issues which relate to improving the thermal comfort of the tenants and presented options for efficient and cost conscious energy services. A priority of the housing association is tackling fuel poverty, however without incurring excessive investment. The objectives of the study were as follows:

- Understand and review how energy efficiency can be applied to the fabric performance of the buildings
- Discuss and evaluate the technical constraints related to alternative heating systems
- Identify and explain the links between energy efficiency and reducing fuel poverty
- Understand the issues surrounding the economic constraints of alternative heating systems.

The study produced a set of guidelines for the improvement of the tenement buildings looking at aspects of building fabric intervention, alternative space and water heating systems and also renewable.

Building fabric options were analysed using a dynamic thermal simulation software, CYMAP (http://www.cymap.com/Cymap/Default.aspx). Two case study apartments were modelled before implementation of various interventions, for example, insulation on external walls, improvement in draught proofing, and change of windows. The resulting energy saving were then estimated. This information was then used to suggest different solutions in order to reduce the CO_2 emissions.

In terms of space and water heating a number of alternatives were suggested by looking at more efficient devices that can lower the demand for electricity or can use alternative energy sources, for example, renewables or natural gas. These alternatives were explored together with their pros and cons in the specific context of implementation at the site in question.

A cost analysis was also carried out which considered the solutions as low, medium and high cost.

The optimum solution would appear to be improving the insulation of the building fabric coupled with maintenance/upgrading of the electric space and hot water heating systems. Various options for upgrading the insulation would result in predicted CO_2 savings 19–23 % in one of the first case study apartment and 29–33 % in the second case study. There were practical constraints when considering alternative space and hot water heating systems in the tenement flats. For example, upgrading to gas-fired system would be difficult due to lack of space and where feasible installing a gas supply would require legal agreement between all tenants; problems may occur with routing the water distribution from a solar hot water (SHW) system to all of the apartments. The report considers that, if considering renewable technologies, a mixture of photovoltaics (PVs) and SHW is recommended. It suggests that electricity produced by PVs is used in communal areas, for lighting and door entry systems, and the surplus energy sold to the grid.

The best utilisation of SHW would be to supply the apartments directly below the panels.

The report also considers various options which should be considered in effecting overall energy efficiency improvements to the tenements, many of which are low cost compared with upgrades to insulation and heating. Table 2 summarises the interventions and their cost band.

The three feasibility studies outlined above propose potential solutions for upgrading tenements. Following refurbishment, in order to assess performance vis-à-vis the specification of the upgrade strategy, an evaluation of energy use and user experience should be carried out. The following study [17, 18] carried out by the Mackintosh Environmental Architecture Research Unit (MEARU) in conjunction with Assist Architects analysed the theoretical and in use performance of five refurbished flatted dwellings and an office space in Gilmour's Close, Edinburgh.

2.4 Gilmour's Close, Edinburgh

Gilmour's Close is a 4-storey, nineteenth century stone tenement, with commercial ground floor, located in the World Heritage site of Edinburgh's Grassmarket (Fig. 2). Refurbishment of this building was completed by Assist Architects in 2008, to provide social rented and supported housing for Hillcrest Housing Association. In the refurbishment process Assist sought not only to conserve the historic aspects of this Category B listed structure but also to incorporate low energy principles to the design in the form of ground source heating, passive solar strategies, mechanical ventilation with heat recovery (MVHR) and upgrade of the fabric's thermal performance by internal lining.

This project assessed the performance of this development in terms of energy use and user experience, through a 3 week monitoring process and subsequent analysis of the small office space within the development and five individual dwellings [17, 18]. The main conclusions were that

- The space and water heating primary energy requirements were found to compare well with contemporary energy efficient dwellings.
- The use of the ground source heat pump was found to provide significant benefits in terms of CO_2 savings compared to a more conventional system of high efficiency gas-fired combi boilers installed in each dwelling.
- Actual energy use for space and water heating was found to be 2.1 times greater than predicted. This, however, reflects a situation common with thermally efficient building performance evaluations. The reasons for this disparity were identified as;
  - Limitation of prediction using SAP, the UK Government's Standard Assessment Procedure for Energy Rating of Dwellings.
  - Energy consumption data was only representative of a 9-month period and not a full year.

Table 2 Summary of energy efficient solutions against cost

Location	Cost band: Low	Medium	High
Communal areas	Energy efficient solutions—applied to all dwellings		
Doors/ windows	Draughtproofing of door; Repair of doors, closing mechanism; Add secondary glazing on doors glazing and above it; Add a properly working mechanical door closer	Add a draught lobby door with a mechanical door closer	Replacement of door with a thermally insulated door and all of the Low and Medium solutions
Lighting	Maintenance on door glazing and above door—letting more natural light in passage way	Install energy efficient fluorescent lighting with presence sensors and daylight sensors	Connect such electrical demand to a Solar PV panel to minimise electrical grid dependence
Fabric—walls	Walls that are communal should be rerendered and any holes, cracks and apertures sealed as much as possible		
Loft insulation	Installation of mineral wool quilt over joist >270 mm; Insulation of water pipes and tanks		
Internal dwelling solutions—applied to all dwellings			
Externally faced walls	Extensive draughtproofing of plaster board wall, sealing: skirting boards, around pipes, all holes, cracks and openings	Application of thin insulation material on the internal face of the plaster board. 10 mm of aerogel applied with a mesh and a skim finish	Filling in behind plasterboard in cavity with polystyrene beads. Alternatively—detach p/board and insulate cavity using wood fibre board or rigid phenolic insulation between studs
Windows	Maintenance to windows—replacement of beads or reveals; Replacement of seals adding low friction seals—brush, silicon or tubular; Sealing around frame and sills	Installation of window wooden shutters that can swing into sections and hide on the window elbows. Can be insulated with 10 mm aerogel to increase thermal properties	Installation of secondary glazing (internally); Alternatively replacement of DG window units with triple glazed window frames and glazing

(continued)

Table 2 (continued)

Location	Cost band: Low	Medium	High
Lighting	Replacement of incandescent light fittings with fluorescent energy efficient systems. Install sensor controls and/or light sensors	Enhance natural light into hall by opening window above entrance door	
Doors—dwellings	Draughtproofing around door and frame, letter box	Installation of 10 mm of aerogel on the inner side of the door improving its thermal performance	
Energy use	Installation of simple energy display metres—sourced by energy supplier	Installation of real time energy display metres—more effective to users and more easily read	
Floors and ceiling	Draughtproofing around skirting boards, junctions, pipe work, and cornices	In bedrooms where carpet is used—replace underlay with a low thermal conductance quilt	
Space and water heating solutions—per dwelling			
Case Study 1. Hamilton Road dwellings			
Space heating system (SHS)	Maintenance to electric storage heaters—install better temperature controlled functions	Replacement of old storage heaters with new efficient storage heaters that have a better control system	Installation of natural gas—metres in each apartment. Installation of combi boilers in stair case cupboard with a balanced flue externally
Water heating system	Insulation around storage water tank and pipe work	Replacement of water storage tank with a more efficient method of heating	Use of combi boiler as above for SHS—Community heating system
Case study 2. Main street dwellings			
Space heating system (SHS)	Maintenance to electric storage heaters—install better temperature controlled functions	Replacement of old storage heaters with new efficient storage heaters that have a better control system	No space for gas boilers or pipe work, Community heating system
Water heating system	Insulation around storage water tank and pipe work	Replacement of water storage tank with a more efficient method of heating	Installation of solar hot water panels on the roof facing south. Will depend on water tank storage capacity and access

Fig. 2 Gilmour's close, Edinburh [17, 18]

– Excessive ventilation rates caused by occupant activity during the heating season.
– Constructed insulation envelope may not achieve the same levels of thermal insulation as design intent.

Various recommendations were made to improve systems and their operation, and also educating residents on efficient use of systems, which should result in a better understanding and improved energy efficiency.

3 Refurbishment of Other Traditional Buildings

Several studies were carried out on other types of Scottish traditional buildings, which also have general relevance.

3.1 Developing Robust Solutions for Roof Upgrades

The aim of the study [13, 14] by ESRU, University of Strathclyde Glasgow and Grigor Mitchell Architect (GMA) was to develop a process which produces robust, practical details and specifications for the thermal improvement to habitable roof spaces of traditional properties in respect to moisture control and the avoidance of interstitial condensation. The thermal upgrading of traditional roofs encompasses a large range of property types and building ages, each with their own particular construction methods and extent of ventilation. There are also a wide range of potential solutions for their thermal upgrade. The scope of the study focused on upgrades to traditional flat roofs. These constructions are deemed as 'hard to treat'; they are often overlooked and therefore most subject to thermal 'discomfort' and heat loss. The solutions derived are also highly relevant to properties of all ages with flat roofs. Flat roofs became more common in the late Victorian period. The construction detailing persisted until the 1930s, when modern methods of roof construction became more typical. There is little precise guidance available on the best practice for insulating the pitched and flat roof structures of traditional properties especially in respect to the avoidance of interstitial condensation. The experience of the architectural team has highlighted caution when specifying thermal upgrades in order to control moisture and avoid interstitial condensation, and also the importance of conserving the key features of traditional properties where they are of high quality.

GMA produced details of four typical roof interfaces (Fig. 3). The specification aimed to ensure optimal thermal performance, decrement delay, air-tightness and thermal bridge free construction. The need for building conservation was taken into consideration. ESRU modelled energy performance and condensation risk of three 'cold' roof and one 'warm' roof alternative upgrade options compared with the original roof details. The upgrades were predicted to show a 50 % reduction in energy use. The 'warm' roof option was preferred, however, due to access limitations and/or ventilation issues, this method is not always viable. The three 'cold roof' options indicate a greater level of condensation risk, albeit small, than the 'warm roof' thermal upgrade. The removal of the existing lathe and plaster and the use of either OSB or a membrane would reduce ceiling void humidity. However, it was beyond the capacity of the ESP-r software to analyse whether this would lead to a seasonal fluctuation of moisture levels in the roof void, ultimately resulting in a progressive build-up of interstitial condensation over a number of years.

The most interesting and potentially influential outcome of the assessment is the high risk posed to perimeter storage spaces adjacent to an occupied space. Although these spaces are within the thermal envelope, the restricted air exchange with the occupied space can lead to lower surface temperatures, higher humidity and surface condensation. Potential improvements to the design of these spaces could involve an increased level of insulation and improved ventilation between the storage and main spaces (louvred doors). Sealing these spaces from the main room does not seem practical.

Fig. 3 Typical roof interfaces [14]

3.2 *Retrofit of an Eighteenth Century Traditional Scottish House Using the Passivhaus Standard*

Edinburgh Napier University in collaboration with SA Estates carried out a feasibility study [8] which explores the retrofit potential of the German Passivhaus standard when applied to a hard-to-treat eighteenth century traditional house in Cellardyke, Fife (Fig. 4). The aim was to create an outline of the barriers and advantages which will produce the integration of the Passivhaus standard for the

Fig. 4 The retrofit potential of the German Passivhaus standard on the eighteenth century traditional house in Cellardyke, Fife [8]

future retrofit of the house. The study examined the key areas which should be addressed and the constraints, with the following objectives:

- To analyse the current state of the home and look at the main elements to retrofit.
- To consider the targets set by the Passivhaus standard.
- To offer guidance to the owner and architect on the areas to be upgraded and the technical requirements.
- To assist the architect in achieving the standard.

The report drew conclusions that were critical of the implementation of the standard in retrofit applications. The standard is primarily focused on the whole house building standard with the potential to use renewable energy as a backup and alternative energy system. The standard does not focus on other important areas in sustainable and energy efficient buildings, for example, ecological elements on site, embodied energy of materials and their origins (e.g. sustainable timbers), toxicity and low volatile organic compounds (VOC's) and the environmental impact of the site type (greenfield or brownfield). Little consideration is given to the occupier and the thermal comfort that may be reduced with faulty equipment or lack of maintenance. Investing in "certified" Passivhaus products and achieving all the criteria required by the standard may be uneconomic. Applying the standard to the retrofit of older properties and hard-to-treat dwellings may not be technically viable. A more sustainable, ecological and holistic approach is preferred, which considers optimising fabric interventions in conjunction with efficient heating systems with low carbon methods, low embodied energy of materials and healthy environmental alternatives that can create a building that fits its aesthetic and environment.

3.3 *Synergy of Fabric and Energy Conservation in Older Historic Properties*

Edinburgh Napier University in collaboration with The Morrison Partnership carried out this study [7] which considered the conversion and extension from a former hospital into a home of a nineteenth century traditional two storey mansion house in Alyth, Perth and Kinross (Fig. 5). A similar methodology to the feasibility study into energy efficiency improvements in tenements in Bellshill [6] was used to identify appropriate solutions for upgrading the fabric and also the implementation of a Low and Zero Carbon Technology for the generation of clean energy for space and water heating.

A combination of fabric improvements could result in savings of 24–44 % CO_2 emission from the building. The package of improvements selected would determine the plant size of the system selected for space and water heating.

Fig. 5 Energy efficiency improvements on the nineteenth century mansion house in Alyth, Perth and Kinross [7]

The study concluded that it is essential to upgrade the performance of the building fabric first, in order to lower energy demand and in a second phase introduce the use of renewable energy systems to fulfil the new building's energy demand. This approach should lower the investment cost of the energy systems. The selection of Low and Zero Carbon Technology would depend on payback tariffs if PV or wind turbines are used. Biomass boilers were also considered as a viable option but solar thermal was rejected.

3.4 An Energy Efficiency Retrofit Cost-Benefit Calculator

Changeworks and Heriot-Watt University [12, 20] developed a spreadsheet-based calculation and analytical tool to inform future investment decisions by social landlords concerned with improving the energy efficiency of their stock. The tool also has potential application for private sector landlords and individual households. The calculator can be applied to assess energy efficiency options for both individual as well as groups of residential properties. The parameters in the spreadsheet design allow for updating, both in relation to cost data as well as including thresholds for compliance with the Scottish Government's Scottish Housing Quality Standard 2015, or subsequent standards addressing fuel poverty, carbon reduction targets and how these relate to different investment options and best value. The model has direct relevance to assessing future funding opportunities, including the Green Deal and the Energy Company Obligation and future benchmarking where statutory standards are increased and their impact assessed. The tool offers clients help in developing well targeted and cost effective carbon reductions and interventions aimed at reducing fuel poverty.

4 Development of Solutions

As well as the holistic approach to developing overall refurbishment solutions, projects were carried out on developing practical techniques and strategies for improving energy efficiency.

4.1 Testing of a Method for Insulation of Masonry and Lath and Plaster Walls

Much of Scotland's traditional housing retains its original features including lath and plaster as the internal finish on masonry with a gap behind the lath and plaster. The main aim of this research project [5], carried out by Robert Gordon University in collaboration with Craigie Levie, was to develop and test the feasibility of a method of insulating an existing house whilst maintaining its original architectural features (see Sect. 8.5).

The method involved using water-blown foam, developed by Canadian company Icynene Inc. This is the first time such insulation has been used in an historic building in Scotland. The water-blown foam was created specifically for injecting into delicate structures. The foam expands slowly, putting little pressure on the fragile inner wall, and contains no harmful blowing agents. Additionally, through its open cell structure, the foam will allow the wall to breathe which will assist in controlling moisture movement. The method was developed using a mock-up with typical cavity dimensions as would be found behind lath and plaster, before a trial was carried out in a house at Fettercairn, Aberdeenshire.

Before injecting the insulation, skirting boards were removed to vacuum the dust and debris accumulated in the cavity. This prevents thermal bridging and helps to ensure effective installation of the insulation. The cavity was inspected with an endoscope to ensure that it was free of debris before filling.

The trial was considered a success, proving the Icynene insulation can be injected behind existing plaster linings without causing any damage. A high level of skill is required, along with an understanding of the construction of the building to ensure that no damage is caused. The process needs to be executed methodically with no time constraints placed on the operatives to ensure optimum installation of insulation. An assessment of in situ thermal performance of this system is required.

4.2 Co-heating test for Alternative Refurbishment Strategy on Hard-to-Treat House on Uist

The study [4], carried out by Glasgow Caledonian University in collaboration with Locate Architects, involved the assessment of two alternative refurbishment strategies applied to a 'hard to treat' house in Daliburgh, South Uist in the Outer Hebrides as part of a wider project by Sustainable Uist (www.sustainableuist.org/hard-to-treat-houses/). 'Hard to treat' housing accounts for about half of the Island's housing stock. 'Co-heating' and air-tightness testing were carried out on the dwelling, which is a typical single storey two bedroom stone walled croft house with a floor area of about 40 m^2.

The house was divided into two symmetrical halves and fitted with contrasting energy efficiency systems for the combined purposes of absolute and comparative testing of thermal performance and installation cost (Fig. 6). There is a well-insulated wall between the two rooms. Both rooms have small single glazed windows which have been secondary glazed with proprietary secondary glazing. The house also has a small entrance hall to act as a buffer zone when entering the

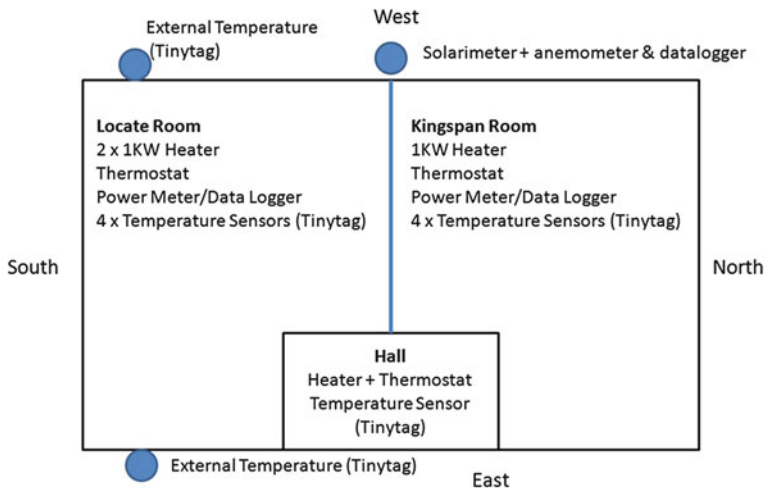

Fig. 6 Daliburgh co-heating test set-up [4]

building. A conventional approach was applied to one half of the building using a Kingspan insulation system. This approach may be considered to be current best practice, but without any particular emphasis on improving air-tightness.

Locate Architects were asked to devise an alternative refurbishment strategy by Sustainable Uist with potential to provide much more cost effective energy efficiency but with minimum intervention and high air-tightness. The Locate solution may be particularly appropriate in the Hebrides because of the high average wind speeds. The strategy consists of fairly conventional ceiling and floor insulation, however no wall insulation was applied and the original stone walls were plastered internally with lime, and particular attention was paid to air-tightness across the whole fabric including use of specialist tapes to seal all junctions.

The objective of the co-heating and air-tightness testing was to evaluate the impact of the two strategies. A co-heating test [22] is a method of measuring the heat loss (W/K) through the fabric and from background air infiltration in an unoccupied dwelling. It involves measuring the energy used to heat the inside of the dwelling to an elevated mean temperature over typically between 1 and 3 weeks. The electrical energy (heat input), internal and external temperatures are measured. Additional measurements of solar radiation and wind speed are useful to determine a solar gain factor and the influence of wind speed on the heat loss due to ventilation (particularly if the building is leaky). In order to obtain a sufficient value of the temperature difference (generally 10 K or more), the co-heating test should be carried out in the heating season. In the case of the Daliburgh house, measurements were carried out during late January and February 2012. A room temperature set point of 21 °C was used to achieve realistic indoor conditions.

The results show that the air-tightness measures undertaken in the Locate room were effective: the air change rate at 50 Pa pressure difference in the Locate room was about 1/3 of that in the Kingspan room. However, the overall heat loss of the Locate rooms was about 1.6 times that of the better insulated Kingspan room.

Following the co-heat test, improvements to the air-tightness of the Kingspan room were carried out and a second pressurisation test carried out, which gave an air change rate similar to the Locate room. Comparing the calculated whole room thermal transmittance values for both rooms after air-tightness measures, the ratio of the Locate to Kingspan values is 2.5, showing a marked improvement in the overall heat loss from the Kingspan room.

The report concluded that:

- Combining insulation and improved air-tightness is the best strategy for maximising energy efficiency of the building fabric (although considering indoor air quality, the measures should be coupled with an improved ventilation system).
- Best practice application of solid wall insulation system should include ensuring the air-tightness of the construction to avoid thermal bypasses and unwanted infiltration.

5 Discussion and Conclusions

Some themes run through the studies, particularly the tenement case studies, which are generally applicable to devising refurbishment strategies for the pre-1919 housing stock in Scotland:

- Assessment of the physical condition of the building.
- Proposal of the upgrading options to the building fabric and services.
- Ranking solutions on the basis of energy efficiency saving by CO_2 reduction and cost to aid the selection of appropriate measures.

The studies demonstrate the value of building simulation in this process. The optimum solution consists of addressing maintenance and repair issues, which may often be effected at comparatively low cost, and applying a refurbishment strategy which combines insulating the fabric and choosing an appropriate space and water heating system.

Post-intervention assessments are advisable both as a check of the actual thermal performance and the important impact of occupancy. These should be addressed in live projects, for example, where new technical solutions are implemented.

Whilst consideration is given to minimum intervention strategies to preserve and conserve traditional or historic features of buildings, risk assessments of the impact of refurbishment strategies should be carried out at an early stage before the final decision on the refurbishment package is made. However, current ongoing research (e.g. Historic Scotland) indicates that this is far from straightforward and requires both practical research and improvements to and better understanding by building professional of modelling software, particular for the study of moisture risk.

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Building Performance Evaluation

Tim Sharpe

Abstract This chapter will include an introduction to the context of the performance of buildings in use. These include changing energy and environmental targets and the development of new designs, materials and technologies to meet these targets. The question that emerges is, are these successful? Are the targets being met and if not why not? And are there related effects on performance - do improvements in one area lead to deficiencies in others? In effect, the construction industry is conducting a series of experiments and it is important that we go back and check the results, and more importantly, learn from these. However, this type of activity is not standard practice in the construction industry. This chapter describes a series of projects that have developed and undertaken building performance evaluation (BPE). These include the development of tools, examples of BPE projects, and case studies of the type of insights that can be gained from such projects; and will conclude with a summary how these can inform both clients and designers.

1 Introduction

This chapter describes research and knowledge exchange activities supported by CIC Start Online that addresses a fundamental research question that lies at the heart of all the initiatives, designs, technologies and interventions that have been discussed thus far. It is this: do they work as intended?

It seems extraordinary, given the level of investment in buildings and their importance both to contemporary objectives of climate change and sustainability, but also the everyday lives of people who use them in terms of comfort, health and satisfaction, that the performance of construction is hardly ever evaluated. For the

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vast majority of buildings, the answer to the question posed above is that we do not know. What is an increasing cause for concern is that in many of the buildings in which the question has been asked through some form of post construction review, it would appear that they frequently do not work as intended. Research has shown that there is a substantial performance gap emerging between the design intentions and measured performance of both new and refurbished buildings in the UK, with some sectors producing more than twice their predicted carbon emissions [10, 40]. In housing, energy and water use can vary by 3–14 times [19, 21, 41]. This gap could preclude achieving the carbon reduction milestones and timelines set forth by public policy [60], as buildings' operational energy demands account for nearly half of carbon emissions in the UK [18].

This gap in performance inevitably leads to a line of enquiry that asks, why is this occurring? Most regulatory requirements used by designers and builders are based around energy design targets, for example Standard Assessment Procedure (SAP) for energy rating of dwellings or Simplified Building Energy Model (SBEM) for estimating energy consumption of non-domestic buildings. However, these tools do not provide evidence to either the regulators or client of what level of performance has actually been achieved in reality. Currently, there are no requirements for proof that new build homes have achieved their planned energy performance in reality [20].

Furthermore, questions are arising about the environmental performance of new buildings, particularly housing. In some cases, there are conflicting goals; for example, energy reduction strategies seek to reduce ventilation rates, whilst those concerned with indoor air quality (IAQ) wish to increase them. Research has highlighted concerns about the possible consequences on indoor air quality of the greater airtightness [16, 17], and has identified the urgent need for further research in this area. As health and well-being are likely to remain as significant agendas for building occupants and landlords, there is a significant risk for the energy reduction agenda if low-energy homes become associated with problems of discomfort or health.

This raises an important issue. Irrespective of the industry, policy and legislative drivers for BPE, there are also ethical dimensions that are rarely considered. BPE frequently refers to effects of occupancy on performance, sometimes characterised as 'bad' behaviour. However, a converse view is that people live in these innovative buildings, and so are, in effect, the subjects of these experiments. So the resulting question is: what are the effects of buildings *on* occupants? There is clearly a moral, ethical and ultimately a professional responsibility to those who produce these buildings, as clients, designers and contractors to ensure that they function well and that there are no unintended negative consequences.

Building performance evaluation (BPE) is an absolutely key requirement in this area. It is the one process that can generate the intelligence needed to learn lessons from buildings in order to make the required changes to improve future design. BPE is the missing link in a feedback loop that can foster evidence informed design. With rapidly changing standards, leading to innovations in materials, technologies and construction, it seems reasonable to say that all new buildings are some form of experiment. However, if we do not evaluate the results of these experiments, how can we ever learn from them?

BPE has previously been defined as "the act of evaluating buildings in a systemic and rigorous manner after they have been built and occupied for some time" [45]. Early BPE methods include the gathering of both quantitative data through monitoring and qualitative data though surveys [29], but more recently, the methodology for this has been developed by studies such as PROBE [28]. In housing, a range of methods and parameters have been developed to capture data [55], and a comprehensive set of criteria for BPE has been set out by the Technology Strategy Board (TSB) Building Performance Evaluation programme [59].

However, undertaking BPE is not necessarily a straightforward process. There are a variety of methodologies and approaches, some of which are still developing. There are a range of building types, tenures and types of occupants to consider, and monitoring is also a rapidly developing area, with continuing advances in sensor technology and data acquisition.

CIC Start Online has been active in promoting, developing and undertaking BPE and other related forms of performance testing of materials and buildings throughout the project. A range of institutions are developing methodologies and reporting findings from innovations, and the examples in this chapter evidence this quite clearly. These studies involve collaborations with a range of stakeholders including architects, housing associations contractors and manufacturers.

This chapter reviews the CIC Start Online contributions to the field of building performance. These are broadly characterised by a series of themes, which address the barriers to BPE. Although by no means mutually exclusive, with several studies contributing to multiple strands, the themes nevertheless represent an approximate taxonomy for characterisation. They include:

- Performance gaps
- Methods and tools
- Occupancy
- Existing buildings
- Focussed studies
- Design integration.

2 Performance Gaps

The nature of the performance gap between design and build in Scotland was examined in a study by the Scottish Energy Centre, Edinburgh Napier University, in collaboration with the Morrison Partnership entitled 'The Gap between Design and Build: Construction compliance towards 2020 in Scotland' [7, 9].

It is becoming increasingly apparent that many buildings are not achieving the energy reductions that were anticipated, and this study provides a thorough overview of the issues leading to performance gaps. As well as identifying some key literature sources in this field, the study undertook a review of compliance requirements and gave concrete examples of performance gaps that occur at design, construction and occupation stages, in both new build and renovation projects. It reviewed possible causes at design stages, including tools, aspirations and specification; at construction stages in terms of workmanship and communication; it identified the role of occupancy post completion; and a clear recommendation from this work was the need for more BPE. It also proposed a more progressive building design and construction model (Fig. 8.1).

A review of BPE was also provided in the 2011 online Conference ‘Resilience of Buildings, Neighbourhoods and Cities’ in a presentation entitled ‘Resilience to Occupancy: Findings from recent Post Occupancy Evaluation projects’ [47]. The presentation outlined the changing context of contemporary housing in Scotland, including reducing volumes and window sizes, increasing airtightness, as well as energy and carbon reductions demands which are driving many of the design innovations discussed in previous chapters. The presentation described a range of research projects undertaken by the Mackintosh Environmental Architecture

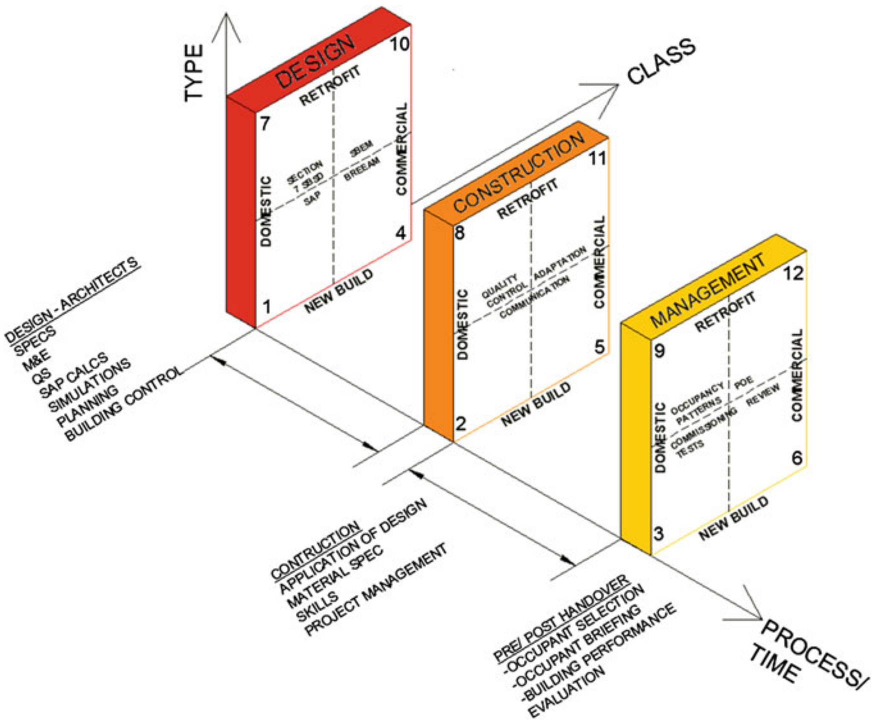

Fig. 8.1 A Progressive building design/construction model [7]

Research Unit (MEARU) that had undertaken forms of post occupancy evaluation of constructed buildings. These included the Priesthill project [49] and the SAP+ study for Scottish Homes [27].

The Priesthill study validated the energy performance of the project, which was higher than predicted, but still a significant improvement in overall terms. The shortfall was found to be higher than predicted ventilation rates, and this was further explored in the SAP+ study, which found both liberal window opening during the day leading to high ventilation losses, but very low ventilation rates at night leading to very high relative humidity (RH) levels. These studies clearly identified the differences between design prediction, legislative targets and real life.

The performance gap in non-domestic buildings has also been identified in other work, for example the article on school design in Innovation Review 10 by Renate Powell from the Carbon Trust [44]. This highlighted performance issues in new school design, including poor comfort, poor balance between daylighting, ventilation and temperature and inadequate environmental sustainability.

In reviewing this context, it seems ironic that meeting building standards in terms of energy use and ventilation *is* a requirement, but proof that the building achieves these standards is not. The Sullivan report, which has led to changes in legislation in terms of energy efficiency and carbon reduction, had as its first recommendation:

> Monitoring of recent private and public sector low carbon domestic and non-domestic buildings in Scotland including behavioural and occupier lifestyle monitoring as well as energy efficiency, carbon footprint, temperature, ventilation, etc. built both with public funding and by the private sector [57].

However, this has yet to be implemented. Research indicates that it is unlikely that voluntary measures on their own will deliver significant change as experience has shown that developers respond most pro-actively to legislation [37]. To this end, getting the message about the importance of BPE out to building clients and policymakers is a critical strategy, and has been a continuing theme across several CIC Start conferences and seminars, including CIC Start online conferences 'Resilience of Buildings, Neighbourhoods and Cities' [12]; 'Build Tight—Ventilate Right?' [13] and 'Building Performance Evaluation—Why and How? [14]. These conferences have included presentations from a range of individuals and organisations both from the UK and internationally, which have provided clear examples of problems and challenges emerging as a result of performance gaps. The 'Build Tight - Ventilate Right?' [13] conference in particular highlighted tensions in respect of seemingly mutually exclusive requirements of reducing ventilation rates for energy conservation versus improving ventilation rates for indoor air quality and health.

3 Methods and Tools

There are considerable barriers to undertaking BPE. As well as a lack of acceptance and understanding in some areas there is also a need to develop robust and deliverable methodologies that are both effective and affordable. The Technology Strategy Board (TSB) is currently undertaking a 4-year, £8 m programme of BPE with over 120 projects across the UK with the intention of developing BPE capacity and knowledge. The 'Building Performance Evaluation—Why and How?' [14] conference brought together domestic TSB projects in Scotland to discuss this area and share knowledge about the various projects.

Studies funded by the TSB BPE programme lasting 2 years are typically £40–60 k, and few, if any housing projects have this element built into the cost plan, particularly, as it is not a legislative requirement. As a result, those clients and organisations wishing to undertake BPE need to make a justification of the cost, but the financial model for housing provides very little room for manoeuvre. To those familiar with this area, it seems self-evident that the expenditure of perhaps 0.5 % of construction on checking that the building works as intended is a good investment, particularly, where such work may lead to improved energy efficiency, reduced running costs and better comfort and health.

However, the rapidly emerging performance gap between design and reality defines a clear need for in-use feedback of building performance on shorter timelines, and with practical methodologies. In the domestic sector, gaining access to houses to undertake BPE can be a considerable challenge. In its most comprehensive form, it can be disruptive to occupants, requiring several visits to fit monitoring and metering equipment, undertake surveys, filling in diaries etc., and so survey fatigue is not uncommon. Whilst in non-domestic buildings occupants are more accessible, in housing there are both ethical and practical barriers that need to be addressed.

Finding ways to minimise disruption is therefore critical, and several CIC Start studies have investigated forms of BPE, which undertake shorter, more intense studies. Whilst these clearly do not provide a holistic view of use throughout the year, or a comprehensive evaluation of a building, they nevertheless provide extremely valuable insights into patterns of occupancy and the energy and environmental performance in these periods. Such studies are also more affordable and may present a thin end of a wedge that can bring BPE into the public and industry consciousness, and also lead to working relationships with SMEs that can then lead to larger studies; examples of these are discussed below.

Stimulating demand through 'light-touch' approaches was addressed in a study "Development of Post Occupancy Evaluation for evaluation of innovative low carbon social housing projects", [30], undertaken in conjunction with John Gilbert Architects (JGA), which was also presented at a webinar in April 2011 [51]. The aim of the feasibility study was to explore the potential for the development of a cost effective Post Occupancy Evaluation (POE) methodology (with a particular sustainability focus) that could be used to gather both quantitative and qualitative information regarding energy and environmental performance of housing.

The study investigated a 'light touch' approach to POE, in which a snapshot of performance could be undertaken through monitoring houses for a short period, in this case two-week periods. This would include both quantitative measurement of environmental conditions, but also gathering of qualitative data through interviews, surveys and observations.

This methodology is less intrusive on the resident and is cost effective for the housing association. The study found that this approach could give valuable insights into the nature of the occupancy, levels of energy consumption and the resultant environmental conditions. It clearly identified performance gaps between SAP calculations and actual consumption, but also highlighted examples of good practice. The work illustrated the benefits of BPE to the housing associations, two of which have gone on to undertake further BPE studies on their properties and one of the participants, Hanover Scotland Housing Association (HSHA) has subsequently collaborated with MEARU on larger TSB-funded projects at Bloom Court, Livingston and Murray Place in Barrhead.

The broad methodology that was piloted in this study was further developed and utilized in a subsequent CIC Start Online academic consultancy "9–11 Gilmour's close—performance evaluation" [50]. This study was undertaken in conjunction with Assist Architects. The study looked at the performance of a Category B-listed tenement refurbishment that had incorporated low-energy principles to the design in the form of ground source heating, passive solar strategies, mechanical ventilation with heat recovery (MVHR) and upgrade of the fabric's thermal performance by internal lining. This had been previously described in an article by Andy Jack in Innovation Review [25].

There had been anecdotal evidence of overheating leading to widespread window opening. Given the low-energy intentions of the building, this was a cause of concern and was the subject of the study. This project assessed the performance of this development in terms of energy use and user experience, through a 3-week monitoring process and subsequent analysis of the small office space and five individual dwellings.

Although a short study, the snapshot revealed significant amount of data for the architects and landlords, highlighting underperformances in the MVHR and heating systems that explained the observed occupant behaviour. The study provided a series of recommendations for future design improvements for new proposals; building alteration/upgrades for Gilmour's Close; occupant support; and areas for further study. The landlord of this development is currently undertaking some of the recommended interventions and it is hoped that a further study will be undertaken to verify their effectiveness.

Both these studies were successful on at least three levels. First, they were able to develop and implement a light-touch methodology that was minimally invasive for the occupants and able to provide a rich dataset within the time and cost constraint of the feasibility study. Second, they were also able to generate useful knowledge about the actual performance of these buildings, and recommendations for actions to improve performance, both in the subject buildings, but also in design. Third, they revealed to the client organisations the benefits and insights of BPE, and this has led to further projects and investigations.

As well as these studies, several articles in Innovation Review have identified methodologies and tools that are used for BPE. Park [39] described the core principles of the Soft Landing approach, which requires a 'cradle to occupation' process for the handover of a building and extends the duties of the team during handover and the first 3 years of occupation. Stages include: inception and briefing enabling, design development and review, pre-handover, initial aftercare and extended after care and POE.

Information on the use of some commonly used tools has also been identified and disseminated. Park [38] described the requirements and standards for air-tightness testing introduced under the 2010 Building Standards. As well as general methodologies for BPE, some studies examined the nature of equipment used for environmental monitoring. Glasgow Caledonian University undertook a study for AppleGreen Homes on the 'Application of an innovative energy consumption monitoring system' [2]. The project investigated the application of a wireless sensor network (WSN) infrastructure to support monitoring of an energy efficient built environment, specifically, a mass-market affordable home created by Scottish company Applegreen Homes. The work includes the creation of a feature-set specification for a monitoring system, the development of hardware and software to provide the necessary functionality and an evaluation within a built environment.

One particular area of deficiency that BPE has consistently identified is the management and handover of design and construction information. An important development in this field is likely to be the use of Building Information Management (BIM). This was investigated in the study 'Sustainable BIM-driven post-occupancy evaluation for buildings' by Heriot-Watt University in collaboration with Wylie Shanks Architects [32]. The study explored the need to facilitate this sharing of information among the stakeholders and supply chain at both procurement and operation stages through interviews with key stakeholders. The study identified the key operational and carbon performance variables for Scottish public buildings, which are required to adopt BIM approach as a means of better informing the stakeholders on the performance. If implemented, this could help to develop a smarter procurement strategy based on consistent information to be shared by all stakeholders.

4 Occupancy

An element of building performance that is attracting increasing attention is that of occupant behaviour. This is often characterised as misuse, but it is becoming apparent that many buildings are not designed for contemporary patterns of use, with limited environmental strategies often dictated by legislative requirements, and inadequate controls. Occupants, like designers and clients, frequently have little access to information that might affect their energy consumption and environmental performance.

One of the elements explored by the study with John Gilbert Architects [30] was to develop a sample online POE tool and template documentation, which could be applied to future POE exercises, carried out by Housing Associations. This examined ways of communicating information to the landlord and occupants, including innovative ways of representing data. In this case, a 'weather map' tool was developed, which showed, through colour change, varying environmental conditions in the dwelling.

This issue of feedback and communication to occupants is very important (Fig. 8.2). As the behaviour of building occupants affects the energy and environmental performance, the ways in which users of a building are given guidance on how to use their buildings, particularly when these include novel or unfamiliar technologies, is crucial. This problem was addressed by a study "Developing a Template for a 'Quick Start' User Guide for New Home Owners" [52], undertaken in collaboration with the Home Logbook Company (HLB) that developed guidance for occupants of low-energy homes.

Scottish Government Building Standards Directorate had previously commissioned MEARU in conjunction with 55 North Architecture to develop occupant guides as part of the Building Regulations new Sect. 7 'Sustainability'. This section outlines optional standards for sustainability for new housing—the higher levels include the need for straightforward user information for homes including a 'quick start guide' to the building fabric, mechanical systems, ventilation strategies and other sustainability features [31, 48].

This project was a chance to put this into practice. The HLB Company together with MEARU developed a bespoke 'quick start' guide for housing, including the aspects addressed in the new building standards in Scotland. The aim was to identify the most effective process of gathering this information and to propose a simple template which could be replicated by housing providers to meet the Sect. 7 criteria for new homes (Fig. 8.3).

The 'pilot' guide was tested with a range of new house owners and tenants in both the public and private sectors. Feedback on the guide was obtained from residents, and survey results were overwhelmingly positive. 100 % of the residents said that they found it was easy to read and that the diagrams were easy to understand, and 94 % said that they feel more informed about how to use the house in a more energy efficient manner. There was less confidence about whether the guide helps residents to understand the controls—the guide identifies where information about controls could be found, but in many cases the controls themselves were found to be confusing. Both this study and other research in this area [58] have identified that users' knowledge of how to use low-energy homes is a significant barrier.

On a related theme HLB Ltd also examined home owners' attitudes to water consumption in the study 'Communication strategies to minimise water consumption in social housing' with Heriot-Watt University [22]. It found that there

Fig. 8.2 Innovative communication methods [31]

was a significant lack of awareness regarding water conservation amongst social housing tenants, and explored a variety of ways in which this could be improved through information campaigns with different user groups.

User engagement with energy and resource consumption was investigated in several studies. The use of energy monitoring was an important component of the study ‘A Tool to Calibrate Cost Effectiveness of Energy Efficiency’ by MEARU and University of Sheffield in collaboration with NRGSTYLE Ltd [35]. During the design stages for a low-energy refurbishment, the existing energy consumption was monitored using an EWGECO energy monitor, and the findings used to help define design options. The novel EWGEKO smart meter was also the subject of

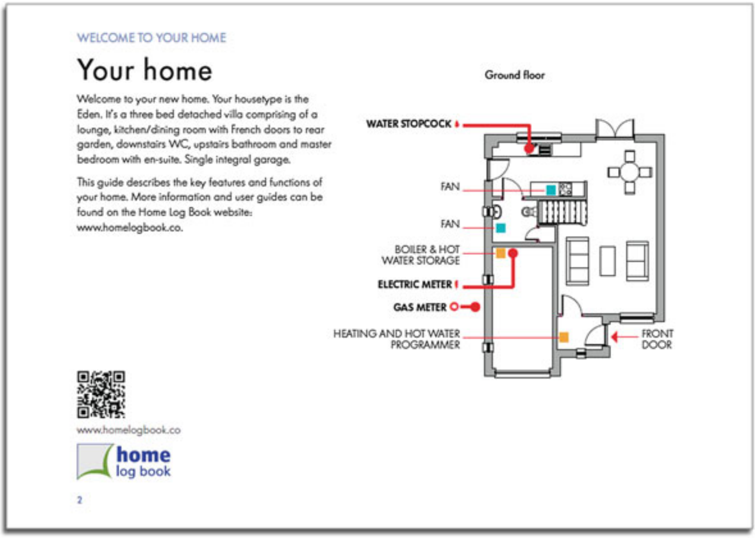

Fig. 8.3 Excerpt from a 'Quick-Start' guide [48]

webinar 39—Integrating Energy Monitoring Systems for Smarter Homes [56], which outlined the benefits and development of a smart metre system.

The effectiveness of a new system for occupant control of heating systems was the focus of a study "Ecotrip Heating Control Field Trial" [46] by Glasgow Caledonian University for Corrour Concepts, which investigated technology for a domestic central heating control. The feasibility study undertook a field trial of the unit to investigate its ease of use and potential energy savings.

5 BPE in Existing Buildings

Refurbishment of existing buildings to reduce energy consumption whilst maintaining the fabric of the building presents a series of very unique challenges and a number of studies have focussed on existing buildings. BPE is equally important in these buildings types, if not more so, as existing conditions may restrict the choice of solutions that can be applied. This was found to be the case in the study at Gilmour's Close, where fire safety measures compromised the performance of the MVHR system [50].

A specific problem in existing buildings is the retrofitting of insulation to achieve a required level of performance, particularly in older stone properties. Moses Jenkins, Senior Technical Officer at Historic Scotland describes in situ measurement of U-values of materials used in historic building refurbishment [26] and a feasibility study entitled "Monitoring building fabric and internal environmental behaviour of a recently insulated historic building" [5] was undertaken by Robert Gordon University in conjunction with Kishorn Developments that monitored the before and after performance of an additional insulation applied to the wall of a traditional stone building. It compared the measured results with CFD simulation. It found some differences; the measured value of relative humidity of insulated wall fell within the range of relative humidity values calculated for the air gap in the simulation 29 % of the time.

This problem was also explored in a feasibility study undertaken by Edinburgh Napier University in collaboration with BCA insulation [8] 'Thermal and condensation analysis of a typical solid wall following a refurbishment intervention'. This study undertook thermographic imaging and in situ testing of U-values of a masonry wall that had partial installation of phenolic internal insulation. Upper parts of the wall had been left un-insulated for aesthetic reasons to avoid hiding the original cornicing. As well as illustrating differences been predicted and measured U-values, it clearly demonstrated the thermal improvement of the insulated elements, but also highlighted risks of the residual cold spots and interstitial condensation (Fig. 8.4).

An alternative solution was assessed in the study 'Testing of a method for insulation of masonry and lath walls' by Robert Gordon University in collaboration with [3, 4]. This study examined the performance of a water-blown foam insulation, Icynene, placed behind a traditional plaster and lath wall. In this instance, the installation performance was the main focus of the study, which highlighted a

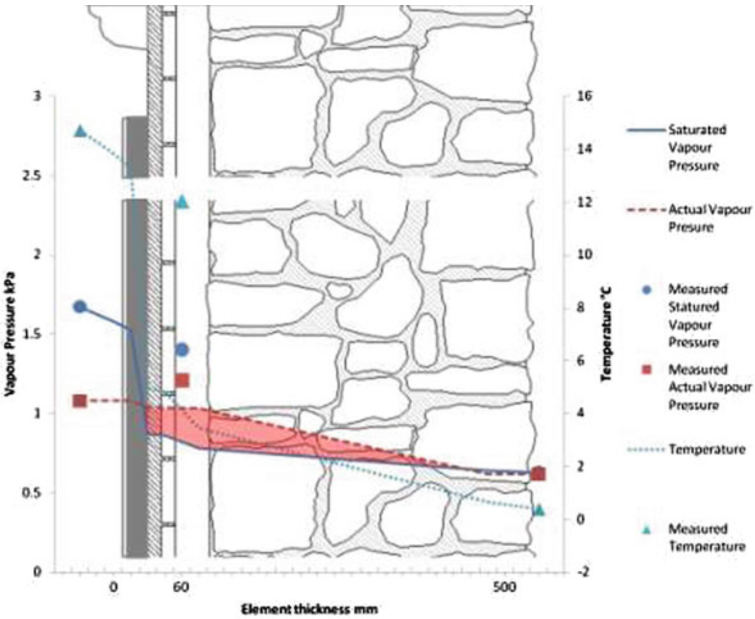

Fig. 8.4 Graph showing the Glaser method results against in situ results [8]

Fig. 8.5 Test installation of Icynene [4]

number of operational problems that need to be resolved when installing insulation into this type of cavity, but demonstrated that the technique is viable (Fig. 8.5).

More specific experimental tests have been conducted in existing buildings. A feasibility study by Glasgow Caledonian University in collaboration with Locate Architects 'Co-heating test for Alternative Refurbishment Strategy on Hard to treat House on Uist' [1] undertook 'real-world' testing of two different improvement strategies—a conventional internal insulation approach, and an alternative that improved airtightness, reduced thermal bridging, improved external waterproofing and retaining exposed thermal mass. The study used a 'Co-heating' test coupled with results of airtightness testing on a typical single storey two bedroom stone-walled croft house with a floor area of about 40 m^2 in Daliburgh, South Uist. The study identified specific benefits of both approaches, but concluded that elements of both strategies are needed.

6 Focussed Studies

In some cases, investigations focus on specific issues. An example of the value of real life assessment of performance was presented in the article by Professor Colin Porteous of MEARU in the article in the Innovation Review. This article summarised the approach and findings of multi-disciplinary, 3-year research project funded by the Engineering and Physical Sciences Research Council (EPSRC) [43]. MEARU led the project in conjunction with two other research units—Research on Indoor Climate and Health (RICH) at Glasgow Caledonian University and Energy Systems Research Unit (ESRU) at the University of Strathclyde. This involved a large scale Post Occupancy study undertaking survey and monitoring of housing in Glasgow, investigating the health and energy implication of domestic laundry practices. In this case, the monitoring then fed back into laboratory testing and computer simulation, a reversal of the normal direction of knowledge flow in construction. The monitoring looked closely at moisture, which has implications for indoor air quality (IAQ) and health, due principally to mould spores, dust mites and chemicals (used in laundering and released from materials and furnishings). IAQ in turn relates to energy consumption for space heating, with control of ventilation playing an increasingly crucial role in limiting fossil fuel consumption and carbon emissions. It also introduced 'Healthy Low Energy Home Laundering', Design Guide which is a key publication arising from the study and now available free-online at www.homelaundrystudy.net [43].

In some cases, very specific investigations have been made into the performance of particular systems or technologies. For example, in the study 'Assessing the energy impact of different strategies of integrating PV/Thermal Heat Recovery systems in Scottish homes' [34] undertaken by MEARU in collaboration with RobertRyan Timber Engineering, the project undertook in situ monitoring of the performance of a full-scale mock-up of a PVT/HR system in Sweden. The observation helped to identify the performance of PV/T modules in question—particularly, the ventilated PV/T mockup under snowy winter conditions. Although results were not positive in this condition, the real life observation helped to identify the negative impact of snow on PV cells leading to an ice dam, if the system is not integrated with building envelope (i.e. roof) properly. This type of insight would not be possible in modelling or simulation.

Effects of airtightness and ventilation were also described in the article 'Seal Tight, Ventilate Right' by Donald Shearer of MEARU in CIC Start Online Innovation Review [53]. This article described a detailed BPE program being undertaken on the Glasgow House, the design intentions of which had been introduced by Stuart Carr from PRP Architects in 'The Glasgow House: A 'low-tech' approach to the problem of fuel poverty' [11]. The study is conducting a number of detailed evaluations of the prototype housing using occupant scenarios to test the relative performance of two construction types. This article identified some shortfalls in performance of the MVHR system in relation to requirements for IAQ.

7 Design Integration

A further barrier exists in the reluctance of those involved in the design and construction of buildings to engage with BPE, perhaps most simply characterised as a fear of 'bad news'. There is an aphorism that "doctors bury their mistakes—architects have to live with them". In fact, quite the opposite is true. The medical profession takes considerable pains to learn from its mistakes to ensure that they are not repeated but the same cannot be said of the construction industry.

As there is currently little verification of performance there is consequently less litigation for non-compliance, but there is a concern in the industry that BPE will reveal deficiencies that would not otherwise have been seen. However, it has become apparent that these fears are unfounded. BPE can reveal positive messages and, in cases where problems are encountered, analysis of these will lead to learning. BPE findings can inform the construction industry, policy and government.

There are considerable advantages for architects to be involved in BPE as a way of increasing knowledge about the implications of design decisions and developing an understanding of how buildings are being used. In recent years, architects have had far less control over the design and construction process. More specialists in the design and construction industries are now involved, but without an overview that links design intention to end product, there is a risk of a fragmentation in the process. BPE can be a way for architects to reclaim some of this territory, if it can lead to an improvement in the services provided, what Bordass and Leaman refer to as a ‘new professionalism’ [6].

BPE, thus presents opportunities for the profession as the driver of the design agenda, but implicit within this is the notion that designs actually perform well. To verify this, it must be tested. Forms of POE are now included in the RIBA 2013 Plan of Work. Whilst this has received something of a lukewarm reception by the profession who characterise it as one more task they have to do within the same fee, it could be developed as a more comprehensive service, which not only provides additional work, but also informs design practice. As the demand for BPE increases, the service will be provided, but it is clear that architects not only have a professional and ethical duty to learn from the designs, but are also best placed to feed this back into design.

As evidenced by these studies, this is a rapid changing area. Architects are seeing that the benefits of BPE in terms of knowledge gained far outweigh any negative aspects. In any event, BPE should be seen as a learning, rather than judgemental activity. Once the participants understand this, a far more fruitful dialogue can occur. This is evidenced in the article ‘Passive solar PassivHaus paradigm for Scotland in zero-carbon quest? Lessons from study tour in Switzerland and Germany’ by Prof. Colin Porteous [42]. The articles describes a series of innovative low-energy buildings in Switzerland and Germany, but crucially also provides substantiation, through monitoring projects, of their performance.

A number of articles on design intentions include information on performance. In her article ‘Affordable Low Allergy Housing’, Prof. Sandy Halliday of Gaia Research describes monitored performance of low allergy housing [23] as evidence of its effectiveness and in the article ‘Plummerswood Active House’, she shares the early performance (Fig. 8.6) of the Plummerswood house by Gaia which is undertaking a TSB funded 2-year BPE study [24].

The need for BPE to feed back into design is a crucial component. This was the subject of a study Embedding Simplified Post Occupancy Evaluation [15, 36] within the design process by the University of Strathclyde Glasgow with Page and Park (P/P). This project developed prototype software (POET) for gathering information on the on-going energy consumption of buildings designed by Page and Park. For a given building, energy use data is recorded and stored in POET

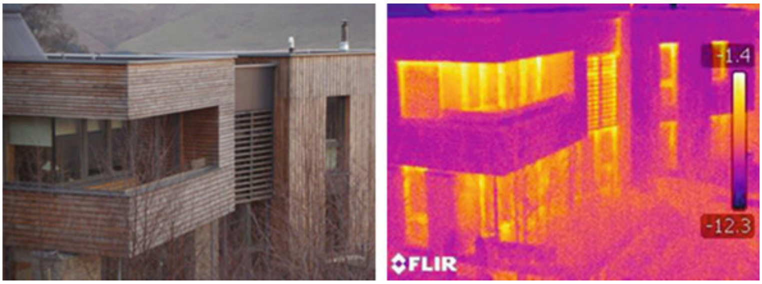

Fig. 8.6 Thermographic Imaging, Plummerswood Active House (Photo S. Haliday, W. Butler)

over a 1–2 year period following occupancy. These figures can then be displayed in the form of graphs and compared with the benchmark performance data within the progra. In addition to the quantitative data, a questionnaire-based building performance evaluation is undertaken by the facility manager (or equivalent) and the outcomes stored in POET. The intention of these evaluations is to capture the building users' consensus view of performance and record how this changes over time. Observational walkthroughs can also be used to corroborate evidence gained. They can be used to record whether people are using the building as intended; where they relax, how they use quiet spaces and what they do to counteract negative environmental features. The study has parallels with the previous projects in that it seeks to develop a more responsive, lighter touch approach than currently exists in industry standard tools such as TM22 and the BUS. Page and Park are utilising the tool in two of their current projects.

The role of BPE in design was also the subject of the study 'Embedding Post Occupation Evaluation into Practice [33, 54], undertaken by Kraft Architecture in collaboration with MEARU. This study had addressed three issues, how can POE be made more affordable and accessible and made a valued routine practice. The study undertook a review of current BPE state of the art and discussed the challenges and possible solutions that may be required, including a review of techniques and solutions that can be applied. Whilst the study was not conceived of as a 'how to' of POE, it provides insights for the construction industry on how to 'mainstream' POE practice and its benefits.

It is evident from the studies presented in previous chapters that forward thinking architects have become more aware of the need to undertake BPE in order to make better buildings and inform their design practice. Chapter 4 has described a series of diverse approaches to sustainable design practice and it is interesting to note the emphasis being placed on post occupancy studies. Over 14 articles in Innovation Review specifically described intentions to monitor the buildings and innovations being proposed.

8 Conclusions

It is clear that the performance gap between design intention and actual performance needs to be closed, not just to meet energy targets, but also to provide sustainable, liveable buildings. Without robust assessment of performance, we cannot understand how buildings perform, how they are used, nor how we can make them better.

Research into, and through BPE, reveals new knowledge about the performance of buildings, their technologies and also their occupants. The ability for this knowledge to inform design practice is invaluable. Early chapters evidenced a range of innovations in design and construction and have identified the pressing need to take a more holistic approach to design that extends throughout the life-cycle of buildings, and that develops methodologies that can close the loops and feed user experiences and building performance back to design stages.

The knowledge generation and dissemination initiated by CIC Start Online has developed and extended the knowledge and practice of BPE and provided insights into the real-life performance of design, materials and technologies. These studies have enabled significant knowledge exchange between architects, building owners, occupants and academics about where performance gaps may be arising, how they might addressed, and how this knowledge can be fed back into the design, procurement and construction processes.

It is evident that significant innovation is required to meet the challenges set down by climate changes and the need for sustainability, but what these studies have demonstrated is that although technology is important it is not a solution in its own right and simple fabric first approaches to building orientation, form and construction; and a concern for the users and occupants of buildings continue to be fundamental tools for the design and production of environmental architecture.

The need to support BPE is clearly evidenced, both in terms of legislation, but also capacity and skills in the construction industry. The studies have met, and also stimulated, an increasing demand for BPE in the construction industry in Scotland. In many aspects this research and innovation is leading the UK.

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Conclusions

Branka Dimitrijević

Looking back As the independent Assessment Panel, established to assess applications for funding of feasibility studies through CIC Start Online, approved only the applications whose outcomes would provide a direct benefit to a business that has applied for funding jointly with academics, the innovations developed through the project were industry driven and indicated areas in which the industry needed assistance. The project has indicated that there is a significant interest in developing innovations both for existing and new buildings, and for assessing their true performance through POE. The studies have enabled SMEs to access laboratories at the participating universities to test innovative building products and technologies. They have increased understanding about clients' decision making in relation to the incentives to reduce carbon emissions and about the tools required.

The scope of the approved studies included not only the environmental impact of buildings, but, in many cases, the social and economic impacts such as fuel poverty, indoor air quality and whole life costs for building occupants. As a consequence, interdisciplinary collaboration of researchers from different departments at the partners' institutions and sometimes with external consultants had been initiated. Feasibility studies and academic consultancies have developed new knowledge regarding the technologies for generating energy from renewable resources and building materials made of recycled or renewable natural resources. They have also increased understanding of how new technologies can be integrated into existing and new buildings to reduce carbon emissions and fuel poverty. Other studies have refined some existing software tools for building modelling, or indicated the limitations in some existing assessment tools or used the tools to indicate improvements required.

Most studies focused on recently completed projects as exemplars of sustainable building design or refurbishment that needed to be verified through monitoring in order to suggest further improvements. Due attention was given to existing building stock by consulting building occupants on how buildings are used, by applying innovative methods for assessing building performance, recommending and estimating costs of potential improvements, and providing guidelines to the building owners on how to undertake future assessments and improvements.

B. Dimitrijević (ed.), *Innovations for Sustainable Building Design and Refurbishment in Scotland*, Green Energy and Technology, DOI: 10.1007/978-3-319-02478-3,

The majority of studies focused on Scottish environmental, social and economic context, thus assisting in addressing local conditions. However, some studies have tackled more generic innovations that can be applied internationally. The results of both approaches assist in increasing the competitiveness of SMEs and project members to whom the outcomes of innovations were disseminated.

The use of online tools for project management enabled efficient working of the Assessment Panel, multiple institutions across Scotland and the project staff, building the consortium confidence in a successful delivery of complex collaborative projects. It also enabled dissemination of the project outputs to professionals and wider public interested in sustainable building design and refurbishment nationally and internationally. As the project outputs can easily be searched through Knowledge Base, the project is gaining new members after its end in February 2013. It will remain a learning resource for students and for continuous professional development of practitioners.

Looking forward At the end of 2010, the project partners agreed to prepare a proposal for a new project entitled 'Mainstreaming Innovation' whose scope would be wider and include low carbon infrastructure within and around buildings. The plan was to include more higher education institutions into the consortium and link with further education institutions to support the development of skills required for creating and maintaining a sustainable built environment. To explain the context and background for the new project, a research on the EU, UK and Scottish policies related to sustainable infrastructures was undertaken. The research was funded by Scottish Government and has been published on the project website www.mainstreaminginnovation.org. This resource is useful for understanding the legislative and policy context in which the industry operates.

The project has started on 1st April 2013 with the funding from Scottish Government. It will assist Scottish businesses to collaborate with universities in developing innovations for integrated low carbon infrastructure, including green infrastructure (landscaping and biodiversity), energy efficiency of buildings, local energy generation from renewable sources (including storage and distribution), sustainable transport (electric vehicles, cycling, walking), water (saving, management and recycling), waste (reduction, reuse, recycling and energy recovery) and Information Communication Technology (ICT) systems for managing infrastructure and interaction with users. The focus is on application of low carbon infrastructure in housing, education and healthcare estates which can also be replicated in other building estates. The project aims to identify innovations that can be put forward for funding to Scottish, UK and EU funding programmes.

The project has established an Advisory Panel whose members are representatives of Resource Efficient Scotland (within Zero Waste Scotland), Glasgow Housing Association, Health Facilities Scotland, Estates Management of the University of St Andrews and Skanska. The project will also collaborate with other related projects, research groups, government organisations, infrastructure services providers and industry involved in R&D and/or delivery of sustainable infrastructure. The project outputs will be disseminated at demonstration events in further education colleges, webinars and quarterly online magazine.

The project is led by Glasgow Caledonian University in collaboration with Edinburgh Napier University, Robert Gordon University, the Glasgow School of Art, Heriot-Watt University, University of Edinburgh, University of Aberdeen, University of Abertay Dundee and University of Strathclyde Glasgow.

Appendix

CIC Start Online Outputs

The lists of the project outputs include the links to the reports approved for publishing on the CIC Start Online website www.cicstart.org, webinar recordings and related articles published in the CIC Start Online Innovation Review.

Feasibility Studies

FS01 Noguchi M, Grassie T, Ringaila A (2010) A Hybrid Solar Thermal Mass System Development for the application to Tenants First Housing Co-operative's zero-carbon affordable homes.
Report at http://www.cicstart.org/fs01.htm
Webinar recording at http://www.cicstart.org/wb01.htm

FS03 Menon R, Gilbert J, Bridgestock M (2010) Development of Post Occupancy Evaluation for evaluation of innovative low carbon social housing projects.
Report at http://www.cicstart.org/fs03.htm
Webinar recording at http://www.cicstart.org/wb03.htm

FS04 Nugent K, Clarke J, Bradley F (2010) Embedding simplified post occupancy evaluation within the design process.
Report at http://www.cicstart.org/fs04.htm
Webinar recording at http://www.cicstart.org/wb04.htm

FS05 Roaf S, MacLennan C (2011) Novel Solar Thermal Collector Design.
Webinar recording at http://www.cicstart.org/wb05.htm

FS06 Jack D, Cockroft J, Hand J (2010) Tenement Flat Carbon Reduction Shopping List.
Report at http://www.cicstart.org/fs06.htm
Webinar recording at http://www.cicstart.org/wb06.htm

B. Dimitrijević (ed.), *Innovations for Sustainable Building Design and Refurbishment in Scotland*, Green Energy and Technology, DOI: 10.1007/978-3-319-02478-3,

FS07 Tuohy P, Cockroft J, Dougall M (2010) Improving Energy and Carbon Performance of Housing - A Glasgow Case Study Garrioch Road Tenement Flats

Report at http://www.cicstart.org/fs07.htm

Webinar recording at http://www.cicstart.org/wb07.htm

FS08 Roaf S, McEwan D (2010) Assessment and Application of Zero Carbon Building in Scotland.

Report at http://www.cicstart.org/fs08.htm

Webinar recording at http://www.cicstart.org/wb08.htm

FS11 Howieson S, McCafferty P (2011) Tarryholme Sustainable Healthy House Study: Project Summary.

Report at http://www.cicstart.org/fs11.htm

FS13 Wang F, Roaf S (2010) A Feasibility study on Solar-Wall systems for domestic heating - an affordable solution for fuel poverty.

Report at http://www.cicstart.org/fs13.htm

Webinar recording at http://www.cicstart.org/wb13.htm

FS15 Moore D R, McDonald S, Abdel-Wahab M (2010) An Investigation of the Adoption of Low-Carbon Technologies by Scottish Housing Associations.

Report at http://www.cicstart.org/fs15.htm

Webinar recording at http://www.cicstart.org/wb15.htm

FS17 Noguchi M, Musau F, Udagawa M, Higuchi Y, Larsson S, Ringaila A (2011) Industry

Aspirations for Building Integrated Photovoltaic Thermal Heat Recovery Systems.

See article: Noguchi M (2011) Industry Aspirations for Building Integrated Photovoltaic Thermal Heat Recovery Systems. CIC Start Online Innovation Review, 8:24-31.

http://www.cicstart.org/r8-24.htm

FS20 Barrie P (2012) The application of low cost wireless sensor network system into a low carbon built environment: Applegreen House.

Report at http://www.cicstart.org/fs20.htm

FS22 Musau F, Deveci G (2013) Assessing the environment and energy impact of occupant behaviour.

Report at http://www.cicstart.org/fs22.htm

FS24 Bennadji A, Levie M C (2012) Testing of a method for insulation of masonry and lath walls in existing domestic Scottish Construction.

Report at http://www.cicstart.org/fs24.htm

Webinar recording at http://www.cicstart.org/wb24.htm

See article: Bennadji A (2012) Testing of a method for insulation of masonry and lath walls in a traditional Scottish domestic building. CIC Start Online Innovation Review, 12:60-69.

http://www.cicstart.org/r12-60.htm

FS25 Hunter C, Pahl O (2013) Investigating New Markets for Recycled Plasterboard.
Report at http://www.cicstart.org/fs25.htm

FS26 Girard A, Irshad W, Muneer T (2011) Optimization of economic, environmental and energy savings in buildings.
Report at http://www.cicstart.org/fs26.htm
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DVDs or Power Point presentations available as indicated below.

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2. 2012 - The Green Deal and sustainable refurbishment of traditional buildings http://www.cicstart.org/c02.htm DVD can be ordered from admin@cicstart.org.
3. 2012 - Circular Economy: Opportunities for Construction Sector in Scotland http://www.cicstart.org/c03.htm
4. 2012 - Mass matters in low carbon building design http://www.cicstart.org/c04.htm
5. 2012 - Green Deal for Real http://www.cicstart.org/c05.htm Power Point presentations available
6. 2012 - ECO and energy efficiency improvements in hard-to-treat housing http://www.cicstart.org/c06.htm DVD can be ordered from admin@cicstart.org.
7. 2012 - Water efficient design http://www.cicstart.org/c07.htm
8. 2012 - Integration of Sustainable Infrastructure Into the Existing Built Environment http://www.cicstart.org/c08.htm DVD can be ordered from admin@cicstart.org.
9. 2012 - BIM and Sustainability http://www.cicstart.org/c09.htm DVD can be ordered from admin@cicstart.org.
10. 2012 - Sustainable Refurbishment of Healthcare Estates http://www.cicstart.org/c10.htm DVD can be ordered from admin@cicstart.org.
11. 2012 - Security of electricity supply, demand side management and Smart Grid strategy http://www.cicstart.org/c11.htm DVD can be ordered from admin@cicstart.org.
12. 2013 - LED Lighting Quality and Performance http://www.cicstart.org/c12.htm DVD can be ordered from admin@cicstart.org.
13. 2013 - Electric Vehicles and the Built Environment http://www.cicstart.org/c13.htm DVD can be ordered from admin@cicstart.org.
14. 2013 - The Use of Recycled Materials in Construction http://www.cicstart.org/c14.htm DVD can be ordered from admin@cicstart.org
15. 2013 - Building Performance Evaluation - Why and How? http://www.cicstart.org/c15.htm DVD can be ordered from admin@cicstart.org
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