Modern Methods of Retrofitting: a socio-technical approach to innovation in the low carbon retrofitting of UK social housing

Andy Wright[1], Mark Lemon[1], Michael Crilly[2] Matthew Cook[3]

[1] Institute of Energy and Sustainable Development, Queens Building, De Montfort University The Gateway, Leicester, LE1 9BH United Kingdom (mlemon@dmu.ac.uk; awright@dmu.ac.uk)

[2] Studio UrbanArea LLP, 2 King Street, Princes Wharf, Quayside, Newcastle upon Tyne, NE1 3UQ (michael@urbanarea.co.uk)

[3] Design Group, Open University, The Design Group, Venables Building, Open University, Walton Hall, Milton Keynes, MK7 6AA (matthew.cook@open.ac.uk)

Abstract

The UK has set a highly ambitious target to reduce greenhouse gas emissions by 80% by 2050. Around 27% of emissions of carbon dioxide [the main greenhouse gas] is generated by housing in use. Around 30% of the UK housing stock is social landlord and local authority owned. Meanwhile, fuel prices are increasing, and consequently fuel poverty. Turnover in the building stock is much lower than for any other product; buildings have a much longer average life, and most new build is additional not replacement, so the most important impacts on energy use and carbon emissions will come from the existing stock even in 2050. Thus considerable innovation and investment is needed to meet the ambitious carbon reduction targets and to contain rising energy costs, by reducing demand and decarbonising supply.

Taken together, these factors create a considerable problem for social housing providers who are increasingly looking for guidance in making investment and management decisions on energy efficiency for new build and especially retrofit. In order to meet targets, simple tried-and-tested measures such as loft insulation are being augmented by a range of innovations. These need to deployed without compromising the ability of providers to offer energy efficient accommodation, and the need to tackle fuel poverty. For example, tenants may not understand complex controls, and so not obtain the benefits they are supposed to provide.

The paper will build upon the experience of the academic and practitioner partners from social housing, construction and manufacturing to develop an integrative understanding of how decisions about innovations within the retrofitting process can be undertaken at the scale[s] required.

Initial analysis of the projects has suggested that a focus on technical innovation alone is insufficient and, by extension, only focusing upon the technological characteristics and affordability of those technologies is also inadequate. Alternatively a focus on the behavioural and process aspects of retrofitting can be equally restrictive. In response, this paper presents a socio-technical approach to the evaluation of innovations by social housing providers for retrofit. The approach will highlight a series of technical and qualitative metrics derived from a synthesis of this theoretical and case-based approach, in particular the Technology Strategy Board Retrofit for the Future projects undertaken by the authors in Leicester and Newcastle, and will consider a range of the physical and process innovations encountered.

Housing and carbon: a socio-technical approach

> *"Whether renovation projects can be rolled out on a mass scale, or go beyond Passivhaus … is yet to be discovered"*[1]

Housing 'in-use' accounts for about 27% of emissions of UK carbon dioxide (the main greenhouse gas) including electricity, and 15.3% of direct emissions of greenhouse gases (i.e. excluding emissions arising from generation of electricity used in homes). The UK has set a highly ambitious target of an 80% reduction in greenhouse gas emissions by 2050 compared to 1990 levels. As emissions have fallen since 1990, the actual overall reduction required from 2010 emissions is 74%[2] and significant reductions are expected from housing. However, the UK has one of the oldest housing stocks in Europe and according to Power[3], "at least 87% of these (22 million) will still be standing in 2050, even at the highest previous demolition rate of two million over 40 years." Almost all new housing is additional and will not replace existing stock; this means that even if new homes are highly energy efficient with very low carbon emissions, the existing stock will need to be very substantially improved to achieve large carbon reductions.

Around 90% of UK homes are heated with natural gas and a key feature of older properties is poor insulation and leaky fabric; together these factors mean that most energy use, and carbon emissions, result from space heating by burning gas, even though its carbon content per unit of energy is low (0.19 kg.C/kWh). The majority of the remaining energy demand and emissions is from the use of gas to heat water, and of electricity for lights and appliances, plus a small amount derived from the use of electricity, and other fuels, for heating[4]. There may be a substantial switch in future decades to the use of electricity for heating, either directly or with heat pumps, as gas becomes more scarce and expensive. If the carbon content of electricity supply was greatly reduced through more renewable and nuclear generation, as planned, then electric heating could result in low carbon emissions. However, this would only make economic sense if heating demand in homes was substantially reduced to a level that the electricity network could cope with (e.g. electricity demand would increase by a factor of three or four in an uninsulated home if gas was replaced with a heat pump - based on a house using a typical 4,000 kWh electricity at present, with a space heating demand of 25,000 kWh. If this were to be met by an air source heat pump with a typical system coefficient of performance of 2.5, this would require 10,000 kWh additional electricity, an increase factor of 3.5) Therefore, to achieve the planned carbon reductions, improved insulation and air tightness, as mechanisms for reducing energy demand in the existing stock, will have the highest priority.

Many have advocated higher fuel prices to improve domestic energy efficiency by making improvements much more financially attractive. However, recent increases in prices have not resulted in substantial efficiency improvements but have contributed to putting many more people into fuel poverty[i] with the number of households classified as such rising from 1.2 million in 2004, to 4.0 million in 2009[5] – other factors being changes to income and demographics. Not only does fuel poverty mean that people are poorer it is also indicative of under-heated and under-ventilated homes, which, apart from being unpleasant, can cause health problems and damage to building fabric through mould and damp. While these issues have a particular resonance with those in private rented accommodation they are also extremely important to social landlords.

These links between the physical fabric and energy performance of a building and the health, well being and finances of its inhabitants are indicative of the interconnected and complex nature of the refurbishment and retrofit process and the product and process innovations that need to be incorporated into an integrative whole house approach.

---

[i] A household is said to be fuel poor if it needs to spend more than 10 per cent of its income on fuel to maintain an adequate level of warmth.

This paper sets out a suggested process for a retrofitting strategy, beginning with establishing a small interdisciplinary team and following systematic project management stages from project initiation and establishing the particulars of the brief through to scoping and modelling or testing options for technical performance, suitability and affordability. It discusses in turn the issues of planning and design for a whole structure solution, following a fabric first approach to air tightness, insulation and reducing thermal bridging in advance of considering mechanical services and renewable energy. It introduces the idea of process innovation through the combination of systematic project management and off-site construction methods to respond to the requirements for quality control. It summarises the measures and metrics appropriate for a ‘simple’ retrofitting strategy that places the innovation emphasis on the project parameters, processes and phasing rather than any technical fix.

Integration and innovation: a whole house approach?

Responding to the global climate change agenda is part of the requirements and context in which we all build and learning from the climate context is something we have historically undertaken and that needs to be re understood[6]. As construction professionals we learn by doing and as such valid evidence-based design and planning has to emerge from reflective practice[7]. In response, this paper summarises some of these lessons learnt by academic and commercial development consortium members from their shared practical experience on TSB Retrofit for the Future projects.

Throughout this work there has been an interdisciplinary team approach that has been an important prerequisite for understanding the importance of ‘whole systems’ be they at the scale of sustainable homes or sustainable communities. This collective team experience, supported by facilitated learning and knowledge transfer, has highlighted the current inadequacies of many current tools and techniques when challenged with real world integrated knowledge and the application of research[8].

Social housing and retrofit

Around 30% of the UK housing stock is owned by Registered Providers [RPs] and local authorities with the majority of their tenants on lower incomes. RPs have strong incentives for an energy efficient stock:

> It is part of their mission to provide good quality accommodation with low running costs;
>
> Lower fuel bills reduce overall housing costs, so that rents are more affordable and fuel poverty reduced;
>
> A well maintained, efficient stock would last longer and be future proofed against fuel price rises;
>
> The refurbishment work can significantly increase the capital value of the property and thus the overall asset base of the RP to support further borrowing, investment and / or development;
>
> Energy costs are likely to become a significant factor in tenants’ choice of provider[9].

The quality of housing has historically been higher within the social sector for new construction[10] and in the approach to refurbishment and improvement standards. This is due in part to the ‘stick’ of regulation conmbined with the ‘carrot’ of financial and grant incentives from central government agencies. Previously, much of the improvement work for RPs homes has been under the ‘Decent Homes’ standard[11] with an emphasis on improvements to kitchens and bathrooms, adequate sound insulation from outside (using double glazing) and key structural and system components being in good order. There is one specific criterion, that

> *“(the dwelling) provides a reasonable degree of thermal comfort”, but only to a minimal extent; “For dwellings with gas/oil programmable heating, cavity wall insulation (if there are cavity*

> *walls that can be insulated effectively) or at least 50mm loft insulation (if there is loft space) is an effective package of insulation", and for heating systems with more expensive fuels "at least 200mm of loft insulation (if there is a loft) and cavity wall insulation (if there are cavity walls that can be insulated effectively)" (criterion D p18).*

This consideration is mainly about being able to achieve thermal comfort without excessive cost, not about energy efficiency, and the first package (i.e. set of measures) for gas/oil heating falls well below even a basic level of insulation by modern standards. However, Decent Homes work usually included a modern gas boiler and programmed control that simply due to the system efficiency, can save a lot of energy (around a third of gas consumption) if replacing an old system. Double-glazing was often also included, but mainly to replace poor windows, reduce maintenance (painting) and improve sound insulation and security, rather than for the energy benefits which are relatively small.

Alongside Decent Homes, many RPs have improved insulation levels on some of their stock to a much greater degree, mainly through improved loft, and some cavity wall, insulation. However, many properties have solid walls, or other constructions which cannot be cavity filled. Even if all the simple and relatively low cost measures were carried out, this would still leave a large gap between the RP stock and new build, or a retrofit standard delivering very large cuts in carbon emissions. RPs have effectively found themselves in the situation where they are encouraged in policy to seek large cuts in carbon emissions, implying radical retrofitting approaches, while being given limited financial incentives to upgrade their housing stock to a minimum level of performance that, while not being quantified in any meaningful way regarding energy and carbon emissions in use falls far short of the ambitious targets cited by national government. There has also been the unforeseen consequence of upgrading properties to a minimum level has potentially made it more difficult and costly to address further upgrading to achieve large scale cuts in carbon emissions, for example in the need to replace double glazing windows or oversized heat and hot water systems after only a few years of use.

The same is also partly true of the owner-occupied and private rented sectors, but RPs are in a generally better position to make improvements, with the economies of scale associated with large organisations and housing stocks and access to and understanding of grant funding, and working capital. Yet in the approach to refurbishment it is equally important to ensure phased work that achieves some benefits in carbon reduction doesn't prevent the larger scale cuts from happening.

It was recognised nationally that a step change in energy improvements would be needed to achieve large carbon reductions and much lower bills for householders across the whole RP housing stock. In order to explore the options available to social landlords, and to evaluate performance of any innovations 'on the ground', the Technology Strategy Board instigated the Retrofit for the Future' competition in 2009 to retrofit a cross-section of the UK social housing stock in order to meet future CO_2 emissions and energy use targets. This was fully funded over two stages; an initial design stage from which selected projects were taken forward to actual housing retrofit projects. 86 projects were completed, most being single houses but with some multiple dwelling projects. These aimed to achieve an overall carbon reduction of 80% in carbon emissions (the 2050 national target) although it was recognised that reductions would vary between projects around this figure.

The authors were associated with several first stage and three second stage retrofit projects that introduced a range of technical and procedural innovations. The key observations have been drawn from the following two projects that encompassed the use of innovative approaches to the use of off-site fabrication as well as integrated project management.

> Project Cottesmore in Leicester (figure 1) was the retrofitting of a small, late 19th Century back of pavement terrace with solid walls and rear extension. Work was based on high level of internal insulation for floors, walls that was complemented with high performance replacement windows and air-sealing throughout the property to a level that required mechanical

ventilation system. Hot water was provided by solar thermal panels linked to a thermal store and new efficient boiler. Novel heating controls and voltage regulation were installed as part of the package. Yet beyond some of these fairly standard and predictable measures there was also the intention to fabricate a new roof room using off site construction methods. One of the implications of a back-of-pavement property was the internal insulation work that had the effect of reducing usable internal floor area by between 10-15%. The proposed pre-fabricated roof pod was considered a means to compensate for this loss of space and maintain an adequate numbers of bedrooms and living areas required by future tenants, albeit the work was undertaken when the property was empty.

Walker Garden Suburb in the east end of Newcastle upon Tyne (figure 2) was a typical inter-war suburban house comprising a brick cavity construction with a floating floor and a cold roof and although it was unimproved by the Decent Homes programme (being selected as one of the least improved homes in the Council's social housing stock and thus work would be unlikely to make any recent improvement to the property redundant) it had a hybrid structure that included a solid floor in a 1980s rear extension. The retrofitting strategy was external structural cladding that included a new two-storey bay window module manufactured off-site (largely to address one of the worst areas of thermal bridging that was identified through the use of thermal imagery). The refurbishment was carried out with the tenants in situ for part of the work period.

Working on these projects at both design stage and in the delivery of solutions, it became clear that a purely technical approach was inadequate in practice. While all of the interventions comprised of building fabric and systems 'hardware' this was not significantly adding to the knowledge of the RPs and project partners and would not necessarily begin to address large scale cuts if the projects were to be scaled up to street, estate or neighbourhood scale. Our collective approach to innovation was to treat these projects as 'proof of concept ' approaches that would become relevant to large-scale refurbishment works. This was reflected in the ambitions of the TSB and in our own project briefs in factors such as speed of delivery, quality control, impact on sitting tenants etc.

While the TSB clearly pursued a range of projects to create a typology approach based on typical ages and forms of construction, we also understood the need to involve attempts to change behaviour through training, capacity building and incentives to the sitting tenant. In so doing, many of the technical evaluation tools became less predictive when many of the design and construction decisions taken involved non-technical issues.

Most significant aspect of this non-technical understanding of the project challenges and brief was the common theme in exploring the potential for off-site manufacturing for both projects in Leicester and Newcastle to speed delivery, ensure quality control, lessen impacts on tenants and reduce costs for multiple but bespoke fabric 'products' – all factors that become significant when thinking of rolling out the retrofitting at a larger scale. For example the roof pod in the Leicester property was the product of a number of interconnected antecedents; firstly the retrofitting of the archetypical building to virtually a zero carbon specification had led to the extensive use of 'bulky' internal insulation materials and corresponding reduction in room size and available space. Secondly, many of the tenants of the housing association had cultural requirements for two sitting rooms – male and female. This necessitated a significant redesign of the property with the roof pod innovation.

A final set of issues can also be raised relating to this vignette. The Retrofit for the Future programme was introduced to identify ways forward for the social housing sector in reducing the carbon footprint of its housing stock. The extent of the problem outlined above (i.e. retrofitting 4.5 million homes) is exacerbated when one considers that the majority of properties are occupied thereby either restricting what can be done, and how it is done, with householders in–situ or decamping residents with the associated practical and economic implications. A further feature of many social housing properties is that they are often pepper-potted throughout communities and, when this is the case, do not lend themselves to the economies of scale available to contiguous dwellings.

These issues were compounded by inadequacies in some of the assessment methods, discussed later. In short, what seemed at the start to be a largely technical and financial exercise (as is the case with simpler insulation measures), turned out to be much more complex and lacking an adequate framework for technological assessments. The scope for innovation was clearly in the process as much as in the technologies adopted. The next section will explore some of the potential areas for process (implementation) and product (fabric and technology) innovation within the retrofit process.

Products and processes: innovation in the energy domain

Each of the retrofit projects was managed around a generic and loose strategy[12] for refurbishment. This idea of a strategy is a consistent theme throughout the academic and practitioner literature[13] [ii], particularly when there are not straightforward building typologies, methods of construction, or socio-cultural conditions that are suitable for standardised responses. Underlying this strategy is a tacit hierarchy of interventions that includes a mix of 'hard' physical and 'soft' management interventions and assimilated practitioners' experiences[14] and arguments for following an integrated approach to design that links policy, metrics and construction[15] and highlights the potential for innovation at policy, practice and user levels. In reality, many case studies include a dominance of overtly technical interventions and solutions for household energy reduction. With few exceptions[iii] strategic advice has been targeted at the individual householder and thus properties rather than structures. Often these have been considered as technically separate building elements of wall, floors roofs and services designed to illustrate hierarchal and incremental technical solutions[iv], as they gradually become cost effective work[16] [v]. There are issues in trying to transpose this technical knowledge gained from the individual household into a strategy appropriate for a RP. The interconnections of the interventions and their 'social construction' by owners, trades and householders are often overlooked in this approach, as indeed is the dynamic nature of these constructions. While this paper argues for a reflective and whole house approach to low carbon retrofit the potential paradoxes arising from this emergent process also need to be taken into account. The 'Rebound Effect'[17] whereby the economic benefit of low carbon interventions can stimulate alternative, and higher carbon, activities provides one example of this.

Planning and Design

> *"A great deal of savings are to be had in prior modelling of refurbishment plans … (t)he planning stage is where a good investment of time should be made in order to minimise*

[ii] This example provides cost effective interventions and strategies at the scale of the individual building and introduces the structured procedural approach to retrofitting, from making the financial case, assessment, design, instillation, quality control and monitoring.

[iii] Some European examples of strategies for multi-occupancy and terraced properties are contained in; Richarz, C., Schulz, C. and Zeitler, F (2007) *Energy-Efficiency Upgrades* (Birkhäuser, Munich).

[iv] The most considered in the Energy Saving Trust's Enhanced Construction Details for a range of construction types including, cavity masonry, timber frame, metal frame and a range of ground floor and ceiling construction details.

[v] This was initially published in response to the fresh challenges for meeting the ambitious government targets for reducing carbon emissions, a policy shift that wasn't fully reflected in appropriate incentives for individual householders and occupants due the relative low cost of energy and corresponding long term payback periods.

mistakes and maximise savings in terms of value for money and value for carbon"[18].

It is difficult to underestimate the potential of process innovation and bringing a structured and systematic approach to overall project management at every stage of the project. Indeed, it may be the case that without some adequate level of 'holistic' and integrative project management many stages in the model project plan would not be included. A key observation from some of the retrofit project team members[19] was the uniqueness of the approach to project management, supporting initial tenant involvement, capacity building and training, project closure meetings and planned knowledge transfer within and outside of partner organisations.

There are clear benefits when representatives from the supply chain became active in design group working and started to understand the interaction and links between their building element(s) and the optimum operation of other elements of the fabric and / or services. There were examples in the relationship between the optimal operation of the mechanical ventilation and heat recovery (MVHR) system and airtightness levels, where in effect the supplier would have a significant input into the operation range for the filtration rate. In understanding the implications for an integrated air and vapour barrier and the scaling of requirements for solar thermal for hot water provision rather than space heating requirements, the suppliers began to appreciate the performance requirements of a super insulated property. This provides one example of how such an innovative and integrated approach requires technical specialists, and specific stakeholders, including residents, to understand the aims of the retrofit and be part of the overall design.

Co-design principles are invaluable where it is possible to work with the existing or proposed occupants. It has been rare for larger projects with imposed output parameters to allow much scope for occupants to become involved in setting design and project management requirements. In practice this has included levels of operational disturbance, structural change and the location of supply side elements of the energy system. It is also one of the factors most likely to become side-lined whenever there are budget restrictions, or ignored when no participatory metrics are included from the outset of the project.

Some incentives for involvement in demonstration projects have been provided to tenants or occupiers where these have additional benefits for overall energy reduction. These include, provision of more efficient electrical goods through to replacement decoration, where re-laid carpets, curtains and even lighting can all mark small contributions to filtration levels and energy consumption. There have been additional benefits for tenant involvement whenever there are unexpected results and additional or remedial work has been required. On a larger scale Electric Corby has included an electric car as an incentive to new householders in the town's extensive development[vi].

Whole house and fabric first solutions

Whole development solutions are consistently recommended due to a mix of cost benefits, the technical difficulties of phased works over a long term and sub optimal and / or unpredictable impacts elsewhere within the system. At the scale of the individual property, this would be considered a 'whole house' solution that integrates improvement to the fabric and the services. The holistic approach would have different implications as scale increases. The difficulties in scaling up a whole house solution and strategy are multiple. For example, there are issues of dealing with terraced housing and multiple owners and forms of tenure and single owners, such as housing associations may also have portfolios that are pepper potted and geographically highly dispersed. These factors, combined with hybrid or mixed methods of construction, cultural and demographic differences among householders, difficulties in understanding thermal store values of existing materials and the lack of purpose-specific

[vi] http://www.moreincorby.co.uk/live/happening-place/electric-corby (accessed 16/04/2012)

modelling tools all question the wisdom of generic approaches that do not account for contextual variability.

The limited literature on retrofitting through whole house solutions emerges from an understanding of the wider policy context including the interrelated issues of climate change, peak oil and growing levels of fuel poverty. The subtext recognises the inherent sustainability around the adaptation of the existing housing stock within the UK, not least as much of this stock has better connections and locations and makes use of the existing infrastructure in a way that is not always available for new developments.

> *"The combined occupation of old houses, combined with performance improvement measures, is the most energy-efficient form of property development."*[20]

This is separate to a targeted consideration of the high levels of embodied energy within the fabric. As such, the understanding of whole house solutions does include a justification based on site, location, facilities and many other factors that potentially impact on sustainability outside of the control of the individual household.

In this context it is difficult to generalise around the challenges for older properties, however the common strategies still highlight the initial problems with the fabric [poor insulation and glazing, poor air-tightness / draught-proofing] and corresponding problems with the heating system [predominantly these are oversized and inefficient when examined alongside any changes and / or improvements to the building fabric]. Practical advice varies for different ages of property but the overall strategy remains fairly constant, namely fabric first improvements to increase insulation levels[vii], followed by the performance of targeted building components such as windows (using secondary glazing insulating blinds where necessary to work[viii]) followed by efficiency improvements to heating systems and levels of control for the occupant, including better management of the existing systems.

One of the peculiarities of many older properties has been the incremental approach to upgrades and improvements, very often as a result of changes in use and sub division into smaller residential units and including the considerable work undertaken as part of the 'Decent Homes' Programme. The outcome of this is a very complex range of property typologies based on original structure and subsequent alterations. The internal spatial standards and dimensions have to be considered, for example with temperature stratification caused by greater floor to ceiling heights. Selection and sizing of any heating system will need to have regard to such internal specifications and variations. We found this was where many technical decision support tools and energy modelling software packages couldn't adequately address the 'best-guess' approach to retrofitting complex hybrid structure.

In our experience it was useful to draw lessons from the original design strategy for the property being treated and to think about subsequent repair and replacement strategies as much as the actual retrofitting. For example, many of the concerns about internal thermal comfort had been treated as part of the original design features. One consideration of this was in the use of internal shutters that can be controlled by the occupants and insulated to form part of low impact improvements. How integral features such as shutters compare to more contemporary solar blinds and whether these can or should be considered in any u-value calculations for windows. A further example was in the

---

vii Including consideration of 'breathable' hygroscopic insulation materials such as sheep's wool. Useful to note that significant improvements to air tightness can be achieved in older properties even with the need to maintain a breathable building skin where air tightness testing allows for diagnostic approach to problem and / or leaky areas within the property.

viii Further details regarding older properties and the use and optimal performance gap of 20mm of secondary glazing is published by English Heritage.

expectation of solid wall construction using the existing stone / brick wall[21] as a thermal store that would impact on any decisions to follow an external 'warm wall' insulating solutions[22] and the risk of interstitial condensation and more rapid heating and cooling.

Airtightness

There is a lack of comparative figures for the air tightness of existing housing stock, but a recent study[23] [ix] of a range of 100 new dwellings shows a broad range, including a significant percentage of new build failing building regulations. This is in spite of airtightness being the first step in low and zero carbon dwellings and in the reduction of energy demand. Guidance[24] in this area has been provided both to overcome some of the perceptions around high levels of air tightness; that it creates stuffy or sick buildings, and to show that the costs are negligible in the light of potential energy savings of up to 40%[25] for commercial buildings. Detailed technical guides use tried and tested alternatives to standard details that are targeted at the most common means of air leakage within buildings, repeating the distinction between planned air changes and unplanned air leakage. Measurement or estimate of heat loss due to infiltration has remained constant but has become an increasing proportion of the overall loss due to improvements in insulation levels in new and existing buildings[26] [x].

Understanding the necessary levels for air tightness for new buildings is a statutory requirement / and has implications for the specification and sizing of heating systems, to the point of setting targets for air tightness for the optimal operation of MVHR systems specified[27] [xi]. There are mixed arguments around the use of off-site MMC systems to achieve the appropriate levels of airtightness as a result of improvements in quality control that can be achieved within a factory setting when the aspirations to achieve *Passiv Haus* or the higher levels in the *Code for Sustainable Homes*. European and particularly German examples of both new build and retrofit have been able to achieve *Passiv Haus* standards of air tightness without any improvement or remedial work with an integrated air barrier – achieved through better build quality using traditional brick and block construction. This suggests that one means of achieving air tightness is through improvements in skills and training. Accordingly, part of the procedural steps included in any skills training is the diagnostic approach to continuous testing on site. For the *Retrofit for the Future* projects[28] this proved necessary to achieve the required levels of air tightness, due to a mix of conflicting advice from different suppliers, partial knowledge (knowing exactly where the air paths and leaks were), joining the ground floor membrane with the external barrier, and the difficulties of treating the connecting properties.

Airtightness as an indicator of cultural change

Core concepts in energy efficient dwellings such as air tightness were often not part of the 'language' of the RP estates managers or the project manager for the contractors or, as a result, the experience of their on-site workforce.

> *"I never thought of, or understood the relevance of, air tightness before, but now we will carry out tests on all our properties. … Initially the lads got fed up with me, e.g. over air tightness; but after time they got it and became obsessive themselves"*[29]

The acceptance and understanding of air tightness, or the receptivity to it[30], provides one example of

---

[ix] This study identifies the most common leaks and was consistent with the report on our TSB project properties.

[x] This can range from 35% - 50% for some building types.

[xi] There are demonstrable benefits form MVHR systems presented as supplier information in addition to independent technical reports.

a cultural change that is necessary at each stage of the retrofit process for the policy maker, supplier, property owner, on-site trades and householder. The mechanism for communicating this insight, and the message developed to do so, will obviously need to be tailored to the relevant audience[31] [32]. It was recognized within the projects that ‘new’ concepts needed to be communicated before they could be incorporated into a new ‘culture’ of working.

The existing culture did not relate necessarily to bad practice e.g. the production of waste on site, but to the changing of ‘habitual’ good practice. For example an insulation membrane, skirt, was trimmed to size rather than leave the excess to enable an airtight corner joint; also the properties of the materials were not clearly understood e.g. avoiding piercing or cutting into insulation panels. These knowledge issues i.e. understanding what is meant by low carbon intervention, and the skills necessary for achieving that aim, were considered to be the main reason for the Leicester project over-running in time and budget.

Insulation strategy

Much of the detail for appropriate insulation is subject to technical suitability and the sourcing of products. Ideally this should be based on a ‘whole structure’ (property, semi or terrace) approach in preference to looking at individual building elements being sequentially treated. One reason is the ability of an insulation strategy to provide appropriate levels of air tightness. An integrated approach (comprising insulation with vapour and air barrier) is normally optimal as the performance of the insulation layer is co-dependent on air tightness and the avoidance of any air gaps[33] although it is recognised that this is not always possible or desirable[34] [xii].

A ‘keep it simple’ insulation strategy may have some interesting implications that are counterintuitive. For example when the external and cavity wall insulation (more secure from occupier impact / damage) is installed before internal insulation, the risk of interstitial condensation can arise. Yet cavity wall insulation tends to settle and degrade in performance over time, and is seldom of sufficient thickness on its own to achieve high performance retrofitting and will not provide an adequate airtight barrier. External insulation systems have proven difficult for roofing (warm roof solutions) due to the thickness of insulation required, and are particularly problematic for terraced housing. Further difficulties emerge from considering separate ownership solutions rather than through the generation of innovative separate ‘whole house’ or structure solutions that may well require extensive negotiation and varied funding arrangements.

Yet keeping things simple isn’t always possible. Some simple approaches, to raising the floor levels with solid insulation board or similar, will have a knock on impact for doors and stairs. There are key design features that exist throughout the existing housing stock that create particular concerns for maintaining a simple insulation strategy. Widely used traditional features such as frontage bays, dormer windows and extensions (being the most common form of hybrid structures with mixed floor and wall constructions) will require considered approaches to the edging detailing, joining of elements and the impact of thermal bridging. Project experience suggests the use of a single strategy to dealing with hybrid elements; such as mixed floor construction; with the choice being made as much around lack of householder disturbance and lower cost as improvements to the insulation. Potential scalability has been less of a practical concern on most projects when faced with mixed construction elements.

There have also been instances where required products, such as service hatches and loft doors, have been unavailable at the required performance specification. Design responses have included the construction of bespoke elements with the use of local trades (in effect adding some additional skills

---

[xii] This provides some advice on technical and aesthetic issues together with discussion around issues of extension, adaptation and the creation of hybrid constructions.

training but limiting any potential for scaling up) to compromise on the level of performance specification based on knowledge of available products. This is in contrast to the wider availability of high performance windows and doors, where the temptation has been to ‘over-specify’ to get the best available product to compensate for potential under performance in other elements above. Similar dilemmas have occurred whenever new products; such as vacuum insulation, voltage regulators and reflector blinds; that remain untested and unproven over time have been used in response to the requirements for innovation in exemplar projects but would be unlikely to be used more widely until evidence of performance becomes available.

A related consideration is the need to take account of the lifestyle and knowledge of the householder, exemplified by the ‘cat flap paradox’ - the failure to consider lifestyle issues such as pet ownership and correspondingly to introduce well-insulated and air-tight cat flaps could lead to their subsequent, and inappropriate, introduction by the householder and the potential undermining of the overall project. Similarly the roof pod that was introduced into the Leicester house highlighted a number of relevant cultural issues; both in terms of the need of some householders for an extra living room as discussed above and in terms of the approach to construction within the project team.

Thermal bridging strategy

One outcome of the planning stage is the identification of real and suspected areas of thermal bridging within the structure; these will have a disproportionate impact on the heat loss as the overall structure becomes better insulated. Inevitably, some of these can be treated and some cannot, or not without radical intervention into the fabric of the structure. An extensive range of archetypical structures have been considered and modelled as part of the Energy Saving Trust’s Enhanced Construction Details. Modelling tools, such as THERM (Two-dimensional building Heat transfer Modelling) can support the exploration of options to address problem areas.

Addressing some of the failing elements within existing structures has been an additional potential area for the use of MMC systems and ‘products’ addressing some of the more common problems area regarding thermal bridging. Difficulties and potential benefits will arise from add-on products that form part of the strategy for external insulation and air tightness, most directly due to issues of contiguity and separate ownerships within single structures (or contiguous elements of larger structures such as continuous roofing on terraces).

Innovation and culture: the use of off-site construction methods

The need for an additional room in the roof of the Leicester property brought to the fore a cultural difference between those project members with a background in manufacturing and those with one in construction – acceptable tolerances were far lower for the former who were keen to adopt an off-site approach to retrofit than for the latter who felt that the only practical way to deal with the ‘variability’ within buildings was to undertake the work on-site. An offsite solution was decided upon; this was in large part due to confidence in the existence of manufacturers who would be able to produce a bespoke roof pod. Confidence on the preferred strategy of using off-site construction was gained from another exemplar project - the prototype SOLTAG “sun roof”[35], a prefabricated roof refurbishment solution funded through the European Commission’s 6th Framework in partnership with Velux. However, this confidence was ultimately misplaced and it was only through the pursuit of a network of acquaintances that a small business was identified that could, and would, develop the product.

> *“We were impressed with them (the small scale off-site company), even if they built it in a shed. Their enthusiasm and knowledge re-invigorated the project; can do attitude. Before this we had nothing – build from scratch, no pod or them. … I did not believe the tolerances could be achieved – using a plumb line, in the hot loft for four hours – rafters out by 1.5 degrees on four metres – very impressive and confidence revived – albeit with some subsequent*

problems. It was a mad rush.'[36]

The use of a plumb line to measure up the pod highlighted another innovation paradox in which a 'state of the art' intervention, the introduction of the off-site fabricated roof pod, was facilitated though the adoption of traditional techniques and expertise. The take up of this approach will however inevitably be accompanied by the adoption of equivalent innovations in measurement and manufacturing.

In the Newcastle property, the challenges for off-site construction initially appeared easier. The identification of the north-facing bay window as a major area of heat loss (thermal bridging due to a mix of poor detailing and construction of the initial bay window) was something common with the remainder of the properties in the same estate that were also undergoing refurbishment and that had to be addressed. Yet the challenge was to find a solution that met the technical performance characteristics but that would also be installed while the property was still occupied[xiii].

The strategy was to oversize the bay to fit around the existing structure, allowing new foundations to be constructed in advance. Tolerances in joining details and the use of an adjustable internal floor level (necessary as the bay had to tie into existing ground and first floor structures) were anticipated as was the approach for delivery and instillation. In practice, the demolition of the existing and replacement with the off-site manufactured bay was carried out in less than a day, with the actual installation of the bay requiring 30minutes.

Services, renewables and quality control

Retrofit projects require an integrated fuel strategy based on the performance of the fabric, the benefits of passive design (solar heating, day lighting, ventilation and cooling as required) and any requirements for renewable energy. Energy solutions are best achieved by following such a strategy that integrates systems into structure and fabric at the earliest stage within any design process[37]. This has been most evident in the use of MVHR systems that not only require low filtration rates but also appropriate installation to be optimal in operation, with some concerns over the energy requirements for the operation of an MVHR system (generally with electric power) set against the potential savings. Often the optimal layout[xiv] is impossible to achieve within a retrofit as it can be limited by the layout of joists, the position of load-bearing walls and compromise locations have to be achieved for the positions of vents.

Some significant work is emerging that looks at the potential use of renewable energy as part of a fabric first retrofitting solution[38]. Appropriate solutions will be dependent on the scale of intervention[39], and thus ownership and control. Many larger solutions will remain within the remit of the local authority or large RP's (the Leicester RP has over fifteen thousand dwellings and the Newcastle ALMO manages over thirty thousand properties for their City Council) that are able to use a mix of statutory powers[40] and incentives to achieve significant carbon savings[xv].

[xiii] In reality the project undertook similar work on the pair of semi-detached properties as a whole house solution. One family remained occupied during the construction period while one family was rehoused for a five-week period.

[xiv] Building Regulations Part F for ventilation as they relate to the design of new build developments, albeit there is some confusion over conflicting standards and best practice guidance for MVHR systems at present.

[xv] Monitored results of several community scale networks and systems are available for download from http://www.concerto-sesac.eu/IMG/pdf/SESAC_Innovative_Sustainable_Construction.pdf (accessed 10/11/11)

To date, the policy focus for fiscal incentives and initiatives has been on individual properties; these include, Feed-in Tariffs (FITs), Renewable Heat Incentive (targeted at small scale energy generation below 5Mw) and the Green Deal for householder energy efficiency improvements. Yet some commentators[41] have argued that many renewable systems cannot be scaled down to meet the reduced demand of smaller households, rather than thinking about larger shared or community systems.

We have seen that appropriate skills and technical understanding within contractors and smaller sub-contractors has been a constant requirement in order to meet the performance standards set. Some resources have been produced at a local level[42] to begin this accreditation process but any significant approach will require some sort of organisational infrastructure and supporting partner organisations. Part of such training has to be an awareness of the interconnected elements of the separate systems and the relationship between building fabric and services. There is potential overlap in useful training material and the range of product specification included in maintenance guide and building-user manual. Training would need to be targeted at both professionals involved in installing and maintaining systems.

Post occupancy monitoring and management

> *"Of the environmental renovations that have been evaluated, on average they perform thermally only half as well as predicted. This could be because of poor installation, occupant behaviour or failure of the materials. … (u)ntil (the Retrofit for the Future) results are in, we are dealing with probabilities only"[43].*

When there are significant discrepancies between energy performance between design stages and in practice, there is a clear argument for undertaking post-occupation[44] evaluation, highlighting the significant differences within the limited body of published work between predicted / modelled data and actual results. Advice ranges from a common systematic approach to post completion evaluation[45] ensuring the beneficial use of performance measures and metrics, a closer understanding of occupant behaviour on technical performance[46], through to more ambitious examples of a full 'belt and braces' approach to technical and post occupancy monitoring[47] to inform ongoing management.

Retrofitting confusion

Having looked at various areas of product and process innovation within the retrofit process we will now briefly consider these in the context of performance metrics for future projects. In setting out any initial project brief that relates to sustainability there has to be an acknowledgement over the confusion around standards and references. Sustainability has been described as a "… monstrously ill-defined, abstract concept (that) is likely to be masking the incompetent application of some half-formed idea vaguely related to the use of resources"[48].

A recent review of the academic and practitioner literature identified over 600 sustainability and environmental assessment tools, each with their own definition and means of validation[49] and a more in-depth evaluation has also been undertaken by the Building Research Establishment (BRE)[50] of the common criteria used within the most significant and recognisable planning and building relevant tools.

In response to this confusion, at a policy level, efforts have been made to provide a 'common language' for the scope of sustainability informed by the guiding principles for sustainable development policy in the UK[51] and structured on the components of sustainable communities[52] as defined in the Egan Report. Yet even with this 'common language' this policy debate appears to be occurring somewhat independently from technical discussions.

The current state of the policy discussion[53] [xvi] for buildings relates to the scope of sustainability and the most appropriate measurement for energy efficiency for the performance of the fabric and services and whether it should include a mandated benchmark. Often where it exists or has been suggested this absolute measure has been determined as a direct result of some form of cost benefit analysis and calculated pay-back period for the cost per tonne of carbon saved. Even at the supposedly more precise technical levels of development there are ever-changing definitions of zero carbon[54] [xvii] and many local variations regarding the precise interpretation of on-site / near-site renewable energy provision and the nature of any exceptions. Confusion is particularly apt as the scale of thinking increases alongside its complexity and the assessment (and assessor) of the project moves from building regulations into the realm of statutory planning.

In this context, it is useful to remember that the *Code for Sustainable Homes*[55] (CSH) was initially introduced as an integrated standard for sustainability, deliberately going beyond a simple measure of energy efficiency to embrace other physical resources and softer issues such as health and well-being within a quasi-statutory definition of sustainable housing[56]. The CSH also has the significance of requiring a structured approach to project management and the formal integration of a registered assessor and experience suggests that this ideally occurs early within a process and includes work within the supporting supply chain[57]. Yet measurement of even the softest aspects of sustainability included in the *CSH* relies upon hard metrics[58] and the statutory regulations still require certification[xviii] for individual homes rather than developments.

Discussion: Metrics and assessment; towards integration?

Within the retrofit field of study the most common metrics used are those that are measurable and quantifiable, and thus have a significant bias towards substantive measures relating to absolute energy usage, carbon emissions and the relationship with the cost per tonne of carbon saved. Often these are straightforward specifications and design parameters[xix] and typically they include shared metrics that are applicable to both new build and retrofit projects[xx]. More technical metrics and measurement tools suitable for use within a detailed design, specification and construction stages of a

---

[xvi] This study suggests that a carbon reduction trajectory should relate to percentage improvements above the minimum building regulations and with a lead being given by government and the public sector for their extensive building stock.

[xvii] The UK Green Buildings Council (UKGB) Task Group Report “Definition of Zero Carbon” proposes a more flexible definition of zero carbon homes than the one used for the current code level 6 of the Code for Sustainable Homes. Some local planning authorities also make distinctions between no-site and near-site provision while others will consider viability of technology as a reason for exceptions to be made or for financial contributions towards a municipal / district heating and energy system to be equal to carbon reduction through renewable energy provision.

[xviii] Statutory regulations as established in the *Housing and Regeneration Act 2008*. Available for download at http://www.legislation.gov.uk/ukpga/2008/17/contents Under section 279 the Act requires “A person who is selling a residential property as a new property must supply the purchaser with [a] a sustainability certificate, or [b] a written statement to the effect that there is no sustainability certificate for the property”.

[xix] Design parameters used within many of the decision support tools include; u-values; air permeability; thermal bridging; product specification; space standards; output from renewable energy provision.

[xx] Examples of ‘shared’ performance output metrics include; primary energy use; percentage improvement in SAP rating; CO_2 savings.

project exist for new buildings[59]. Many of these metrics have been transferred directly into performance standards, with the most relevant and significant being the *Passiv Haus*[60].

Yet in practice whether they can be met is less of a technical question and more one of cost, desirability and social impact. Many of the economic considerations are already central to policy responses. Typically these have been the cost of the retrofitting measures (estimated and actual total property cost and cost per measures[xxi] and per m^2 including the additional cost per m^2 above mandatory minimum building regulations) and how this relates to the cost per tonne of carbon dioxide saved; savings on fuel bills with corresponding benefits on the levels of fuel poverty and affordable warmth[61]; the estimated payback period informed by assumptions for energy pricing and decarbonising of the national supply network[62] [xxii].

We would advocate that within any integrated design strategy the range of technical measures has to be balanced and traded against a number of qualitative and procedural measures. These following metrics are suggested as 'project indicators' appropriate for retrofitting, allowing a degree of flexibility, and innovation, within the design and construction process to examine different options for achieving specific outcomes.

Qualitative metrics used to complement technical measures;

- Occupant strategy and feedback [achieved through post-completion questionnaire] with particular reference to thermal comfort levels;
- Internal air quality for carbon dioxide, humidity and odours;
- Level of occupant disturbance and impact [comparative level of disturbance caused with alternative choices or selection of systems];
- Speed of on-site construction;
- Inclusion of housing health indicators including those that are dependent upon occupant behaviour[63];
- Household carbon foot-printing [overall lifestyle change due in part to project involvement, training provision and building-user guide];
- Future-proofing, including level and ease of maintenance [maintenance requirements as set out within building-user guide].

At a more strategic scale, policy measurements begin to impact on business planning and national government indicators such as (1) reduction of carbon emissions from domestic sources, (2) reduction of fuel poverty; (3) development of the regional low carbon economy (mix of new / retained jobs, skills and innovation). It may be prudent to anticipate that each of these would need to be quantified as part of any approach to scaling up.

Where possible these measure (estimated or actual) have been broken down into individual interventions to the fabric and / or additions to the services and have been recorded per project, individual dwelling and per m^2. Yet many measures are interdependent and subject to more 'messy' influences such as underlying assumptions in energy costs, comparison against a base or control property, the use of estimates due to lack of historic and / or current data and are framed by a variety of different energy modelling approaches which have different underlying assumptions, emphasise

---

[xxi] Some sample figures that includes comparison with operating costs at www.cepheus.de (accessed 10/11/11)

[xxii] This report provides cost benefits of range of individual and phased measures.

different property elements and thus produce different results.

Discussions over the comparative strengths and weakness of SAP (Standard Assessment Procedure) and PHPP (Passive House Planning Package) models as the best known and well used software assessment packages suggest the while the most accurate model is PHPP[64] it is also the most laborious and detailed and often inappropriate for modelling at outline stages for larger design projects. While there is some suggestion that higher *CSH* levels based on SAP don't necessarily result in reduced carbon emissions[65], there is also a debate present within the commercial literature and trade press as to whether PHPP; as a fabric based modelling package; is suitable for retrofit projects, being initially designed for new build and thus relative simpler non-hybrid projects[xxiii]. Some suggest it has been shown to be accurate for renovations when it is used "… to weigh up the pros and cons of different strategies"[66] in effect becoming an experimental rather than predictive tool. In practice there is still a fall back position to action undertaken based on a strategy, or in some cases instinct about the most appropriate action or detail. The design process therefore needs to retain the tacit knowledge of a broad and integrated team including the building user as possibly the most insightful about potential energy requirements.

In line with an emphasis on new construction for tools and techniques, there is a focus on the minutiae of definitions for new sustainable construction. We would argue that in comparison there is a significant 'gap' in metrics that have been identified with regard to retrofitting requirements – delayed because they are largely non-statutory and unenforceable[67]. Some comparative work on the impact of renovation to new build energy efficiency standards[68] [xxiv] exists; including qualitative impacts[69] and some assessment of cost per tonne of carbon saved and integration within future management of the property[70] [xxv]; and practical examples are becoming more widely disseminated with examples for different structures[71] and clients[72].

Many reviews of sustainable construction projects highlight the significance of occupation on the actual versus the modelled whole house energy consumption[73] [xxvi] and the importance of understanding the occupancy strategy[74] [xxvii]and monitoring of behaviour change alongside the hard energy consumption levels[75] [xxviii]. This remains the forgotten elements of many schemes, yet critical within retrofit schemes that remain dominated by technically driven briefs.

The suggested means of overcoming many of these concerns is to extend the scope of the project and use the multiple metrics within estimated ranges drawing from several available software packages as opposed to absolutes, all using the worst case scenario for property default.

[xxiii] There are also connections with affordability and comparisons between new build and refurbishment standards to CEPHUS [Cost Efficient Passive Houses as European Standards].

[xxiv] The report provides estimates from a sampled set of six properties.

[xxv] Case study evidence of Retrofitting 17 St Augustine's Road, Camden provides outline figures for cost per tonne of carbon saved were solar pv cells £17,860 solar thermal £16,000, windows £18,460, roof insulation £1,940, wall insulation £3,330; albeit these were not assessed incrementally.

[xxvi] This report shows the 'disappointing' differences as-designed and as-constructed performance of Elm Tree Mews York in the context of other studies and the regulatory trajectory to zero carbon.

[xxvii] This references two well established and large scale Passiv Haus developments [22 homes at Wiesdaben constructed in 1997 and 32 terraced units at Kronsberg constructed in 1998] where the average recorded energy consumption within the development was below the 15 kWh/[m2a].

[xxviii] This report on the BedZed development includes comparative electricity and heating consumption according to tenure and house type and compared to modeled / predicted consumption.

Conclusions

In common with many areas of planning policy and construction practice, retrofitting social housing appears to have an 'implementation gap' where policies and fiscal incentives are often separate from lessons learned through practice. If there is any consistency across national and local policies regarding retrofitting, the considerations are fixed on the role of technical innovations to lead the reduction in carbon emissions. This focus is reflected in the shared technical performance and economic metrics for both new build and retrofitting that are often mandated and continue to define requirements and outcomes for many social housing projects.

Yet the 'implementation gap' has the potential to be filled by taking a bespoke approach to project metrics that firstly integrates a broader scope of social impacts and outcomes, most significantly regarding the involvement and benefits for existing and future tenants, the level of disturbance created by capital works, the speed of delivery, guarantee of quality control to meet design expectations, and secondly follows a simplicity in approach that is reflected in the ease of long-term management and maintenance of any new systems. Mixed and multiple project metrics that are able to integrate fiscal, social and qualitative measures with some of the more technical and physical requirements begin to allow the appropriate trade-offs between costs, performance and social impacts.

In this context of process innovation supported by procedural and management measures, we have found that the use of off-site construction techniques (both timber and metal frame products) have measurable benefits in speed of delivery, reduction of impact and assurances on quality, particularly regarding air tightness and addressing traditional build areas of thermal bridging. Modern methods of retrofitting also have the potential to deliver on many of the cost saving metrics if and when the UK has a large scale retrofitting programmes to follow similar *Passiv Haus* principles.

References

[1] Thorpe, D (2010) *Sustainable Home Refurbishment: The Earthscan Expert Guide to Retrofitting Homes for Efficiency* (Earthscan, London) p 94.

[2] DECC (2012) *Statistical Release 2010, UK Greenhouse Gas Emissions, Final Figures* http://www.decc.gov.uk/assets/decc/11/stats/climate-change/4282-statistical-release-2010-uk-greenhouse-gas-emissi.pdf (accessed 18/04/12).

[3] Power, A (2008) Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability? *Energy Policy*, pp 4487-4501.

[4] Wright, A (2008) 'What is the relationship between built form and energy use in dwellings?' *Energy Policy* 36 pp 4544-4547.

[5] DECC (2011) *Annual Report On fuel Poverty statistics* http://www.decc.gov.uk/assets/decc/Statistics/fuelpoverty/2181-annual-report-fuel-poverty-stats-2011.pdf (accessed 20/04/12)

[6] Roaf, S., Crichton, D. and Nicol, F (2005) *Adapting buildings and cities for climate change; a 21st century survival guide* (Elsevier, Oxford).

[7] Krizek, K., Forysth, A. and Slotterback, C (2009) 'Is there a role for Evidence-Based Practice in Urban Planning and Policy?' *Planning Theory and Practice* 10(4) pp 459-478.

[8] BIS (January 2010) *Going for Growth: Our Future Prosperity* http://webarchive.nationalarchives.gov.uk/+/http://www.bis.gov.uk/wp-content/uploads/2010/01/GoingForGrowth.pdf (accessed 20/04/12).

[9] Personal communication – RP, Head of Asset Management, 2011.

[10] HCA and CABE (April 2009) *Affordable Housing Survey: A review of the quality of affordable housing in England* (Homes and Communities Agency, London).

[11] DCLG (2006) '*A Decent Home: Definition and guidance for implementation– Update'*, June http://www.communities.gov.uk/documents/housing/pdf/138355.pdf (accessed 20/04/12).

[12] Lowe, R (2007) 'Technical options and strategies for decarbonizing UK housing', *Building Research & Information* 35(4) pp 412 – 425.

[13] Clark, W (1997) *Retrofitting for Energy Conservation: Source Book for Energy Conservation Design* (McGraw Hill, New York).

[14] Honour, J (October 2010) *Sustainable Housing Refurbishment: An Update on Current Guidance and Sources of Information* BRE Information Paper IP 18/10 (BRE Press, Watford).

[15] Rovers, R (2008) *Sustainable Housing Projects: Implementing a Conceptual Approach* (Techne Press, Amsterdam).

[16] Smith, Peter F (2004) *Eco-Refurbishment: A Practical Guide to Creating an Energy Efficient Home* (Architectural Press, Oxford).

[17] UKERC (2007) 'The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency' http://www.ukerc.ac.uk/Downloads/PDF/07/0710ReboundEffect/0710ReboundEffectReport.pdf (accessed 12/04/12).

[18] p8 in; Thorpe, David (2010) *Sustainable Home Refurbishment: The Earthscan Expert Guide to Retrofitting Homes for Efficiency* (Earthscan, London).

[19] Comments in record from Notes from Walker Garden Suburb Retrofit for the Future Project Closure Meeting, Live Theatre, Newcastle 1st November 2010.

20 p16 in; Cook, Martin Godfrey (2009) *Energy Efficiency in Old Houses* (Crowood Press, Marlborough).

[21] Energy Saving Trust (2006) *Practical refurbishment of solid walled houses. CE 184* (Energy Saving Trust, London).

[22] Energy Saving Trust (2005) *Advanced insulation in housing refurbishment. CE 97* (Energy Saving Trust, London).

[23] Energy Saving Trust (Revised October 2005) *Improving airtightness in dwellings: GPG224* (Energy Saving Trust, London).

[24] Morgan, Chris (2006) *Design and Detailing for Airtightness: SEDA Design Guides for Scotland No. 2* Report by SEDA (Scottish Ecological Design Association) for Architecture and Design Scotland http://www.seda.uk.net/assets/files/guides/dfa.pdf (accessed 10/11/11)

[25] p3 in; BRE (2002) *Airtightness in Commercial and Public Buildings* (BRE, Watford).

[26] Jennings, P (2001) 'Airtightness in buildings'. *Buildings for a Future* Winter.

[27] AECB (January 2009) *Comparing energy use and CO_2 emissions from natural ventilation and MVHR in a Passivhaus house A CarbonLite Information Paper* (AECB, Llandysul). http://www.aecb.net/PDFs/9Jan2009_MVHR_Final-2.pdf (accessed 10/11/11)

[28] Notes from Walker Garden Suburb Retrofit for the Future *Project Closure Meeting*, Live Theatre, Newcastle 1st November 2010.

---

[29] Project review records, Property Manager for the Leicester Retrofit RP 2011.

[30] Jeffrey P, Seaton R (2004) 'A Conceptual Model of Receptivity Applied to the Design and Deployment of Water Policy Mechanisms'. *Environmental Sciences* 1 (3) pp 277 – 300.

[31] Stubbs, M. Lemon, M and Longhurst, P (2000) 'Intelligent Urban Management: Learning to Manage and Managing to Learn, Together for a Change'. *Urban Studies* 37 (10), pp 1801-1811.

[32] Stubbs, M. and Lemon, M. (2001) 'Learning to Network and Networking to Learn: Facilitating the Process of Adaptive Management in a Local Response to the UK's Air Quality Strategy', *Environmental Management* 27 (8) pp 321-334.

[33] Künzel, H., Künzel, H,.and Sedlbauer, M (2006) 'Long-term performance of external thermal insulation systems', *Architectura* 5(1) pp 11-24.

[34] Pickles, D. Brocklebank, I and Wood, C (November 2010) Energy Efficiency and Historic Buildings: Application of part L of the Building Regulations to historic and traditionally constructed buildings (English Heritage, London).

[35] Guzowski, M (2010) *Towards Zero Energy Architecture: New Solar Design* (Laurence King, London).

[36] Project review records, Property Manager for the Leicester Retrofit RP 2011.

[37] Daniels, K and Hamann, R (2009) *Energy Design for Tomorrow* (Gazelle, Lancaster).

[38] Mambo, Abdulhameed Danjuma (2011) *Zero Carbon Emission in UK's Domestic Buildings: The Potentials of Onsite Renewables and Retrofitting* (VDM Verlag, Saarbrücken).

[39] TCPA, CHPA and LDA Design (November 2010) *Community Energy: Planning, Development and Delivery* (London Development Agency, London). www.lda-design.co.uk/downloads/Comm_Energy_PlanDevDel.pdf (accessed 10/11/11)

[40] Planning Advisory Service (June 2011) *Taking the Lead on Energy Issues* (PAS, London). www.pas.gov.uk/pas/core/page.do?pageId=29433800 (accessed 10/11/11)

[41] Schuetze, Chris (2011) 'Home Advantage'. *CIBSE Journal* 3(9) p18.

[42] Schlichtmann, Gabi and Sievers Hermann (Eds.) (2007) *Short Trainings on Quality Assurance: Work sheet for implementing short trainings on quality assurance for craftsmen and skilled workers in the field of energy recovering building refurbishment* (target GmbH, Hannover).

[43] p2 in; Thorpe, D (2010) *Sustainable Home Refurbishment: The Earthscan Expert Guide to Retrofitting Homes for Efficiency* (Earthscan, London).

[44] Gupta;Rajat and Chandiwala, Smita (2010) 'Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments'. *Building Research & Information* 1466-4321 38(5) pp530 – 548.

[45] Way, Mark and Leaman, Adrian (2009) *The Soft Landings Framework for better briefing, design. handover and building performance in-use. Report for BSRIA and the Usable Buildings Trust.* www.softlandings.org.uk (accessed 10/11/11)

[46] Stevenson, Fionn and Rijal Hom B (2010) 'Developing occupancy feedback from a prototype to improve housing production'. *Building Research & Information* 1466-4321 38(5) pp 549 – 563. Gill; Zachary M; Tierney, Michael J; Pegg Ian M and Allan Neil (2010) 'Low-energy dwellings: the contribution of behaviours to actual performance'. *Building Research & Information* 1466-4321 38(5) pp 491 – 508.

[47] Homes and Communities Agency and Oxford Brookes University (2010) *Monitoring Guide for Carbon Emissions, Energy and Water Use: The Carbon Challenge: developing an environmental evaluation of housing performance in new communities* (Homes and Communities Agency, London). Available from http://www.homesandcommunities.co.uk/carbon_challenge (accessed 10/11/11)

[48] p17 in; Campbell, Kelvin (2011) *Massive Small: The Operating Programme for Smart Urbanism* (Urban Exchange, London).

[49] Karol, Elizabeth and Brunner, Julie (2009) 'Tools for Measuring Progress towards Sustainable Neighborhood Environments'. *Sustainability* 1 pp 612-627.

[50] McCreadie, M (2006) *Assessment of Sustainability Tools* (Building Research Establishment and University of Dundee, Dundee).

[51] HM Government (2005) *Securing our Future: Delivering the UK sustainable development strategy: The UK Government Sustainable Development Strategy Cm 6467* (HMSO, Norwich).

[52] p19 in; ODPM (April 2004) *The Egan Review: Skills for Sustainable Communities* (Office of the Deputy Prime Minister, London).

[53] Communities and Local Government (July 2011) *Zero carbon non-domestic buildings: Phase 3 final report* by AECOM for (Department of Communities and Local Government, London).

[54] Communities and Local Government (November 2010) *Summary of changes to the Code for Sustainable Homes technical guidance* (Department of Communities and Local Government, London).

[55] Communities and Local Government (July 2007) *The future of the Code for Sustainable Homes: Making a rating mandatory* (Department for Communities and Local Government, London).

[56] Banfill, P and Peacock, D (2007) 'Energy-efficient new housing – the UK reaches for sustainability'. *Building Research & Information* 1466-4321 35(4) pp 426 – 436.

[57] Sustainable Homes (April 2008) *Cracking the Code: How to Achieve Code Level Three and Above* (Sustainable Homes, Kingston upon Thames).

[58] Communities and Local Government (May 2009) *Code for Sustainable Homes: Technical Guide* (RIBA Publishing, London).

[59] Roaf, Sue; Horsley, Andrew and Gupta, Rajat (2003) *Closing the Loop: Benchmarks for sustainable buildings* (RIBA Enterprises, London).

[60] Passive House institute (2010) *Active for more comfort: The Passive House* (International Passive House Association, Darmstadt).

[61] Boardman, Brenda (2010) *Fixing Fuel Poverty: Challenges and Solutions* (Earthscan, London).

[62] De Jonge, Tom (2005) *Cost Effectiveness of Sustainable Housing Investments* (Delft University Press, Delft).

[63] Hasselaar, E (2006) *Health Performance of Housing: Indicators and Tools* (IOS Press, Amsterdam).

[64] p26 in; Thorpe, David (2010) *Sustainable Home Refurbishment: The Earthscan Expert Guide to Retrofitting Homes for Efficiency* (Earthscan, London).

[65] Reason, Liz and Clarke, Alan (January 2008) *Projecting energy use and CO2 emissions from low energy buildings: A comparison of the Passivhaus Planning Package (PHPP) and SAP* (AECB, Llandysul). Available for download from http://www.aecb.net/PDFs/Combined_PHPP_SAP_FINAL.pdf (accessed 10/11/11).

---

[66] p89 in; Thorpe, David (2010) *Sustainable Home Refurbishment: The Earthscan Expert Guide to Retrofitting Homes for Efficiency* (Earthscan, London).

[67] Wilson, Clare; Smith, Barry and Dunn, Peter (August 2007) *EcoHomes XB: A guide to the EcoHomes methodology for existing buildings bream:ecohomesXB* (Sustainable Homes Ltd, Kingston upon Thames).

[68] BSHF (2008) *New tricks with old bricks* (Building and Social Housing Foundation, Coalville).

[69] Hough, Cathy (2008) 'For Place's Sake – Refurbish, Don't Rebuild' pp46-47 in; O'Rourke, Juliana (Ed.) *Placemaking: A synthesis of professional practice and case studies about better living environments* (RUDI and the Academy of Urbanism, London).

[70] Chong, Chit and Ridley, Ian (2010) 'Retrofit lessons from the Camden Eco House'. Presentation at the *Cutting the Carbon* conference, Camden, 3rd February.

[71] Reference to practical refurbishment example of multi occupancy property at http://www.concerto-act2.eu/en/information/download_act2_documents/fact_sheets/ (accessed 10/11/11).

[72] Collected examples from; http://www.rethinkinghousingrefurbishment.co.uk/filelibrary/projects/rethinking_housing_reburbishment/Local_authority_private_sector_refurbishment.pdf (accessed 10/11/11).

[73] Bell, Malcolm *et al.* (November 2010) *Low Carbon Housing: Lessons from Elm Tree Mews* (Joseph Rowntree Foundation, York).

[74] Reason, Liz (2010) 'How Passivhaus can help deliver zero carbon in the UK'. *Cutting the Carbon* conference, Camden, 3rd February.

[75] BioRegional (July 2009) *BedZED seven years on: The impact of the UK's best known eco-village and its residents* (BioRegional Development Group, Sutton).