The UK homeowner-retrofitter as an innovator in a socio-technical system

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Abstract

Policy on domestic thermal retrofits is usually designed as a top-down enterprise, setting standards and inducing homeowners to retrofit accordingly. Its underlying assumption is that correct retrofit technology is developed by experts and comes down through supply chains to households, who apply it as designed to their properties. However, this model is challenged by the insight from socio-technical systems studies (STST) that technology and society mutually form and influence each other at every level of society. Using this conceptual framework, this study investigated whether innovations are happening among retrofitting households, and what support these have for diffusion upwards into supply chains and outwards to other households. Qualitative data was gathered through semi-structured interviews among homeowner-retrofitters plus building professionals and citizens' initiatives which support these, in Cambridge, UK. Significant local innovation was found in the development of new retrofit technology and novel reconfiguring of existing solutions. Much of this was triggered by clashes between standard retrofit solutions and heritage or aesthetic values, by economic necessity, or by building professionals' lack of knowledge or experience. The findings suggest UK thermal retrofit policy needs to broaden to support and foster these useful innovations developed by homeowners.

Keywords

Socio-technical systems; thermal retrofits; heritage

1. Introduction

This paper explores the role of homeowners as innovators of thermal retrofit technology, methods and rules. Much popular discussion frames homeowners as passive recipients of thermal retrofit technology that comes down to them from policymakers, technologists, manufacturers, designers and rule-makers. The decisions as to what can or must be done in thermal retrofitting are seen as formed at these upper levels, in which policy requirements are negotiated with what is technically and economically possible, technology is developed and produced in conformity with policy, and a supply chain mediates the technology and the rules to the retrofitting homeowner.

This is of course a simplification of how most parties would see the phenomenon of thermal retrofitting. Some of the materials and technology on the market are better than the rules require; some regularly fail to fulfil the requirements; often the economics of retrofitting a particular home cause rules to have to be bent and/or technology and materials to be innovatively adapted; often the supply chain is inadequate to meet the demand; many thermal retrofit measures are ad hoc and do not conform to requirements, or they make use of alternative technology or materials.

The important point, however, is that policy tends to be designed under the top-down assumption, and even where policy considers the needs of intermediaries in the supply chain, there is little if any recognition in policy of the possible roles that homeowners might have in influencing and improving the nature of thermal retrofits and the way they are enabled and facilitated.

This is of particular interest in a country like the UK, due to a number of factors. There is a great variety of types of dwellings; there are widespread concerns not to spoil traditional façades and features with bland insulation measures; there is much fuel poverty, where occupants cannot afford a full, comprehensive thermal makeover for their home but would value targeted measures in specific rooms or features; and there is a strong tradition of do-it-yourself (DIY) home improvement activity with its well-developed supply chain.

Policy in the UK and elsewhere in Europe tends to frame homeowners as passive receptors of retrofit technology who are bound to act under pre-formed regulatory constraints that are often very strict and demanding. Germany's 'Energy Saving Regulations' *(Energetische Einsparverordnung* – EnEV), for example, mandates strict thermal standards which homeowners have to achieve if they renovate any feature of their home (Galvin, 2014). The rules come 'down' from the federal government, and the materials, technology and construction methods are generally seen as already designed and perfected by the building industry.

The roots of this top-down approach can be traced back to policy instruments in the 1990s, with, for example, Denmark's mandatory energy certification scheme (*Energie Maerkningsordningen*), which served as an example for the Energy Performance Certificates (EPCs) of the EC Energy Performance of Buildings Directive (EPBD) (Sunikka, 2006), which now tends to dominate European policies on retrofitting.

Non-regulatory policy options can also fail to engage with specific households' consumption patterns or aspirations for their homes. The Netherlands' Energy Performance Advice (EPA) tool provided surveys of location and building characteristics, leading to advice on energy saving measures. However, it resulted in relatively small energy savings, with almost three quarters of customers indicating that the EPA advice had not changed their planned investments in the energy performance of their home (Beerepoot and Sunikka, 2005; Harmelink et al., 2005). The Dutch government's current program 'More with Less' (*Meer met Minder*) aims to make 2.4 million existing buildings 20-30% more energy efficient by 2020, to at least the B-label of the Energy Performance Certificate, deepening towards A++ after 2020 (Klinckenberg et al., 2013). While this ambitious depth of retrofit is positive for climate change mitigation, the focus is top-down, with the assumption that measures and aspirations coming from policymakers and experts will suit the buildings, be benignly accepted by the households, and pay back through fuel savings (on which see, e.g., Galvin and Sunikka-Blank, 2013).

A further example is France's *Éco-prêt à taux zero,* an interest-free loan scheme for thermal retrofits, which targets the thermally worst performing buildings (F- and G-ratings). To qualify for the loan, a residential thermal retrofit must include at least two types of thermal upgrade measures chosen from loft or wall insulation, new windows, replacement of heating system and/or renewable energy for heating or water heating, e.g. heat pumps and heat recovery ventilation systems (Klinckeberg et al., 2013). There is no reward for measures desired or devised by homeowners that lie outside this list of measures, nor for single measures even if these make the best sense to homeowners in a particular situation.

The UK's Green Deal is more flexible in this respect, as individual measures can qualify for a loan, which is debited to the dwelling rather than its owners. However, the criterion is that the costs of retrofit measures must pay back through fuel savings, and this automatically excludes a wide range of measures, such as those which would aim to combine renovation of aesthetically significant features with a degree of thermal improvement – which is just the area where homeowner creativity comes into play.

In general, then, the assumption behind a great deal of thermal retrofit policy is that the correct rules and methods of thermal retrofitting are set at a level well above the homeowner, and are delivered down to her or him as packages of standards and mandates, which may also include incentives and rewards.

A closer and more detailed look at thermal retrofit measures taking place in actual homes suggests this model is far from an adequate description of what is actually happening. A framework that can provide helpful insights in this regard is what may be broadly termed 'socio-technical systems theory' which we abbreviate as STST in this paper. This approach asks basic questions about how society and technology develop in relation to each other. Its key insight is that technology and society mutually form each other, i.e. that society is constantly forming and developing technology, while technology is constantly influencing society, and the two are inseparable (e.g. Bijker et al., 1997; Hughes, 1983; 1987; MacKenzie and Wajcman, 1985). It is fallacious, in this view, to think of technology as being formed by some elite caste of professionals and passed down to society. Rather, society and technology are constantly influencing each other at every level, from super-hi-tech laboratories such as NERN, right 'down' to the level of the humble household. This influence goes in all directions: both up and down, and to and from people and objects.

Applying this insight to domestic thermal retrofits would lead us to notice all the actors in the regulatory institutions, supply chain and application end: craftspeople, contractors, designers, manufacturers, research and development personnel, homeowners, salespeople, advertisers, policymakers, financiers, academic critics, relevant voluntary organisations, etc. together with their tools, materials, infrastructure, literature and jargon, plus the existing homes of would-be renovators. Central government policy might demand that insulation have a certain U-value, but this decision has *already* been influenced by this great network of actors, materials and institutions (which, for the sake of brevity, we will simply call 'the socio-technical system' in this paper), and the implementation of the policy at the level of a private dwelling can only happen by grace of all the networks in between.

A number of recent studies explore domestic energy retrofitting within an STST framework, explicitly or implicitly. These consider the interconnected elements which need to come together to make retrofits happen – such as markets, knowledge, know-how, and regulatory and policy contexts – asking how these could better fit together to make retrofits more effective or numerous. Examples include Fawcett et al.'s (2013) comparison of the retrofit context in the UK and France; and Killip's (2012) exploration of how the Green Deal could help or hinder retrofitting, given the way market and contracting actors interlink. In the same vein, Killip (2013) investigates whether the skills and knowledge of home renovation contractors can deliver effective thermal upgrades at levels that will be needed to meet emissions targets. Dixon and Eames (2013) explore the co-ordination and planning one level up from individual households, namely at city level, asking how certain socio-technical systems need to be developed to enable city-wide thermal retrofitting to increase.

A strength of these approaches is that they explore the networks of influences close to homeowners, which interact to determine the ease or likelihood of these homeowners going ahead with such measures. However, these studies tend to be principally concerned with the yes/no decision of homeowners to undertake thermal retrofits or include thermal measures in renovations they are already considering. Their focus is on the need to induce or persuade homeowners to retrofit, rather than exploring the contribution these people might make to retrofit technology or to the socio-technical regime it belongs within. The framing for such studies represents one particular branch of STST, often called transition studies (see discussion in Geels, 2004; 2005). Its overriding concern is to explore how the various types of actors, institutions, regulations, materials and technologies can be so aligned as to lead to a steadily increasing adoption of the technology or process – in this case effective thermal retrofit measures. To date we find no STST study that addresses the question of the bottom-up influence homeowners might have on the networks of actors and institutions which bring the technology, know-how, rules, etc., to bear on thermal retrofitting. Instead, homeowners are seen as passive receptors of technology, rules and know-how that come from an active, creative socio-technical system that sits somewhat above them and acts downwards on them.

Two examples illustrate this in more detail. Rishold and Berker (2010) interview 11 Norwegian owner-occupiers on their experience of renovating their homes. One of their findings is that building related craftsmen (sic) are 'an important barrier to energy retrofitting' because of homeowners' previous experience of these workers' bad advice or poor work quality. Nevertheless, these authors also find that 'handy' homeowners, who have a certain level of knowledge, are able to filter advice critically from their network of craftspeople, and consequently have more success in getting effective thermal measures incorporated into renovation projects. But there is no discussion of the role of these 'handy' homeowners in influencing or improving the bank of knowledge or know-how for thermal retrofit measures, either among these networks of craftspeople or beyond them to the supply chain. If there is such influence it is not picked up in this study.

Vergragt and Brown (2012) use an STS framework to explore what they call 'grassroots' innovations in home energy retrofits. Their empirical investigation concerns the interactions between homeowners and other relevant actors in the Worcester Housing, Energy and Community (WoHEC) group in Worcester, a town of 175,000 in Massachusetts. This is a citizens' initiative that brings together stakeholders and actors relevant to energy retrofitting, including suppliers, contractors, financiers and estate agents, set within the local regulatory and planning context. Drawing on transitions literature within STST (Geels, 2005; Hegger et al., 2007; Rip et a., 2010), the authors frame these interactions as learning at the level of a niche, in which innovation takes place which would have the potential to be scaled upwards so as to foster a transition on a larger scale. In their words:

> …learning takes place when actors representing a range of interpretive frames, problem definitions and core competences engage in intense interactions around a technological innovation, an issue, a problem or an idea (*op cit:* 409).

The main object of this learning, however, is to increase the number of homeowners who decide to undertake energy retrofits. Homeowners are again seen as passive recipients of retrofit technology rather than as having a role in developing it.

In different but related fields several studies do see homeowners as exercising influence upwards into the socio-technical system that (normally) brings eco- technology to homes. Ornetzeder and Rohracher (2006) document user innovation in biomass heating systems and solar thermal panels in Austria; Seyfang (2009) investigates user development of straw bale housing; and Hyysalo et al. (2013) explore user inventions in heat pump and wood pellet heating systems in Finland. But the question of how homeowners can (or routinely do) exert influence upward in thermal retrofitting, or in the thermal measures that often happen along with renovation, has not yet been explored.

Further, invention is only one of the ways we can conceive of users exerting influence upward. Other possibilities might include reconfiguring existing solutions in novel ways, or imparting knowledge upwards in the chain, from homeowner to professionals, not to mention the mundane influence on the market of choices homeowners make for this or that retrofit technology.

This paper therefore focuses on the very lowest level of the socio-technical system, the homeowner. It asks what sort of influences or potential influences, if any, retrofitting homeowners have on the socio-technical system that delivers effective thermal retrofit technology. It also asks whether policy could be developed or adjusted to foster or allow for these influences, so that they can make a wider contribution to energy and CO2 emission reduction in the built environment.

Hence, while the research of this paper is set within an STST framework, it does not frame this as a socio-technical 'transition' in the sense of the above cited studies. It is not concerned with how an innovation takes hold in a niche market, is adopted by more and more consumers, and finally becomes mainstream. Rather, it seeks to make a space for observing and recognising the influences that homeowners have (or can have) on elements of the socio-technical system relevant to thermal retrofits – i.e. on builders, contractors, architects, salespeople, product development, and ultimately policymakers.

This paper uses a vertical metaphor, namely 'layers' (or 'levels') to identify different elements and groupings in the retrofit socio-technical system. Placing homeowner-retrofitters at the 'bottom' level and policymakers at the 'top' level is not meant to imply any value judgement as to their relative worth, but merely to enable readers to picture the argument as it proceeds through the paper.

The remainder of the paper proceeds as follows. Section 2 outlines the methodology developed for the research. Section 3 reports the findings. Section 5 draws conclusions together and offers policy recommendations.

2. Methodology

The empirical research for this study took place in Cambridge, UK, a city of about 120,000 people with a buoyant economy fuelled largely by Cambridge University and its high-tech and bio-science spin-off enterprises. Housing in Cambridge is diverse, with a number of pre-Victorian homes and a full range of Victorian, Edwardian, post-Word-War I and post-Word-War II homes, with dwelling size ranging from very small to very large in all these categories.

The city is served by a strong network of citizens' groups focused on environmental and climate issues, many of which have links to university faculties which have their own initiatives in the technological or social science aspects of sustainability in the built environment. This also includes Cambridge's second university, Anglia Ruskin. In addition, the universities and the citizens' groups often offer public lectures and seminars on topics related to energy saving and thermal retrofitting.

A number of comprehensive home retrofit projects have been undertaken under the auspices of the University (e.g. Moncaster and Sahagin, 2014; Sunikka-Blank et al., 2012), but more important for this study are the inter-linkages between citizens' initiatives that foster and support thermal retrofitting at the level of the individual homeowner. Two of these voluntary organisations, Cambridge Transitions (CT) and Cambridge Carbon Footprint (CCF), have actively encouraged thermal retrofitting for at least the last decade, and in two main ways: by bringing together homeowners with professionals in the socio-technical system relevant to thermal retrofitting (e.g. architects, sales representatives, building contractors); and facilitating the sharing of information and experience of homeowners who have already undertaken thermal retrofit measures.

The object of the empirical part of this study was to find whether there are specific examples of thermal retrofitting in which homeowners have clearly influenced the retrofit socio-technical system in some tangible way. This is a qualitative (rather than quantitative) exploration, in that we are seeking to discover what sorts of things are happening, rather than how much or what percentage of a given set of things is happening. Semi-structured interviews are ideally suited to this end. This involves asking a small set of carefully targeted but open-ended questions that allow the interviewee to respond fully and freely, so that new things are heard which might not have been uttered if the questions were too narrowly restricted or there were too many of them (Flyvberg , 2004). At the same time the questions are carefully focussed to keep the subject of discussion on the point of the research questions.

The interviewees were chosen to engage with three areas: (a) case studies of retrofits; (b) the citizens' initiatives that network these retrofitting households to each other and to relevant knowledge and expertise; and (c) professionals who do the actual retrofitting or design and plan it in communication with households. This kept the focus at the lowest levels of the retrofit socio-technical system. The case studies, where retrofits actually take place, are at the bottom level and are the main focus of our interest. The professionals can be conceived of being one or two levels up from this. They work directly on retrofit jobs but also help connect these to supply chains, policy, rules, wider know-how and the full range of available technology. The citizens' initiatives have a role that straddles these two levels. They work directly with both retrofitting households and professionals as facilitators and go-betweens.

Group (a) consisted of five households who had retrofitted. Group (b) included a key player in each of the main citizens' initiatives (CT and CCF), while group (c) were architects who had been involved in local retrofit projects and were well known to CT or CCF. There was a total of 9 interviews (see Table 1), taking place in February – April 2014.

Interviewees were formally approached in writing, including a clear explanation of the ethical guidelines governing the interviews and use of data. These guidelines and the research procedure were approved by the sponsoring university's ethics committee.

Interviews lasted 40-60 minutes, and were digitally recorded and transcribed. The transcripts were analysed and coded using a grounded theory approach (Charmaz, 2006), in which the themes are identified that are common across the interview transcripts and which are highly relevant to the research question. All interviewees were given pseudonyms from the transcript stage onwards.

Table 1. Interview labels, interviewee aliases and position or role

Interview label	Alias	Position or role
A	Rod & Iris	Homeowners
B	Ingrid	CCF leader
C	Gail	CT leader
D	Lydia	Architect
E	Alan	Homeowners
F	Oliver & Annette	Homeowners
G	Christopher & Linda	Homeowner & Partner
H	Erica	Architect
I	Laurence & Yolande	Homeowner

3. Results

3.1 Overview

Two principal themes in relation to the research question were evident in the interview data. These can be loosely described as: (a) the various types of bottom-up influence the homeowner-retrofitter exerts on the socio-technical system; and (b) the wider, citizens'-initiative-based retrofit community fostering and reinforcing this influence.

It also became clear in the interview analysis that there were two contextual themes which frequently intersected with these or at least lay in the background: utility renovations in relation to thermal retrofit measures; and the need to preserve or cope with aesthetic or heritage values. Before presenting the two principle themes we offer a brief overview of these background contextual themes.

3.2 Utility renovations

Some of the retrofits that were investigated or alluded to in interviews were not originally planned as thermal retrofits, but as utility renovations. In these cases, homeowners had not started with the intention of making their home warmer or cutting their heating fuel bills, but of doing necessary maintenance or general home improvements. For example, Iris and Rod had planned and overseen a comprehensive thermal retrofit of their large Victorian home. Iris explained:

> … when we started this project it wasn't about thermal insulation. It was about replacing a very old part of the façade of the building which had originally been a shop. And we didn't even *think* [emphasised] about the thermal aspects until we actually spoke to an architect**.** (Interview A)

Lydia, an architect, commented:

> I think most ordinary householders approach their house with much more conventional ideas, like I need a new bathroom, or I need a new kitchen. And it's been my own experience that you can say, well if you're going to have a new window, let's look at external insulation, because even for that bit of the house it's worth doing. (Interview C)

This resonates with the finding of Wilson (2013) that in a very high proportion of cases, thermal retrofitting happens as a consequence of homeowners' decisions to undertake utility renovations.

However, in the current study this was not always the case. For Christopher (Interview G), the main three considerations were the desire to reduce his carbon footprint, to make the house warmer and to reduce indoor moisture and condensation. He had also been planning extensions, but maintained this was additional to the primary motivation to retrofit.

For Oliver and Annette (Interview F), the decision to have loft and cavity wall insulation installed was because:

> We received some information, I think it was through the door, saying that because our son is disabled we're entitled to have that for free. And we were keen to reduce our energy bills. (Interview F)

The couple also had an extension done to make the house more suitable for their son's needs, but this was not a trigger for retrofitting. Some years earlier, Oliver himself had applied internal insulation in the main bedroom 'to solve a condensation and mould problem'.

For Alan, (Interview E), the retrofit decision was motivated by thermal comfort issues:

> Sure the house needed a facelift inside … But there was nothing wrong with it as a building. It was just cold and draughty. (Interview E).

Further, one of the most common thermal improvements mentioned by citizens' initiative interviewees was draught-stopping. CF facilitates this with 'draught-busting parties' (Interview D), in which trained volunteers use inexpensive foam strips to seal air gaps in windows and doors in a selected house. As CF representative Ingrid (interview B) explained, this is accompanied by educational input on how to avoid condensation and mould due to too little air exchange. Clearly, this is a purely thermal upgrade measure, not done as a consequence of utility renovations.

However, in some retrofit cases the trigger for thermal improvement was general maintenance or the desire for utility renovation, and in all the interviews this theme was never very far away. It was often interwoven (but not always) with the second background theme, that of preserving or coping with aesthetic or heritage values.

3.3 Aesthetic and heritage values

A problem frequently experienced by utility and thermal renovators was how to renovate deteriorating features of their building which held aesthetic value due to their historically significant architecture. An example frequently cited was bay windows on external façades. For Rod and Iris it was concern for deteriorating Victorian bay windows that led them to start retrofitting (see above). This led to Iris designing an innovative reconfiguring of the façade decoration so as to integrate the lines of a new bay into the existing form of the façade. In Rod's words:

> If you stand outside and look at it you'll notice that the lines of the Victorian bay are carried across to the lines of the modern bay. (Interview A)

Here the need for maintenance led to retrofitting, which led to creative design by the homeowner, to preserve aesthetic value by integrating the new with the old.

Although Christopher (Interview G) applied external wall insulation to the side and back of this house, he chose internal insulation for the façade, 'to preserve the character of the front of the house', but also because:

> I don't want it to be sticking out like a sore thumb because it looks completely different from the other houses on the street. (Interview G).

Another example of the preservation of aesthetic features was seen in Alan's (Interview E) innovative method of under-floor insulation. The advice Alan received from a number of professional sources was to lift the floorboards and fit slabs of polystyrene foam between the floor joists (also affirmed in Interview H with Erica, an architect). Alan commented:

> It's a basic, plain house but everybody comments on the lovely floorboards. To lift them I'd have to cut them right across the grain, because the brick walls either side sit on top of them. Lifting them would also split them here and there because the nails holding them in are very big and a bit rusty, and they're stuck very hard into the joists … So I … came up with the idea of doing it from underneath … and that meant inventing a way of using glass wool rather than polystyrene. (Interview E)

In this situation the need to preserve an aesthetic feature of a house – perhaps its one and only 'lovely' feature – led to innovation which would be reproducible in houses with similar floor structures.

However, it was not always the *protection* of aesthetically pleasing features that led to inventiveness; in one case a retrofit innovation was geared to *bring* aesthetic quality where it was lacking. Laurence and Yolande perceived the façade of their 1960s townhouse as ugly, because of its tile cladding, and because the squat shape of its windows clashed with its long thin vertical form. They engaged a firm to replace the cladding with a foam insulation and render, while also personally designing a vertical lengthening of the main windows to fit the overall façade shape. At the same time they were able to get structural maintenance done on the building envelope, which had been their main motivation in starting the project. Laurence commented that this gave three advantages in one: 'structural repair, aesthetics, and warmth. It killed all the birds with one stone, so to speak'. (Interview I).

So, although the need to preserve existing aesthetic features often triggered creativity in thermal retrofitting, this could also be a means to improve aesthetic appeal.

With these two underlying and interweaving background themes in mind, we consider the themes that relate most directly to our research question.

3.3. The bottom-up influence of homeowner-retrofitters

The interviews revealed four main ways homeowner-retrofitters were exerting influence upward on the retrofit socio-technical system, quite apart from their market influence of selecting from a variety of already existing solutions: (a) by fostering relevant skills among contractors; (b) by inventing new skills, devices, technologies or solutions or significantly modifying existing ones; (c) by innovating in ways that influence, or potentially influence, the solutions that are already available; and (d) by imparting their own knowledge and skills to building contractors.

An example of the first kind of influence, from Rod and Iris (Interview A) illustrated how homeowner-retrofitters can foster relevant retrofit skills. They described two features of traditional aesthetic value in their Victorian home which needed to be re-constructed due to the disruption of thermal retrofitting: indoor cornices and a traditional type of shallow angled lead roofing. Rod commented:

> This maintenance of the old trade I think is quite a significant aspect, because if you don't, if you just leave the building as it is and don't touch it, eventually it sort of falls into disarray, and you've got no one to fix it. Whereas if you actually continually maintain the building by doing things like the thermal retrofits, you actually, you know, maintain craftsmen who can do that sort of stuff and you're keeping the skills up. (Interview A).

While this type of bottom-up influence is subtle and often invisible, the second type of influence, at the other end of the scale, is far more overt. Here, homeowner-retrofitters act as inventors and innovators. An example that emerged several times in interviews was in the preservation of heritage windows. Lydia, an architect, told of a homeowner who wanted to improve the thermal quality of his home's Edwardian Bay windows while preserving their frames entirely and their original appearance as much as possible. This person was:

> … completely concerned aesthetically [and] worked very, very hard to get permission for a listed house, to take out the old windows and re-glaze them with slim-line, very, very narrow double glazing, which is extremely warm… he managed to convince the planners … that he should be allowed to try and adapt it, a trial. (Interview D)

Another group of innovations centred around ways of attaching an internal, second layer of glazing to window frames so as to produce a simple set of double-glazed panes. In one of Laurence's rental homes a conservation officer forbade him (Interview I) from adding internal second glazing inside deep-framed front wall bay windows. So he developed a method of fitting a glass pane half way into the frame, unobtrusively. He then invited the officer to identify, from the outside, which window was double-glazed.

The officer admitted he could not identify the glazed window, and reversed his decision on permission.

A perennial problem with such devices is that the second pane needs to be removed regularly to de-moisten and clean the window and frame. Lydia told of the owner of an Edwardian home who invented a set of magnetic fasteners for this. While the home had no conservation order he '… reacted completely negatively to the idea that you should take out old fittings and replace them with high performance fittings.' (Interview D)

Another homeowner, who wished to avoid using synthetic insulating materials in his heritage house, developed his own insulating materials:

> It was a freezing cold bathroom upstairs on the terrace – and he used natural materials, and he used clay plaster and micro-porous paint. And he said, it's not supposed to be particularly high performance but it's the warmest room in the house. (Interview D)

A further innovation concerned the adaptation of passive house technology and methods to heritage houses which will be retrofitted to standards far lower than that of a passive house. A group of homeowners who are also software engineers had adapted passive house software for cost-benefit analyses of individual retrofit measures in homes with aesthetic value. For example, they use the software to plot curves for the optimum insulation thickness in specific cases. (Interview D)

These developments and innovations can be seen as technology being developed or modified from the bottom up, at the lowest stratum of the socio-technical system. But there is a third cluster of innovations which, rather than producing new technology, offer novel methods or configurations of what is already available. In this vein we noted, above, the example of Alan devising a novel method of under-floor insulation so as to preserve the aesthetic appeal of the polished floorboards. He continued:

> Another problem with polystyrene between the joists is that each block has to be a perfect fit, and I didn't feel confident to do that… And I didn't want the under-floor sealed against water or drinks that get spilled on the floor, moisture going through the cracks and getting trapped between the floorboards and the polystyrene. I'd rather it just dripped right down to the ground underneath (Interview E)

The solution Alan devised was to fit layers of glass wool loft insulation between the joists from underneath, cutting these just wider than the gaps so they held in place long enough for him to support them from underneath with strips of duct tape, stapled to the underside of the joists.

A contribution of a more technical nature was described by Rod and Iris, who opted for a combined space-heating and mains-pressure water heating system that integrated solar thermal panels, a highly efficient gas boiler and an outdoor temperature sensor.

> We wanted … mains pressure throughout, so that we could get a shower up on the top floor, which meant a complete re-plumb, so that they basically specified Vaillant [brand] boilers, which are very good, and have very good controls… We also wanted solar thermal as well, but we found out later on that you couldn't get the Vaillant solar thermal controls in this country. Now fortunately the builder's got a, one of his sons lives in Germany, ordered it for us and shipped it over. And then we got a German friend to translate the manual for us... And so we got enough of the manual translated to understand how to work it. (Interview A)

Although the retrofit was supervised by an architect, it was the initiative and resourcefulness of the homeowners that brought the various elements of the technology together. The fact that they needed to translate the manual into English indicates they were ahead of the play, as does their use of informal networks to get the equipment to the UK.

Further examples of homeowners reconfiguring or employing existing technology in novel ways included home-dyed papier maché for filling draughty cracks in floorboards, designing and implementing fine facia work to integrate new windows with the lines and features of existing heritage windows (see above), setting up a central heating system without a central thermostat to avoid overriding controls in individual rooms and integrating this with active central timing and water temperature controls on the boiler; and designing a dual under-floor and radiator heading system with two sets of controls to optimise the different thermal lags of the two systems.

The fourth way in which homeowner-retrofitters influence the retrofit socio-technical system is as trainers of the contractors who do the retrofitting. Christopher's retrofit (Interview G) was full and comprehensive, involving external and internal wall insulation, under-floor heating in the main living area with radiators elsewhere, an integrated solar and gas hot water system, mechanical heat recovery ventilation (MHRV), and a rainwater system for toilets and washing machine. He had to intervene to correct major mistakes being made by the builder, the plumber and the electrician, but was 'too forgiving' (in his partner's words) to correct a major mistake by the architect. The builder 'put in the beams too low' for the under-floor heating. The mistake required major correction, but it was only because Christopher himself was literate in retrofit technology that he noticed it early enough so that its consequences did not multiply.

The plumber got the pipes wrong for the MHRV, so that, in Christopher's words:

> Instead of circulating air from outside to the inside, and recovering the heat, I think what they're doing is circulating the air inside, circulating the air outside, and in between they're losing all the warm, or the heat from the warm air, to the outside. (Interview G)

Finally, the electrician mistakenly combined the two heating systems in a single control unit, which, in Christopher's words:

> … rather defeats the point, because for under-floor heating you need the timer to be on a different cycle from the rest of the house. (Interview G)

Rod and Iris, too, had to teach their contractors some basic knowledge in retrofit technology. For example, the builder, unable to grasp the concept of controlled ventilation, left gaps in wall-floor joins to let outside air in. As Rod sought to correct his mistake, the builder insisted on the need for air gaps. Rod commented

> He's very old school, I mean he … kind of thought I was obsessed with draughts. You know he's used to the fact that a British house is a draughty house. (Interview A)

In the same vein, Erica, an architect, commented that, from a builder's point of view:

> … good ventilation means that if something lets water in, then it dries out and it's not a problem (Interview H).

Oliver and Annette also found shortfalls in their contractors' retrofit work. The loft insulation was laid non-optimally in relation to the beams, to save time, and the trapdoor was not sealed against warm moist air coming up from the body of the house, leading to continuous condensation in the loft. A one-metre wide band of cavity wall right around the house was not filled with insulation because it would have taken too much time to remove decorative tiles from this section. Hot water pipes were encased in floor and wall conduits without being lagged. However, the couple's knowledge was not allowed to influence the contractors, as the jobs were subsidised due to the disability in the family, and contractor time had to be strictly adhered to. Annette commented, regarding the loft insulation:

> They just were there to deposit the insulation and leave, but actually not to make it leak-proof. (Interview F)

In this way an opportunity for building and retrofit contractors to learn from homeowner-retrofitters was missed.

3.4 The role of citizens' initiatives

Interviews with leaders in citizens' initiatives made it clear that these networks' role was not confined to seeking to induce homeowners to undertake thermal retrofits, as appears to be the case in the Worcester, Massachusetts initiatives (Vergragt and Brown, 2012). Through an initiative of CT known as Cambridge Open Eco-Homes (COEH), group tours are arranged to enable those who have done some retrofitting to display and explain it to others who are interested. This is an entirely bottom-up procedure. The emphasis is not on telling what should be done, but on curiosity about what has been tried and tested. As COEH committee member Gail commented, it is '… trial and error or a bit of expertise, gradually accumulated information.' (Interview C)

Further, in an ongoing initiative from CT, public meetings are organised where building professionals and actors from the supply chain are invited to present their wares and skills to interested members of the public. This is a two-way process, with people in the audience responding with their own experiences of what did and did not work for them. As Gail explained:

> The reps talk about their products, what they're supposed to be selling; and the householders say, 'Yeah, but when we did this it didn't work', or 'I know that worked only because I oversaw it myself,' or whatever. (Interview C)

The audience includes experienced homeowner-retrofitters who have been known to respond incredulously to gaps in knowledge displayed by the expert presenter – such as when a sales representative for wall insulation materials turned out to be unaware of issues of post-insulation moisture build-up, which can cause indoor mould growth if not dealt with properly.

The citizens' initiatives also have an educative role among homeowner-retrofitters. For example, as CCF leader Ingrid explained (Interview B), one of the difficult issues with draught-stopping tape is its very cheapness, so that DIY suppliers have little or no incentive to train their staff to be able to give helpful advice on which products to use for what purpose. Here the community activities of CT and CFF are able to fill gaps in knowledge and know-how.

Nevertheless, it was difficult to see any route or conduit whereby useful innovations among homeowner-retrofitters could become known to higher levels of the socio-technical system or to other homeowner-retrofitters elsewhere. One of Christopher's retrofit problems (Interview G) was how to preserve the slope of outdoor windowsills when external wall insulation was added, in this case 10cm thick. When we had our interview his architect was still trying to find a solution for this. Days later, in an interview with another architect (Erica, Interview H), an innovation was mentioned which would have solved this: an insulation firm in Birmingham had designed and patented a universally adaptable angled insulation block for just such a purpose. It was partly because of the coincidence that both Erica's assistant and the head of the Birmingham firm were Polish, that the connection had been made and the device discovered. Nevertheless, architects are in a relatively good position to discover and identify solutions from higher layers of the socio-technical system, such as insulation manufacturers, who have purpose-designed websites and supply connections. It is much more difficult for local innovations by homeowner-retrofitters to become known, adequately critiqued and disseminated if more widely useful.

A further point raised by Erica is that UK laws are not favourable towards such innovation:

> The issue that an architect and a builder have is that the way the law is set up for domestic work, the domestic client is a consumer, and they are deemed to not have any responsibility at all… So using a [window-]sill, someone's patented sill that's only just come on the market, do I take that risk? Why would I take that risk? 'Cause I don't want in 10 years' time someone coming and saying that this didn't work and I've got a leak here. I mean I'm just using that example, but in terms of innovating or using details that you haven't used before, there's a huge weight of legislation against you all the time. (Interview H)

Hence there is not only a lack of mechanisms for diffusion of homeowner-retrofitter innovations, but effectively a legislative bias against such diffusion.

4. Discussion and conclusions

This inquiry into the role and influence of the bottom layer of the retrofit socio-technical system brought to light important issues for policy, local citizens' initiatives, those in the supply chain, and homeowner-retrofitters, while also suggesting implications for STST theory.

The interviews demonstrate that homeowner-retrofitters do not merely apply technologies and methods that come down from above. Rather, we see their willingness and ability to gather information from different sources and put it into practice, from specification to supervision, from the level of draught taping to that of a complex, integrated, computer-controlled heating system. A number of factors lead them to make innovative contributions to retrofit technology and methodology. Firstly, where there are heritage or aesthetic issues, such as with front bay windows, standard top-down solutions often do not suit the particular homeowner's aspirations or might fall foul of conservation rules. This can trigger a creative spirit leading to novel solutions, which may depend on what the homeowner wants her or his house to look or feel like.

Secondly, older homes often present practical problems that can stimulate homeowners to devise solutions that at least modify or reconfigure existing technologies. An example is under-floor insulation where the need for porosity, full gap filling, and the avoidance of timber scarring led to a non-standard but effective solution using existing materials.

Sometimes thermal and aesthetic issues combine to stimulate other kinds of solutions. An example is where internal wall insulation will destroy existing cornices and architraves. Here homeowners felt that their engagement of specialist craftspeople helped to preserve traditional skills which might otherwise tend to die out.

Further, homeowner-retrofitters sometimes become teachers of their retrofit contractors, including builders, electricians, plumbers, and loft and cavity wall insulators. In some cases they also needed to be in charge as there was a lack of knowledge among building professionals who would each focus on their individual task and rely on conventional standards (e.g. accepting draughtiness). Often, however, contractual and grant structures militate against this learning, and consumer laws can make professionals reluctant to embrace innovations even if they seem appropriate.

Citizens' initiatives play an important role in fostering these bottom-up initiatives. They network retrofitters with each other and with possible future retrofitters, facilitating the exchange and propagation of knowledge and skill, while they also facilitate the engagement of this bottom layer of innovation and experience with experts and professionals in the next layers up.

Policymakers would do well to take these issues into account. A large proportion of UK properties are seen as having some aesthetic value, and for some of these, alterations which would change the general appearance of the area would be seen as detrimental, even if they are not under conservation order. This can lead to aspirations for non-mainstream retrofit measures that enable the original character and architectural features of the building to be preserved. On the other hand, some properties may be seen as in dire need of aesthetic appeal, and at least one case in this study shows how this, too, led to homeowner creativity. This study suggests there is already a rich set of such measures at large in the community, but knowledge of these tends to be confined to niches in the lower levels of the socio-technical system, where it is not easy for it to be propagated and known to the wider community. Even where heritage and aesthetics are not an issue, budgets and the actual desires and aspirations of homeowners can lead to novel solutions, or corrections to standard ones, but these tend not to become widely known.

The interviews also suggest that current thermal retrofit policies in the UK do not seem to influence or stimulate homeowners. None of the interviewed households had made use of Green Deal financing or other subsidies, apart from the couple who were approached to install free insulation as they were entitled to it. Further, even if homeowners were keen to find out information about energy measures by themselves, government material on retrofits was considered as hard to read, even compared to literature on German passive house standard.

There seems to be a need for a nationwide policy initiative to identify innovation at the bottom level of the retrofit socio-technical system, offer constructive criticism where appropriate, and bring many of these innovations into the light of day.

Building professionals could also play a role in identifying useful innovations and reporting these upwards into their professional networks where they might have a chance of taking hold in mainstream retrofit technology.

Further, it seems that many professionals and product representatives could learn much about their products' effects and usefulness directly from homeowner-retrofitters.

The shortcomings of this study need to be noted. The findings may not be representative of UK communities in general. Cambridge is a small, socially tightly integrated city with above-average incomes, frequent interactions among a possibly disproportionate number of innovative, well-resourced people, and a large number of older homes with various degrees of heritage or aesthetic value. It is also recognised that most of these case studies are too costly and knowledge-intense to become a norm to solve the general problem of large-scale retrofitting. Nevertheless, the issues found here, of homeowners' unique views and aspirations for their properties, community networking, the prevalence of DIY skills, and the intimate familiarity a homeowner has with her or his property are likely to be found throughout the UK, if not in other countries of similar housing stock and economy.

The conceptual framework that guided this study was socio-technical systems theory (STST). This way of conceiving how society and technology mutually influence each other has been critically developed since its conception in the 1980s. In particular, STST draws attention to this mutual formation at all levels of society. It is not simply that highly skilled and resourced actors invent and refine technologies which centralised governance and big business then promote among the masses. Rather, there are technological innovations emerging constantly at all levels of society, together with both formal and informal processes that promote or propagate these innovations. The crucial issue is to identify these innovations when they occur, so that they have a better chance of developing and influencing the mainstream.

Most STST studies in recent years have been concerned with 'transition theory', i.e. how a technological innovation – which usually happens or crystalizes at a higher, elite level – can be promoted among early adopters and beyond until it becomes mainstream.

This study covers a different kind of transition: the dissemination of invention and innovation from the workshop level, upwards into the mainstream of available solutions on offer. In this sense it returns to the roots of STST, perhaps in the tradition of Bijker's (1997) classic study of the early development of the bicycle. Having used STST concepts to identify a layer of innovation at the lowest level, it offers the challenge to policymakers and actors at higher levels to foster, critique and nurture this type of innovation for the wider benefit of thermal retrofitting of UK homes.

References

Beerepoot M., Sunikka M (2005) The contribution of the EC energy certificate in improving sustainability of the housing stock, Environment and Planning B, 32 (1), pp. 21-31.

Bijker W (1997) Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change. Cambridge, MAS: MIT Press

Bijker W, Hughes T, Pinch T (eds.) (1987) The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology, Cambridge MA/London: MIT Press.

Charmaz K (2006) Constructing Grounded Theory: A Practical Guide through Qualitative Analysis. London: SAGE Publications.

Ecocitoyens (2014) Éco-prêt à taux zero. Available at: http://ecocitoyens.ademe.fr/financer-mon-projet/renovation/eco-pret-a-taux-zero [Accessed 29 April 2013].

Fawcett T, Killip G, Janda K (2013) Building Expertise: Identifying policy gaps and new ideas in housing eco-renovation in the UK and France. ECEE Summer Study Proceedings 2013.

Flyvberg B (2004) Five misunderstandings about case-study research, in: C. Seale, G. Gabo, J.F. Gubrium, D. Silverman (Eds.), Qualitative Research Practice, Sage, London/Thousand Oaks, CA, pp. 420–434.

Galvin, R (2014) Why German homeowners are reluctant to retrofit. Building Research and Information. Article in press, available at http://dx.doi.org/10.1080/09613218.2014.882738

Galvin R, Sunikka-Blank M (2013) A Critical Assessment of Germany's Thermal Retrofit Policy, Turning Down the Heat, Springer: London.

Geels F (2004) From sectoral systems of innovation to socio-technical systems Insights about dynamics and change from sociology and institutional theory. Research Policy 33: 897–920.

Geels F (2005) The dynamics of transitions in socio-technical systems: A multilevel analysis of the transition pathway from horse-drawn carriage to automobiles (1860–1930). Technology Analysis & Strategic Management 17: 445–476.

Harmelink M, Joosen S, Blok K (2005) The theory-based policy evaluation method applied to the ex-post evaluation of climate change policies in the built environment in the Netherlands, Proceedings of the ECEEE 2005 Summer Study, European Council for an Energy-Efficient Economy: Stockholm.

Hegger D, van Vliet J, van Vliet B (2007) Niche management and its contribution to regime change: The case of innovation in sanitation. Technology Analysis & Strategic Management 19: 729–746.

Hughes T (1983) Networks of Power: Electrification in Western Society 1880-1930, Baltimore, MD: The John Hopkins University Press.

Hughes, Thomas P. (1987), 'The Evolution of Large technological Systems,' in: W. E. Bijker, T. P. Hughes and T. J. Pinch, (edsm) The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology, Cambridge MA, MIT Press, pp. 51-82.

Hyysalo S, Juntunen J, Freeman S (2013) User innovation in sustainable home energy technologies. Energy Policy 55: 490–500.

Killip G (2012) Beyond the Green Deal: Market Transformation for low-carbon housing refurbishment in the UK. Working paper, Environmental Change Institute, Oxford University.

Killip G (2013) Products, practices and processes: exploring the innovation potential for low-carbon housing refurbishment among small and medium-sized enterprises (SMEs) in the UK construction industry. Energy Policy62: 522–530.

Klinckenberg F, Forbes Pirie M, McAndrew L(2013) Renovation Roadmaps for Buildings, London: The Policy Partners / EURIMA. Available at: http://www.eurima.org/uploads/ModuleXtender/Publications/96/Renovation_Roadmaps_for_Buildings_PP_FINAL_Report_20_02_2013.pdf [accessed 29 April 2013]

MacKenzie D, Wajcman J (eds) (1985) The Social Shaping of Technology, Buckingham and Bristol: Open University Press.

Moncaster A, Sahagun D (2014) How much do we spend to save? Calculating the embodied carbon costs of retrofit. In: Retrofit 2012, 2012-1-26 to 2012-1-28, Salford, UK. (Unpublished) Available at http://webcache.googleusercontent.com/search?q=cache:http://publications.eng.cam.ac.uk/396316/ Accessed 02 April, 2014.

Ornetzeder M, Rohracher H (2006) User-led innovations and participation processes: lessons from sustainable energy technologies. Energy Policy 34: 138–150.

Rip A, Joly P, Callon M (2010) Reinventing innovation. In *Governance and innovation: Firms, clusters, and institutions in a changing setting*, ed. Maarten Arentsen. Cheltenham: Edward Elgar.

Rishold B, Berker T (2013) Success for energy efficient renovation of dwellings—Learning from private homeowners. Energy Policy 61: 1022–1030.

Seyfang G (2009) The New Economics of Sustainable Consumption: Seeds of Change (Energy, Climate and the Environment). Palgrave Macmillan, New York.

Sunikka-Blank M, Chen J, Britnell J, Dantsiou D (2012) Improving Energy Efficiency of Social Housing Areas: A Case Study of a Retrofit Achieving an "A" Energy Performance Rating in the UK. European Planning Studies 20(1): 133-147.

Sunikka M (2006) Policies for improving energy efficiency if the European housing stock, IOS Press: Amsterdam.

Vergragt P, Brown H (2012) The challenge of energy retrofitting the residential housing stock: grassroots innovations and socio-technical system change in Worcester, MA. Technology Analysis & Strategic Management 24(4): 407–420.

Wilson C (2013) Understanding homeowners' renovation decisions: findings of the VERD project, UKERC, London.