

MICROGENERATION TECHNOLOGIES IN NEW BUILD HOUSING: TECHNOLOGICAL TRAJECTORIES AND USER EXPERIENCES

DR. TIM LEES

University of Reading, Innovative Construction Research Centre,
School of Construction Management and Engineering, Whiteknights Campus, Reading, RG6
6AW.
t.j.lees@reading.ac.uk

PROF. MARTIN SEXTON

University of Reading, School of Construction Management and Engineering

Abstract

The UK has set a target for a reduction in CO₂ emissions by 80% by 2050 compared to 1990 levels. The domestic sector accounts for 25% of UK emissions from the generation of heat and electricity for homes. For this sector to move to a low-carbon path, it will need to transform the environmental performance of housing. The transformation will require system-wide innovation and change comprising new technologies, new markets and new institutional supporting systems. There is an urgent research needed to better understand, and therefore, steer this system innovation. The ongoing research project reported here contributes to this need by addressing the impact of the growing raft of environmental regulations on the UK housing development. The primary focus is on microgeneration technology (MGT) field within this sector. This research recognizes that the challenge of integrating MGTs is not merely a technical one for housing developers; rather, it has significant technical, social and economic implications for housing developers and their supply chains, as well as for home buyers.

Keywords: Innovation, diffusion, sustainability, housing, technology.

INTRODUCTION

The UK housing sector has a significant role to play in the UK Governments legally binding target to reduce CO₂ emissions by 50% by 2050 compared to 1990 levels (DECC, 2008). If the CO₂ emissions generated by new homes built between now and 2050 are not curbed then there is a significant possibility that this could offset any progress made in other sectors. In order to induce the UK house building sector to move onto a more sustainable trajectory the Government introduced the zero carbon homes agenda articulated through the Code for Sustainable Homes (CfSH or the Code). The CfSH is coupled to a series of planned changes to the Building Regulations (in particular, Part L) demanding increasingly higher levels of environmental performance, culminating in zero-carbon (yet to be defined) by 2016. CfSH is not mandatory in terms of it prescribes performance thresholds which new housing must achieve, but a rating for new homes against the six levels of the Code is mandatory. However, the changes contained within it are mirrored by the upcoming changes to Building Regulations which are mandatory. In this paper when we describe the changes required under the CfSH and the changes to the Building Regulation which will mandate that the targets and levels of performance specified in the Code are adopted for all new homes. Further, we discuss the early stages of an ongoing research project investigation microgeneration technology innovation systems in the new house building sector.

THE CODE FOR SUSTAINABLE HOMES

In 2005 the case for developing the CfSH was presented by the Government and, following a consultation period, policy was confirmed from 2008 onwards all new homes were to be rated against the CfSH was made (ODPM, 2005). The Code is based upon six levels of performance and assessed against nine different areas. These areas include improvements in building materials and energy/CO₂ emissions but also address waste production, water management and ecology among others. In order to achieve a CfSH home rating of 4* a 44% reduction in CO₂ emissions, based on 2006 Part L Building Regulations requirements, is needed (CLG, 2006). The precise definition of zero-carbon is still to be determined (** ZCH report reference **). The expression of emissions target as a percentage reduction has been identified as potentially confusing (Zero Carbon Hub, 2010). In order to make requirements more explicit a carbon compliance measure has been adopted. The carbon compliance measure expresses emissions as a measurement of kilograms of carbon dioxide produced per metre squared of internal floor space per annum (kgCO₂/m²/year). This means that the CfSH home ratings of 4*, 5*, and 6* dwelling described above can be expressed in absolute terms of 20, 14 and 0 kgCO₂/m²/year emissions respectively. A dwelling complying with the 2006 Part L Building Regulations would be expected to emit typically 25 kgCO₂/m²/year. Currently all new homes are required to be 4*. By 2013 this will be increased to 5* and by 2016 further increased to 6*.

The sources of CO₂ emissions from the home are not evenly distributed. Typically 55% of the emissions emanate from space and water heating, 28% from appliances and the remainder from cooking, lighting, pumps and fans (NHBC Foundation 2009a). The challenge of reducing emissions resulting from space and water heating are distinct from those of reducing emissions from the other sources and the strategies for tackling them are correspondingly different (Zero Carbon Hub, 2010). Emissions from heating water and space can be reduced through better specified materials, improved workmanship in the construction of the dwelling and more efficient boilers. They can be further reduced by the use of heat recovery systems and a range of technologies such as air and ground source heat pumps, biomass and potentially combined heat and power units. Once emissions from heating have been reduced offsetting the emissions stemming from the other sources, and any remaining emissions from heating, relies on the active generation of energy on- or off-site. The potential for onsite generation at a dwelling level depends on dwelling type. For example, the use of photovoltaic cells to generate electricity, for example, depends significantly on, among other factors, the area of roof space available per unit. This area is much higher in detached houses than it is in high rise apartment blocks. Different solutions may be more appropriate for sites with greater dwelling densities compared to sites with lower densities. Solutions may also be targeted at a community level (for example a biomass fuelled CHP unit) or, alternatively, off-site renewable generation. The use of off-site renewable generation to offset the emissions generated on-site is termed an allowable solution within the CfSH. The exact nature and extent of the use of allowable solutions when meeting the emission targets set in the Code have not yet been specified.

To reiterate, the exact specification of a 'zero carbon' home is still developing. The definition of the carbon compliance level has helped. However, the lack of clarity surrounding the meaning of zero carbon, coupled with the unknown nature and extent of allowable solutions, creates a very uncertain business environment for house builders at the very time they are being asked to invest significant resources into developing new design and

production approaches. Indeed, the scale and scope of the challenge is such that it will require system-wide innovation in terms of new institutional arrangements, technologies and markets. To further compound this situation a great number of different technologies are competing to penetrate into the housing sector and provide a solution to lowering carbon emissions. The NHBC Foundation review of microgeneration technologies has 11 separate groups of technologies, many with multiple formats within each (NHBC Foundation, 2009b). No single technology will be appropriate for all situations. In combination, the uncertainty generated by the number of new technologies available and the lack of clarity regarding the meaning of zero carbon presents a very real commercial risk to the house building industry. The next section draws upon the technological development literature to provide a theoretical basis for understanding the potential dynamics at work as the new house building sector selects, absorbs and uses new, in this case microgeneration, technologies.

TECHNOLOGICAL DEVELOPMENT – KEY ISSUES FROM THE LITERATURE

Technological development within firms and sectors can follow two principal paths; either, multiple small, incremental improvements in products and processes, or through rapid, disruptive changes. Tushman and Anderson (1986) present a model of technological change where long periods of incremental change are punctuated by technological discontinuities. These punctuations are followed by periods of great uncertainty termed the era of ferment. In this period there is no dominant technology and a greater amount of competitive uncertainty. The emergence of a dominant technology reduces the competitive uncertainty and concludes the era of ferment. We speculate that the UK housing sector has entered into such an era of ferment with regard to microgeneration technologies. House builders are unsure which of the technologies, or group of technologies, are likely to assert themselves as the dominant way of achieving the energy saving and onsite generation required in the CfSH.

Dominant technologies emerge through a combination of both disruptive and incremental changes. The opening of the market through disruptive changes allows the entry of radical new technologies which have the potential of significant performance and/or cost benefits over the existing technologies. These technologies are often not proven and learning has to occur to exploit them – in combination, they create business risks and uncertainty. From the growing number of alternatives one (or perhaps a group) of technologies begin to establish a dominant position within the industry. This technology is then refined over time through a series of smaller, more incremental improvements. Dominant technology evolution is often not based on pure rational choice. A wealth of factors, including political, economic, technical and individual, contribute to the emergence of a dominant technology and its supporting practices.

The construction industry in the UK, particularly the house building sector, is presented as having a low level of internally sourced innovation. A great deal of innovation within the industry is driven by compliance to regulation rather than competition on performance. Using Pavitt's (1984) typology of industries the construction industry would be classified as supplier-dominated. Supply-dominated industries source most of their innovations from outside of their sector and act as carriers for innovations from other sectors. The supply chain of the construction industry is the primary source of product innovations. This is the case with microgeneration technologies. The new technologies will be supplied by companies external to the house building sector. In this environment where supply chains are the primary mechanism of innovation, factors such as marketing, incentivisation and

relationship capital can become even more influential in determining which technology emerges as dominant. Particularly as often the industry is looking to its supply chain to provide a solution to meeting a regulatory requirement and not to differentiate its product through performance.

The challenge of meeting the targets presented in the CfSH has the potential to cause both component and architectural innovations in the standard designs used by the house builders (Henderson and Clark, 1990). Component innovations are changes in individual elements of a design with no changes in the relationships between the components. Architectural innovation is a change in the relationship between the components with no changes in the components themselves. This classification of technologies is useful when considering the affect that microgeneration technologies have on the standard design of a home. Some technologies, such as photovoltaic cells, are 'bolt on' component innovations that demand little change in the standard design. Others, such as ground source heat pumps, may require alternative heating systems within the home, such as under floor heating, which requires different designs and construction processes each with their associates skills, competencies and knowledge.

There is currently no empirical research within the housing sector to support the industry in dealing with the challenge of dominant technology selection. Although it is unlikely that dominant technology selection can be managed in the strictest sense of the word understanding how it can be encouraged and what factors could steer selection would be of immense value. To begin to address this stemming from this work should be a deeper understanding of how dominant technologies emerge with the construction industry, how they gain purchase and traction and breakthrough into the mainstream. The work will provide evidence for the effects of these technologies once they arrive within the industry and how the arrival of these technologies can be better steered and prepared for.

METHODOLOGY

The development and execution of this research has been underpinned and defined by industry and academe working together in an iterative process of coproduction. Throughout this work the research questions, aims and methods have been jointly guided by input from the research staff and from senior representatives with the UK house building sector. For each package of the work discussion papers have been produce and passed between the partners until a consensus has been reached. This method of communicating has been supplemented by regular meetings, phone call and e-mail discussions. The discussion papers have provided the main vehicle for capturing, refining and reaching agreement upon ideas.

The work has been split into two phases and the first phase will inform the development and execution of the second. Phase one focuses on the challenge of identifying and shaping the emergence of the dominant microgeneration technology while phase two seeks to understand more completely how people are accepting, or not, these new technologies into their homes and daily practices.

Phase one approach

Rogers (1995, p.14) developed five criteria which influence the rate at which innovation diffuse, if they do so at all. These criteria are:-

- *Relative advantage* – the degree to which a new innovation is perceived by the housing developer as being better than the previous.
- *Compatibility* – the degree to which an innovation is perceived as consistent with its existing capabilities and the needs of potential users.
- *Complexity* – the degree to which an innovation is perceived as relatively difficult to understand and use.
- *Trialability* – the degree to which an innovation may be experimented with on a limited basis.
- *Observability* – the degree to which the results or the benefits of an innovation are visible to others.

Although it is possible to contest if these criteria are appropriate for the diffusion of process based innovations they do provide a useful framework to analyse the uptake of product based technologies such as microgeneration technologies.

Rogers' criteria were used to inform the development of a web-based questionnaire. The questionnaire contains both open and closed questions to establish both the current use of microgeneration technologies and the trajectory of their use i.e. to establish if the current used technologies are becoming more entrenched within the sector or losing their position to other competing technology. The survey also explores the reasoning behind why one technology is selected in preference to another.

The most difficult aspect of deploying any web-based research tool is control over the sample set. While this remains a challenge several steps were introduced in order to minimise problems generated by inconsistencies in the sample set. Firstly, invitations to participate in the survey were sent by our industrial partners through their contact databases to increase the legitimacy of the work to the participants. Secondly, the first two questions in the survey were used to identify if the respondent was involved in the process of building new homes (from concept through to handover and sales) and if the respondent had previously answered the questionnaire. In the first case those not directly involved in the house building sector were thanked for their time but prevented from answering any further questions. In the second case respondents were directed to a different version of the survey to capture what had changed in their opinions and why since the first time they had completed the survey.

Invitation to participate in the questionnaire was sent to 3,000 individuals involved in the design, construction and sales of new housing. Individuals were selected so as to give an even distribution of participation geographically. Although other criteria could have been used to stratify the sample set this was the most practical and simplest to control across the partners' distribution lists.

In order to maximise response rate the invitation to participate in the survey was sent as part of a wider series of structured communications. One week prior to the survey being released an initial message was sent by the industrial partners through their distribution lists. This message emphasised the importance of a piece of research to raise the legitimacy of the research in the eyes of the respondents. The e-mail clearly indicated the nature of the research, a time line and reinforced the independence of the researchers and autonomy of responses. One week following this initial message the industrial partners sent an invitation to participate in the survey. This message contained the link to the survey and another statement to the importance of the research, an indication of the commitment (i.e. 20 minute web-based questionnaire), a statement relating to informed consent (covering data protection

and research ethics). Following the invitation to participate a reminder message was sent each each following Friday afternoon for 3 weeks. The survey then closed.

Phase two approach

Phase one of the project addresses technology uptake and trajectory. Phase two of the project follows on and engages the same challenge from a different perspective. Meeting the emissions reduction targets set out in the introduction will require individuals to accept and use the new technologies within their homes. This adds another complex dimension to the design of homes. Should designers and engineers design for the optimum technical performance or try to accommodate user's behaviour and practice? Designers and engineers often assume that people use buildings and the technologies in a rational, predictable way that optimises performance. The decision making process of the 'rational user' is driven by logic and reason often rooted in stark performance comparisons and economics. In truth, actual behaviour is often some distance from this 'ideal' decision making and can appear whimsical and difficult to predict. On a daily basis our behaviour is shaped by a plethora of factors including economic, cultural, social and behavioural.

Technologies can and do shape our behaviours and practices. Where we sleep, eat and socialise within the home is often directed by where the kitchen, bedrooms and living spaces are (Shove, 2007). This is not to say that the layout of our homes dictates these practises only that it has a part to play in them. Over time people often change their homes to better accommodate their practices or the practices which they aspire to (for example, put in an extension to accommodate a growing family, reorganise a kitchen to encourage family meals etc.).

This co-evolution of home and practice can be in stark contrast to the challenge laid down by very new, disruptive technologies. In particular, technologies which have specific user behaviour 'scripted' in. These are technologies in which the designers have particular user behaviour in mind and attempts to 'foolproof' against other patterns of use, forcing the user to comply with the technologies intended use. This often leads to the intended benefits of the technology not being realised and its use being 'subverted' or abandoned all together through 'workarounds.'

This phase of the project will deploy an ethnography like approach to study the everyday 'lived in' experiences of people living in homes incorporating microgeneration technologies. Ethnographic approaches such as interviews, observations and shadowing will be used to build up a detailed understanding of the way in which home occupiers interact with the technologies incorporated within their homes. Detailed study of these interaction will reveal how our sample group affect, and are affected by, these technologies in the context of the environment where the interaction takes place. This approach will provide a narrow but deep, and hence qualitatively rich, understanding of the day to day interactions, both constructive and destructive, which take place with the new technologies entering the home.

The research team will then begin the ethnographic-like study using the following broad plan:-

- Meeting 1 (60 minutes) – establish family/participant background, previous experience of MGTs, dwelling history/background, establish participant's relationship to the 'green agenda' and motivations for living in a low carbon home, brief introduction to the home, capture of 'headline' issues.

- Meeting 2 (60 minutes) – further explorations of benefits and limitations of living in a low carbon home, demonstration of some of the technologies (if possible), identification of supporting or destructive practices (workarounds), identification of modification of behaviours and practices enabled, or not, by MGTs.

- Meeting 3 (60 minutes) – final meeting to expand upon any issues raised in the previous two meetings and to explain to the participants the next steps in the research.

A very important factor for the success of ethnography is access to, and willingness of, the participants to be involved in the project. Access to participants is being provided through the industrial partners on the project. A minimum of three visits to each home will be conducted to build up a relationship between the researcher and participant and to allow trust and confidence to develop. The researcher will aim to be as unobtrusive as possible while guiding the participant to demonstrate and talk about their interaction with the technologies within their home. During this time the researcher will be making observations of the layout, use and interactions with the technologies within the home. Where appropriate the researcher may take images or recordings of these interactions.

The sample set will include up to 20 homes spread across two different locations. The sample set will encompass different home user profiles (families, individuals, couple etc.), different primary microgeneration technologies and different periods of time living with the new technologies.

PHASE ONE UPDATE

A total of six discussion papers, three for each phases, have been written and have been through a series of drafts to reach a consensus on each of the topics covered. The discussion papers have been through 3 to 6 iterations each. This approach had provided a common ground upon which to base conversations and the development of the research methods and strategy.

The broad structure of the survey questionnaire maps onto the theoretical framework set out in Rogers (1995) as detailed in the ‘Phase 1 approach’ section above. As would be expected, demographic information about the respondent is captured. This information includes details about the individual replying but also the company they work for. We then move on to interrogate which low- and zero-carbon technologies the respondent would consider using in a variety of dwelling and site types (greenfield vs brownfield vs conversion, terrace vs semi-detached vs detached vs apartment). Having established which technologies the respondent would consider using in which situations the respondent’s opinions on various factors relating to the low- and zero-carbon technologies are established. These factors broadly map onto the Rogers’ criteria and goal will be to investigate which factors are, or are not, important in shaping which technologies are deployed. Up until this point the data collected is set in the present. Having questioned which technologies are used in which sectors, and having looked at which factors appear to have shaped the inclusion of these technologies, the survey then asks about the respondents their opinion of future trajectories. In doing this we hope to identify which technologies are likely to become more entrenched and which less so.

At the time of writing the web-based survey is live and data is being collected. The iterative cycle of co-production deployed in this research has taken time but has led to a robust, industrially relevant research tool. Data collection will be complete by the end of May 2011 and we will report the results in future papers.

The results from this phase of the project should provide a comprehensive picture of the current low- and zero-carbon technology use. The data should illuminate the important factors shaping the selection of which technologies to use and give an indication of which technologies the sector feels are likely to become dominant. This will be of great interest to the house building sector as greater understanding of how dominant technologies emerge within the house building industry provides them with additional information with which to plan and to manage their risks.

CONCLUSION

Although the project it reports on is still very much a work in progress this paper lays out the challenges facing the UK new build housing sector in meeting the requirements of the CfSH. The various levels of the Code and the carbon compliance level are introduced in the context of meeting the Government's carbon reduction obligations. The challenges of both reducing the consumption of energy and of generating energy on-site are outlined framed by the different levels of the Code. Some of the uncertainties in the environment in which the house builders operate, stemming from the lack of absolute definition of zero carbon, the nature and extent of allowable solutions and the number of new to the sector technologies are identified.

The problem facing the industry in correctly identifying which of the different technologies is likely to become dominant is described. This problem represents a very real commercial risk in where to invest in supply chain and skill development, how to design and construct homes which perform reliably and how to market and sell homes which contain microgeneration technology. Phase one of the project, by addressing technological uptake and trajectory, will deepen our understanding of the factors shaping the uptake of technologies in the sector. Phase two of the project will provide a rich, qualitative insight into how microgeneration technologies are accepted into everyday routines and practices.

Phase one of the project will be complete and the data and analysis ready to present at the time of the conference.

REFERENCES

CLG, (2006). '*Code for Sustainable Homes: A step-change in sustainable building practice*', Department for Communities and Local Government, Communities and Local Government Publishers, Wetherby. [WEBDOC] available at http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf assessed 28th January 2011.

DECC, (2008). '*Climate Change Act 2008: Impact Assessment*', Department for Energy Change and Climate Change. [WEBDOC] available at http://www.decc.gov.uk/assets/decc/85_20090310164124_e_@@_climatechangeactia.pdf accessed 15th January 2011.

Henderson, R.H., and Clark, K.B., (1990). 'Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms', *Administrative Science Quarterly*, **35**, 9 – 30.

NHBC Foundation, (2009a). '*Zero carbon homes: An introductory guide for house builders*', NHBC Foundation, Amersham, Buckinghamshire. [WEBDOC] available at <http://www.nhbcfoundation.org/LinkClick.aspx?fileticket=8/949UUO/W4%3D&tabid=339&mid=774&language=en-GB> assessed 28th January 2011.

NHBC Foundation, (2009a). '*A review of microgeneration and renewable technologies*', NHBC Foundation, Amersham, Buckinghamshire. [WEBDOC] available at <http://www.nhbcfoundation.org/LinkClick.aspx?fileticket=UzYVWRQW/TY%3D&tabid=339&mid=774&language=en-GB> assessed 28th January 2011.

Pavitt, K., (1984). 'Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory', *Research Policy*, **13**, 374-73.

ODPM, (2005). '*Proposals for introducing a code for sustainable home*', Office of the Deputy Prime Minister, London. [WEBDOC] available at <http://www.communities.gov.uk/documents/planningandbuilding/pdf/142865.pdf> accessed 15th January 2011.

Rogers, E.M., (1995). 'Diffusion of Innovations', 5th Edition, Free Press, New York.

Shove, E., (2007). '*The Design of Everyday Life*', Oxford International Publishers Ltd., Oxford, UK.

Tushman, M.L., and Anderson, P., (1986). 'Technological Discontinuities and Organizational Environments', *Administrative Science Quarterly*, **31**, 439-465.

Zero Carbon Hub, (2010). '*Carbon Compliance: What is the appropriate level for 2016? Interim Report*', Zero Carbon Hub, Milton Keynes. [WEB DOC] available at http://www.zerocarbonhub.org/resourcefiles/Carbon_Compliance_Interim_Report_16_12_10.pdf assessed 28th January 2011.