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Title: A UK Practitioner View of Domestic Energy Performance Measurement

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Abstract

There is a growing body of evidence concerning the energy efficiency performance of domestic buildings in the UK, driven by policy-based agendas, such as the need for zero carbon homes by 2016 for new build homes, and Green Deal and ECO for sustainable refurbishment. While there have been a number of studies funded and results presented in this area, little work has been done to understand the drivers, practices and issues of data collection and analysis. There are a number of major building performance evaluation studies in the UK, yet behind many of these research projects are practical issues of data loss, experimental error, data analysis variances and resident issues that are common when studies move from the actual to the *living lab*. In this paper the issues of domestic energy are addressed by leading Building Performance Evaluation (BPE) practitioners in the UK. They identify issues of client demands, technical failure, costs and implementation. This work provides insights of both academic and industry-based practitioners and considers, not only the practicalities of building performance studies, but also considerations for these types of studies in the future.

Keywords: Buildings, structures & design, energy conservation, field-testing & monitoring

1. Introduction

Research into domestic energy performance of buildings has grown in recent years in response to the policy agenda. There have been a large number of projects as identified by Gupta and Gregg (2012), including the Building Performance Evaluation (BPE) Programme (Menezes et al., 2012) undertaken for Innovate UK (TSB), as well as other grant funded and private research. The drivers to undertake research vary. Government requires an evidence base (DECC, 2014) to drive and inform policy, while the manufacturing and installation companies need to understand the evidence for the performance of their products and services. There has been a long-standing argument that buildings rarely perform as modelled in the field (Jaffe & Stavins, 1994; Zero Carbon Hub, 2013, 2014). The reasons for this have been widely discussed (Bordass et al., 2001; Wingfield et al., 2008; Wingfield, 2011; Zero Carbon Hub, 2014). The growth in field-testing of domestic properties and products has not been balanced by a wider discussion about the methodological issues of gathering data in the field.

Nine experienced UK domestic practitioners from the Innovate UK Domestic BPE Panel were interviewed to investigate their perspectives of the issues of the methods and practical issues of fieldwork and analysis. What emerged is a pattern of practices that potentially point to a measurement and analysis gap that needs to be addressed to better understand the problems of building performance (Stafford, Bell, & Gorse, 2012).

The introduction of the Climate Change Act (2008) created a legislative binding target to reduce CO_2 emissions by 80% by 2050. In 2010, the UK domestic housing stock accounted for approximately 27% of UK CO_2 emissions (Palmer et al., 2011). This policy agenda provides a potential driver to better understand the performance

of the existing housing stock in terms of its energy use and CO_2 emissions. The new build market delivered 109,370 homes in 2013 (DCLG, 2014) and is subject to building regulations, specifically Part L of the Building Regulations that relates to fuel conservation and has become more stringent in recent years. There is a requirement for zero carbon homes by 2016. This places pressure on the UK house builders to understand how to achieve these levels of performance (Osmani and O'Reilly, 2009). New build housing has been identified as suffering from a performance gap, the gap between designed and measured performance (ZCH, 2013, 2014). It is perhaps only recently that consideration of the measurement side of the equation has been given more thought. The understanding of a potential measurement gap by the industry, driven by methodological issues of domestic building performance evaluation, is of interest to the policy makers, manufacturers, installers, stockholders and end users.

There are approximately 26 million homes in the UK (Swan et al., 2013) and of this existing stock 70-80% will remain by 2050 (Ravetz, 2008). In terms of policy ambitions for emissions from the domestic sector, this is the biggest challenge (Kelly, 2009). In the retrofit market, the Green Deal (Dowson et al., 2012) has been implemented as part of the Energy Act 2011. The Green Deal is a loan facility attached to the property that uses potential energy savings to fund improvements to the property, such as insulation, or new heating systems. The Green Deal loan is currently constrained by the golden rule that requires that the savings of energy must be equal to or more than the cost of the loan, leaving the occupant no worse off than if they had not taken out the loan (Guertler, 2012). These savings are modelled using the often criticised RdSAP model (Wetherell and Hawkes, 2012). The Energy Company Obligation (ECO) is a form of supplier obligation. There are three types of ECO, all of which deliver a range of retrofit improvements to properties, with many similarities to the Green Deal in terms of eligible measures, which are modelled using RdSAP.

An accurate view of the performance of individual actions and packages of measures both prior and post-installation is important. There are policy and financial interests that rely on data provided by the BPE sector, this is an industry that is difficult to fully identify, perhaps due to its broad range of activities that might be determined as BPE.

2. What is Building Performance Evaluation?

The growing research into building performance is largely driven by energy consumption and its related outcomes (Gupta and Gregg, 2012), such as ventilation, condensation and issues of building pathology. However, this is a more complex issue than merely measuring the energy consumption of the property; boundary conditions, building fabric and form, systems, controls, and occupant factors, such as comfort, health, economic and psychological factors, all come into play when evaluating not only performance, but underlying factors that drive this performance (Oreszczyn and Lowe, 2010).

Leamen et al. (2010) focused mainly on commercial buildings and identified that building performance evaluation falls into the category of real world research and this position is equally applicable to domestic properties. This highlights the practical nature of building performance problems identified and determines that Building Performance Evaluation should create *actionable knowledge*. This school of thought builds on the work of Bordass et al. (2001) that looked at practical tools for commercial buildings. It identified a wide number of potential outcomes and embeds building performance evaluation within a practical research philosophy. Gupta and Gregg (2012) outlined the current research profile of energy and buildings in the domestic sector and identified the sheer complexity and range of research questions

that are covered. They also identified how research questions are shaped depending on where the focus of outcome is placed.

While it is not the intention to address the debate of the philosophical structure of building performance energy research, it is clear that there is an important debate to be had about both why and how we undertake this research in this strategically important area. While BPE generally addresses both domestic and non-domestic buildings, in order to bound the discussion we have considered the question of how the heating energy performance of a domestic building is measured. It is recognised that energy consumption is expansive and includes issues such as lighting, appliances and cooking (Palmer et al., 2011). The focus here is on the key variables that influence heating energy performance; fabric, systems and occupants.

2. 1 What do we measure when we evaluate Building Performance?

The measurement of energy consumption in domestic properties, as discussed by the interviewees, could be viewed as a mixed method case study (Johnson and Onwegbuzie, 2004) reflecting the range of qualitative and quantitative factors as identified below. While larger statistical studies can describe performance at the highest level, such as Shipworth et al. (2010), the Housing Energy Fact File (Palmer et al., 2011) or the National Energy Efficiency Database Framework (DECC, 2011), the BPE professionals interviewed here look at the underlying reasons that shape energy performance and so have a more detailed focus that considers the interrelationships between elements of individual properties or groups of properties.

Boundary conditions have a major impact on the performance of the properties (Karlson and Moshfegh, 2006). Clearly, the external temperature will influence internal temperature and so must be measured. Additionally, energy inputs from

solar gain in the fabric and through glazing will impact the internal temperature of the property (Centre for the Built Environment, 2010). Wind will impact the performance of the fabric as it alters the convective heat loss of elements and can also lead to wind washing (Yazdanian and Klems, 1994; Ito, Kimura, and Oka, 1972), and although not widely researched, rain has an impact on the conductivity performance of the building fabric (Blocken and Carmeliet, 2004).

A further consideration is the fabric of the building itself. Major issues are the losses and gains related to the property through conduction and convection. Conduction gains and losses are through the different elements of the building fabric and is determined by the conductivity of the elements, measured in the U-Value (Anderson, 2006). Typical approaches are heat flux measures of building elements (Baker, 2008) or whole house approaches, such as co-heating (Sutton et al., 2012). Heat may be lost or gained through convection, when air passes through the fabric of the building transmitting heat energy. This is commonly measured using an air permeability test, which measures the air supplied to the building per m^2 using a pressure differential of 50Pa (ATTMA, 2010). These types of analyses link to building surveying and pathology, the underlying factors in fabric performance, such as thermal bridging due to poor design or construction, that might drive actual performance, as highlighted by the Zero Carbon Hub Report (2014). While important these have not been directly covered as the study focuses on the standard data collection tools of domestic BPE as identified by the interviewees. The heating system performance is an additional element that requires an understanding of energy inputs and efficiency of the system. This is commonly a heat source and a series of emitters, such as a wet radiator system. The heating system may be measured in terms of energy consumption and heating output, to understand the efficiency of the system (Energy Savings Trust, 2010).

The internal environment must be measured to understand the relationship between consumption and outcomes. This has an influence in locating energy efficiency in terms of outcomes for the occupant i.e. how much is energy is used to attain a certain level of comfort. To understand heating energy, the primary measure is internal temperature, generally gathered in multiple locations throughout the property. Additionally, due to their impact in occupant comfort, relative humidity and internal ventilation data may be collected.

Finally, an understanding of the occupant is essential. How the individuals manage their comfort, their physiology and psychology, as well as a number of socio-economic factors (Nicol et al., 2012). In these interviews we have investigated the process of collecting data from the occupant and their role in the wider BPE process in occupied properties, rather than their influence on energy performance.

In summary, this study focused on the reasons for undertaking studies and the practical issues of collecting data and presenting results, rather than investigating the underlying theory of BPE and its constituent theoretical elements. The goal is to understand the practice of data collection and analysis that can influence findings from the practitioner perspective.

3. Methodology, sample and analysis

The study focuses on the practice and experience of experts in measuring the energy performance of domestic buildings in the UK. The study objectives were to explore the understanding experts had of their role in measurement, their practice and approach to measurement and their reflections about this process. The sample frame used to identify respondents (i.e. experts) was the Technology Strategy Board's BPE Panel, which is made up of 42 academic and industry experts in the

field. Each was contacted via e-mail or phone and the nature of the study discussed. This initial framing of the study considered BPE as a whole as a starting point. However, all of the responses came from the Domestic BPE panel. At the time of the study, this panel contained 23 individual experts. Of these, nine agreed to participate in the study. The study took an exploratory approach, with no pre-formed hypothesis in order to avoid a research bias. Semi-structured interview methods were used. As Burman (1994) identified, such methods offer opportunities to not only identify the details as to what is done, but also the "*contradictions and complexities"* (p.50) as to how things work in practice. The question themes were;

- How did the interviewee define BPE?
- What tests and data collection approaches did they take?
- How were tests defined and commissioned?
- What were the practical issues of data collection?
- What were the issues around data analysis and reporting?

The interviews were undertaken face-to-face and via telephone and were audio recorded. These interviews were then transcribed verbatim. All respondents were assured of their anonymity. The details of the sample are described in Table 1. The respondents come from a range of different backgrounds. Although most came from the building professions, two individuals with the least BPE experience came from a physics background, which may indicate an increased level of scientific engagement with buildings and energy. Those with the greatest experience came from backgrounds more traditionally associated with building performance, such as architects, energy managers and building services engineers, professions more closely associated with engineering rather than pure science.

The qualitative software package QSR Nvivo was used to store, manage and analyse the textual data. A sequential approach to thematic analysis was used following the guidelines of King and Horrocks (2010). The analytical strategy involved a process of reading and re-reading of the transcripts and sifting the text into key issues and themes.

4. Findings

The following section highlights the thematic responses from the interviewees. While the interviewees were asked to reflect on their own practice, they do consider the wider BPE sector as a whole.

4.1 What is Domestic Building Performance Evaluation and what is it for?

There was a shared view with regards to context of what entailed building performance. All of the practitioners had been involved in both commercially funded and Government funded projects.

> *"Different people do it (BPE) for different reasons. A lot of people… are quite interested in issues of health. It's [BPE] … to see if they are using energy in the same way. That's a starting point for a lot of projects… It is things like this that clients are asking. Is this stuff that we spent a lot of money on and fitted actually working or not?" Interviewee H*

The performance gap between the designed and the actual performance of buildings was seen as the major issue by many of the interviewees.

"My own personal view is that it should be a fundamental part of the construction process. I can conceive of no other sort of design in which it wouldn't be acceptable to see if the thing you designed actually works or not." Interviewee H

There were concerns from six interviewees around the difficulties of defining research questions for BPE projects. Given the range of techniques available and the varying conditions between properties, the respondents indicated that while often quantitative in nature, the studies appeared to be better defined as mixed method case studies. The propositions of those case studies are driven by the desired outcomes, with appropriate data collection being applied. However, seven of the interviewees highlighted that the question was often shaped by the more prosaic issues of who paid for the work and how much resource was available.

All of the interviewees' views on what elements constitute building performance evaluation were expressed in terms of the individual tests that were used in concert to establish the performance of the building. These ranged from fabric tests, environmental monitoring and understanding of the occupant when addressing occupied properties. This reflects the perceived socio-technical nature of the research question. The interviewee skill sets with regards to carrying out specific tests varied, but all understood the wider range of available tests. The greatest variation was between those that engaged with occupants and internal environments (3 interviewees) and those that tended to focus solely around building fabric (5 interviewees). Interviewee B reflected the whole house perspective that was shared by the all of the interviewees,

"If you call a whole dwelling a product. That is looking at most aspects right from ventilation right through to fabric performance." Interviewee B

The fabric tests referenced in the interviews were thermography, air permeability tests, in situ U-values and whole house heating tests, such as co-heating. All of these were viewed by at least one of the interviewees as not being without difficulties. Interviewees A and B identified that thermography has a powerful visual impact but also has a number of complexities in its delivery due to wind, solar and temperature differentials between the inside and outside of the properties for reliable results, issues also raised by Balaras and Argiriou (2002).

> *"Thermography is the flavour of the moment, because it's very visual and it's very useful too. But comparing two buildings at potentially two years apart in the study will yield different results." Interviewee A*

Internal and external environmental monitoring were identified by all of the interviewees as within their skill sets. This included temperature and relative humidity, ventilation measures, sometimes using CO_2 as a proxy measure, energy consumption and weather data. Where the sample diverged was with their inclusion of resident data. This did not appear to be a philosophical decision, rather it was based around skill sets, as noted above. Interviewee B identified themselves as a fabric specialist.

> *"For me, personally, you have to understand how the fabric of the dwelling works before you can then ascribe anything to what an actual what the occupants…" Interviewee B*

Interviewee H identified themselves as a post-occupancy evaluation specialist and therefore focused more strongly on occupants as part of the research process.

"I think one of the other techniques that I've used pre retrofit would be something … like a comfort satisfaction study. That tends to point you in a much better direction than most data will, because that's the actual things that people notice in buildings that they actually care about." Interviewee H

Despite these differences, the view of the group was that all of the issues were important, but they focused on their specialisms, potentially identifying the need for multi-disciplinary teams in the whole house assessment.

4.2 Clients for domestic Building Performance Evaluation

The shaping of the research question, as well as the limitations of the study were identified as being driven by the knowledge, needs and aspirations of the client.

"It does vary depending on the nature of the client and the project and certainly the funding behind it." Interviewee H

Key clients highlighted by the interviewees were the UK Technology Strategy Board, as part of their Building Performance Evaluation Programme, which given the nature of the sample was clear. Another key client group was UK social housing, which as large stockholders of properties appeared to be driving some of the market, particularly in terms of evaluating the performance of retrofit.

"Social Housing wanting to know what return they are getting on their investment [in retrofit]." Interviewee A

However, Interviewee G stated another set of objectives for social housing.

"They [social housing providers] want somebody to say how well they've done and, indirectly, it's kudos, they want status and money. They have done it in order to attract attention and the attention comes back as a PR thing." Interviewee G

Manufacturers also are involved in commissioning BPE work in order to evaluate their products.

"We have, on occasion, worked for manufacturers where they are developing products. And in that sense, obviously it's essential they have a sort of before and after scenario." Interviewee E

The private commissioning of research of this type is not without its complications. The issue of bad news in consultancy work was raised by 5 of the interviewees in terms of how it impacted the independence of the research.

"There may need to be some degree of independence to this process in order that it's verifiable and that it's thorough and it's reportable and the people aren't "burying the bodies", so to speak. That goes back to the question of what do people do about bad news?" Interviewee H

There was also a perceived gap in understanding the need for effective monitoring by clients, which constrains not only the extent of monitoring, but also the perceived need.

"…that's usually down to the experience of the client in how to do an experiment. Largely, they are developers, builders, social housing and they

come from a completely different industry and don't recognise that need at all." Interviewee F

4.3 Project Constraints

The major constraints identified by the interviewees were the timing of the studies and costs. In terms of timing, difficulties were highlighted with regards to the ability of the interviewees to undertake effective pre and post monitoring, highlighted by Interviewee A.

"I would say there is too little emphasis placed on pre-…" Interviewee A

Another issue highlighted was the need to link monitoring to build programmes. This presented difficulties for two main reasons. The first was the issues of dealing with tests that are constrained by the heating season, such as thermography, co-heating and in situ U Values. The second was the issue of buildings not being *settled* after construction works, potentially giving rise to errors.

"Obviously, with construction timeframes….we've had a number of times [where] we've had to squeeze a test into the end of a heating season….We might be testing buildings that are too green. They have got a lot of moisture in there. That causes problems because obviously your materials might have high thermal conductivity because they might have moisture in there and also that you find you bring out a lot of moisture into the dwelling and then you could have problems such as mould." Interviewee B

The commissioning client often constrained the project by their ability to fund the project to fully answer the question at hand. Three of the interviewees identified that budgets often put clients off engaging with the process.

> *"When they are in the audience who are wanting to understand more about BP, but not done it before themselves hear some of the project costs, they get absolutely horrified and go, how much?" Interviewee A*

This can also lead to issues where the project may be potentially reduced. Interviewee D went on to indicate that the client could find people to deliver in the market place at reduced costs at the expense of rigour.

> *"When I mentioned £2,000 to do a job on it they just said, well, it's far too expensive. So then the bottom line. What can you do for £750? I said, we won't be doing anything for £750 because there is nothing that we would put our name to that's going to help you or the people involved, so take it or leave it." Interviewee D*

4.4 Equipment

Issues with equipment were a major issue for all of the interviewees. This was particularly the case where internal and external monitoring was undertaken. The interviewees identified four key issues; technical performance of the equipment, installation issues, battery life and communications.

The non-performance of equipment was a common problem.

"…a lot of the projects we are looking at bits of kit have gone wrong." Interview H

This was exacerbated by the fact that often it was difficult to establish when equipment failed, with failures often being discovered well into projects. Monitoring systems were often identified as being installed incorrectly, such as heat metering on heating systems, or sensors placed incorrectly leading to incorrect readings. The issue of communications, required when collecting data remotely, and battery life were also considered major issues by all the interviewees who used this equipment.

"Comms is the biggest problem and power is the second problem." Interviewee E

These basic technical issues can derail an expensive monitoring project.

"We use wireless sensors and they do fail. That is challenging and depending on when the battery goes, it can also be project killing as well." Interviewee F

Among those interviewees who undertook internal and external environmental monitoring, the consensus appeared to be that the market for equipment was immature, with improvements being made, but a perceived lack of robustness for field testing that injected a certain amount of risk into field based data collection.

4.5 Occupants

Assessing properties in occupation gives a detailed understanding of the property in use, but proved a major issue for those interviewees that worked in occupied properties;

> *"The biggest problem tends to be access. Getting access to houses, particularly. Once your equipment is in, you are relying on a certain amount of goodwill and cooperation from people in there to give you reasonable access and, with the best will in the world, you can make all the best endeavours to make sure you get access and sometimes you can just turn up and if there is no-one in and so access is an issue." Interviewee A*

This issue is also replicated in the authors experience, where a 40 sample study was subject to drop out and replacement rates of the sample of some 40% of the original agreed properties despite incentives. Additionally, access to the property does not guarantee co-operation;

> *"…in use monitoring, we have always got a problem with the people in there. We've got people… switching off loggers. Switching off sensors. Dropping in sensors in the bath." Interviewee B*

Additional examples include issues removal of sensors because they thought they would affect pets and blowing smoke into sensors. This was not universal; Interviewee F indicated high levels of engagement with residents. In terms of occupied properties, accessing homes, and engaging with them was identified as an essential skill when undertaking domestic monitoring.

4.6 Standards and data analysis

The recent growth of interest in building energy performance was highlighted as a problem in terms of maintaining quality and standards. Interviewee I identified that a

more detailed understanding of the practice in terms of setting questions, collecting data and drawing conclusions needed to be better established.

> *"…There is excitement that just needs to be curbed a little bit I guess and just make sure that we are doing it for the right reasons and we are monitoring the right thing." Interviewee I*

However, the issue of standards, even between respected professionals, was a complex one, with two individuals stating that they often developed their own approaches to solve specific problems.

> *"For me it's very similar with experiments. So you are always looking for a common point. At the moment, I don't see any of those common points in the methods. I would do things differently." Interviewee G*

However, despite stating their preference for their own solutions Interviewee I did respond to the growth in the sector with recognition of a need for more formal standards.

> *"I think there is a need for it, because if more people start doing this then it needs to be more kind of structured." Interviewee I*

The interviewees also considered how the data was presented in a way that decisions could be made.

> *"You just sit there and there is this wonderfully spiky line. What am I supposed to tell from that? Be a bit more savvy and think around it and start to come up with some more sensible presentations for data." Interviewee I*

The interviewees also indicated issues of monitoring teams sometimes not being aware of what the data might mean; due to a lack of experience in understanding building performance might lead to an inability to spot errors in the data or the drawing of incorrect conclusions. This potentially links back to the skills gap that the growth in the sector had created.

5. Conclusions

This study explored the debate surrounding practical methodological considerations of domestic BPE. Due to the sample size the study can only suggest tentative conclusions. Issues of experimental design, data collection error and fieldwork practicalities are not uncommon to any data collection and analysis exercise of this type. However, the area of building performance, particularly around energy is strategically important. The developing space for BPE in the domestic sector indicates that there are potential gaps in both measurement and analysis, which can undermine the need to address the performance gap by the wider construction industry.

Within the sector, there are movements to better understand the flow from data collection to actionable knowledge. It requires the development of a community of practice (Wenger and Snyder, 2000), where the issues of equipment, data collection and data analysis can be effectively debated. This space needs to recognise its failures as much as it’s successes if the debate is to be extended and the situation improved. To some extent this is already happening with leading institutions, both academic and professional, looking to establish such a network, although this is in the developmental stage.

Although the Technology Strategy Board (Technology Strategy Board, 2009) and Energy Saving Trust (Energy Savings Trust, 2005) have developed guidance for domestic monitoring the adoption of standards outside their own funded work was unclear. Many of the individual tests have ISO or British Standards (BSI, 1999: ISO, 1994) but the use of these requires commissioning clients to appreciate their existence. The distribution of standards among various bodies can mean that a mixed method case, such as that of domestic energy monitoring, brings a wide range of expertise to ensure key standards are recognised and adhered to.

The quality of the data collected is identified as only part of the problem. It is the conversion of this data, if of good quality, into useable data. There are multiple data streams, and qualitative data, that need to be analysed and presented into actionable information. This creates an argument for both an improvement in more widely available, robust analytical tools, and also an improvement in interpretive skills. The quality of data collection, analysis and communication all need to improve to better support the real problem of improving the energy performance of buildings.

References

Anderson, B. (2006). *BR 443 Conventions for U Value Calculation*. BRE. Watford, UK

Air Tightness Testing and Measurement Association. (2010). *Technical Standard L1 Measuring Air Permeability of Building Envelopes (Dwellings)*. ATTMA, Northampton, UK.

Baker, P. (2008). *In situ U-value measurements in traditional buildings–preliminary results*. Historic, Edinburgh, UK.

Balaras, C. A., and Argiriou, A.A. (2002) Infrared thermography for building diagnostics. *Energy and buildings* 34(2): 171-183.

Blocken, B., and Carmeliet, J. (2004). A review of wind-driven rain research in building science. *Journal of Wind Engineering and Industrial Aerodynamics* 92: 1079-1130.

Bordass, B., Leaman, A., and Ruyssevelt, P. (2001). Assessing building performance in use 5: conclusions and implications. *Building Research & Information* 29(2): 144-157.

BSI (1999). Thermal performance of buildings. Qualitative detection of thermal irregularities in building envelopes. Infrared method. BSI, London, UK

Burman, E. (1994) 'Interviewing', in P. Banister, E. Burman, I. Parker, M. Taylor, and C. Tindall (Eds) *Qualitative Methods in Psychology*. Open University: Buckingham, UK

Centre for the Built Environment (2010). *Whole House Heat Loss Test Method (Coheating)*. CEBE, Leeds, UK

Department of Communities and Local Government (2014) *Housing Statistical Release.* DCLG, London, UK

Department for Energy and Climate Change (2011) *National Energy Efficiency Data Framework: Report on the development of the data- framework and initial analysis*. DECC, London, UK

Department of Energy and Climate Change (2014) *Developing DECC's Evidence Base*. DECC, London, UK

Dowson, M., Poole, A., Harrison, D., and Susman, G. (2012). Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal. *Energy Policy* 50: 294-305.

Energy Saving Trust. (2005*). Post-construction testing – a professionals guide to testing housing for energy efficiency* (2005 edition). Energy Saving Trust, London, UK

Energy Saving Trust . (2010). *In-situ monitoring of efficiencies of condensing boilers - TPI control project extension*. Energy Savings Trust, London, UK

Guertler, P. (2012). Can the Green Deal be fair too? Exploring new possibilities for alleviating fuel poverty. *Energy Policy* 49: 91-97.

Gupta, R., and Gregg, M. (2012). Appraisal of UK funding frameworks for energy research in housing. *Building Research & Information* 40(4): 446-460.

ISO (1994). ISO 9869: 1994 Thermal Insulation - Building elements - In-situ measurement of thermal resisitance and thermal transmittance. International Organization for Standardization, Geneva, Switzerland

Ito, M., Kimura, K., and Oka, j. (1972). A field experiment study on the convective heat transfer coefficients on exterior surface of a building. *ASHRAE Transcripts* 78(1): 184-191.

Jaffe, A. B., and Stavins, R. N. (1994). The energy-efficiency gap What does it mean? *Energy policy* 22(10): 804-810.

Johnson, R. B., and Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational researcher* 33(7): 14-26.

Karlsson, J. F., and Moshfegh, B. (2006). Energy demand and indoor climate in a low energy building—changed control strategies and boundary conditions. *Energy and Buildings* 38(4): 315-326.

Kelly, M. J. (2009). Retrofitting the existing UK building stock. *Building Research & Information* 37(2): 196-200.

King, N., & Horrocks, C. (2010). *Interviews in qualitative research*. Sage, London, UK.

Leaman, A., Stevenson, F., and Bordass, B. (2010). Building evaluation: practice and principles. *Building Research & Information* 38(5): 564-577.

Menezes, A. C., Cripps, A., Bouchlaghem, D., and Buswell, R. (2012). Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Applied Energy* 97: 355-364.

Nicol, F., Humphreys, M., & Roaf, S. (2012). *Adaptive thermal comfort: Principles and practice*. Taylor & Francis. Oxford, UK.

Osmani, M., & O'Reilly, A. (2009). Feasibility of zero carbon homes in England by 2016: a house builder's perspective. *Building and Environment* 44(9): 1917-1924.

Oreszczyn, T., & Lowe, R. (2010). Challenges for energy and buildings research: objectives, methods and funding mechanisms. *Building Research & Information* 38(1): 107-122.

Palmer, J., Cooper, I., Cheng, V., Summerton, P. and Cambridge Econometrics. (2011). *Great Britain's housing energy fact file 2011*. DECC, London, UK.

Ravetz, J. (2008) State of the stock – What do we know about existing buildings and their future prospects? *Energy Policy* 36: 4462 – 4470

Shipworth, M., Firth, S.K., Gentry, M.I., Wright, A.J., Shipworth, D., and Lomas, K.J. (2010). Central heating thermostat settings and timing: building demographics. *Building Research & Information* 38(1), 50-69.

Stafford, A., Bell, M., and Gorse, C. (2012). *Building Confidence - A working paper*. The Centre for Low Carbon Futures, Leeds, UK

Sutton, R, Stafford, A. Gorse, C. (2012) The Coheating Test: The value of a number. *International Energy Agency, Annex 58, Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements. Bilbao, Spain, April 2 - 4th 2012.*

Swan, W., Ruddock, L., Fitton, R, and Smith, L (2013) Adoption of sustainable retrofit in UK social housing. *Structural Survey* 31(3): 181-193.

Technology Strategy Board. (2009). *EST TSB Retrofit for the Future monitoring guidance document* . Technology Strategy Board, London, UK

Wenger, E. C., and Snyder, W. M. (2000). Communities of practice: The organizational frontier. *Harvard business review*, 78(1): 139-146.

Wetherell, S., Hawkes, J. (2011). Are SAP based assessments an accurate way of predicting the energy savings made through refurbishment? 'Buildings don't use energy, people do?' *Research Students' Conference on Domestic Energy Use and CO2 Emissions in Existing Dwellings (pp. 43-54)*. Bath: Centre for Alternative Technology .

Wingfield, J., Bell, M., Miles-Shenton, D., Lowe, B. and South, T. (2008) *Lessons from Stamford Brook – Understanding the Gap between Designed and Real Performance,* Report 8 from Evaluating the Impact of an Enhanced Energy Performance Standard on Load- Bearing Masonry Domestic Construction, Partners in Innovation Project CI 39/3/663, Leeds, Leeds Metropolitan University.

Wingfield, J. (2011). *Elm Tree Mews Field Trial – Evaluation and Monitoring of Dwellings Performance*. CEBE, Leeds, UK.

Yazdanian, M., & Klems, J. H. (1994). Measurement of the exterior convective film coefficient for windows in low rise buildings. *ASHRAE Transcripts* 94-14-4, 1087-1096.

Zero Carbon Hub (2013) *Closing the Gap Between Design and As-Built Performance – Interim Report.* ZCH, London, UK.

Zero Carbon Hub (2014) *Closing the Gap Between Design and As-Built Performance – End of Term Report.* ZCH, London, UK.