ANGLIA RUSKIN UNIVERSITY

THE FACULTY OF SCIENCE AND TECHNOLOGY

THE EFFECTIVENESS OF INSTALLATION AND COMMISSIONING PROCESSES IN DELIVERING NEW MASS LOW CARBON SOCIAL HOUSING

Terence Patrick Keech

A thesis in partial fulfilment of the requirements of

Anglia Ruskin University for the degree of

Professional Doctorate

Submitted August 2016

Acknowledgments

This research would not have been possible without the support, time and energy that so many people have selflessly provided me along the way. Firstly, I would like to thank my family, Suzie, Joseph and Alice, for their unending support, understanding and good humour, which has kept me going throughout the long and difficult times. I could not have completed the thesis without them and they deserve credit as part of the team that got me through.

I would particularly like to thank my supervisors; Dr Ian Frame and Dr Carlos Jimenez Bescos. Their guidance and encouragement throughout this Professional Doctorate has been invaluable. Their patience and good sense of humour have given me reassurance when struggling with the academic structure and vocabulary. I would also like to thank my practice-based supervisor Dr Peter Defoe, who whilst dealing with his own workload, has always taken the time to listen and support me with constructive feedback and ideas.

I am also very grateful and appreciative of the support I have received from my colleagues and friends at Calfordseaden, and for the opportunity to undertake the Professional Doctorate. Their continued support and kindness throughout the journey, especially Charlotte Aldhouse for help with the thesis structure and corrections, has been a great encouragement.

Finally, I would like to thank the client and construction teams that have helped me along the way. Their time spent filling in questionnaires, interviews and allowing me to observe and participate in their work has been part of an incredible journey, along which, I have made some great and lasting friendships.

ANGLIA RUSKIN UNIVERSITY
ABSTRACT
THE FACULTY OF SCIENCE AND TECHNOLOGY
PROFESSIONAL DOCTORATE

THE EFFECTIVENESS OF INSTALLATION AND COMMISSIONING PROCESSES IN DELIVERING NEW MASS LOW CARBON SOCIAL HOUSING

TERENCE PATRICK KEECH
AUGUST 2016

Purpose
This research explores the installation and commissioning performance issues with the goal to improve and develop new practice for low carbon homes. With changes adopted by government to reduce assessment in low carbon housing and the removal of the Code for Sustainable Homes, this research comes as a timely investigation of performance of mass low carbon new build homes in the UK.

Research Design
The research investigation is based on the epistemology of pragmatism. It uses the exploration of the existing literature and practice to investigate an approach to implementing improvement to performance within mass low carbon housing. The approach is explored primarily through a stakeholder wide survey, followed by site observations and interventions utilising the mixed methods with the action research methodology, on three separate projects. The research has generated empirical data which when analysed, both quantitatively and qualitatively, leads to the identification of a number of issues, which contribute to both the practical implementation and theoretical knowledge of low carbon technology performance in housing.

Findings
The research findings demonstrate that a structured and mutually agreed monitoring process set within a 'real world' learning environment, both on and off site, can contribute to the reduction of energy and carbon emissions through the installation and commissioning process. This research has found that by engaging at a practitioner level, in the day-to-day process, change can be instigated, demonstrated in a small way in the interventions cycle.

Conclusions
The research has demonstrated the practical implication that change through monitoring and training can achieve, with significant improvements in energy and carbon performance. It has also highlighted, from the practitioner perspective, the elements of change required to effect sustained improvement. In highlighting these changes, the research has indicated the barriers that exist to the change process, and in no way underestimates, the level of challenge required for change to be enacted. Therefore, from a practical perspective the research has given a voice to this issue of relatively limited research through stakeholder engagement. It has opened the opportunity for further research in an area, which could have a dramatic effect on the reduction of CO_2 in affordable housing.

Key Words: professional doctorate, installation, commissioning, low carbon, low energy, social housing, stakeholder research, monitoring, communication, knowledge transfer

Abbreviations and Glossary

- ADL 1 - Approved Document (Building Regulations Part L) 1
- ADL 2 - Approved Document (Building Regulations Part L) 2
- BIM - Building Information Modelling
- BRE - Building Research Establishment
- BREEAM - Building Research Establishment Energy Assessment Method
- CfSH - Code for Sustainable Homes
- CHP - Combined Heat and Power
- D&B - Design and Build Contract
- DECC - Department of Energy and Climate Change
- EPC - Energy Performance Certificate
- HA - Housing Association
- HCA - Homes and Communities Agency
- HIU - Heat Interface Unit
- OM - Organisational Memory
- PV - Photovoltaic Panel
- SAP - Standard Assessment Procedure
- RP - Registered Provider
- RSL - Registered Social Landlord
- VE - Value Engineering

- The Professional Practice - The current practice at which the research is engaged
- Commissioning defined as: Process by which an equipment, facility, or plant (which is installed, or is complete or near completion) is tested to verify if it functions according to its design objectives or specifications. (Oxford Dictionary 2014)

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Part 1 Research Introduction and Structure
Chapter 1

1.1 Introduction

This chapter provides an introduction to the thesis through a description of the research problem and rationale for the study. The background to professional practice and how this has influenced the research subject are discussed, along with the main and subsidiary research questions, which emanate from practice. The chapter will outline the structure of the research project and the thesis, giving a brief description of the professional journey to the start of the doctorate. To conclude the chapter will reflect on the context and the reasons for the research and the implications for professional practice.

1.2 Background to the Professional Practice

The professional practice from which the research is drawn is a multidisciplinary practice covering a range of consultancy disciplines in construction, including building services engineering covering mass low carbon new build homes. The extent of involvement within this field of construction includes design, inspection and monitoring services, with extensive involvement and collaboration with the construction industry. The practice has an integrated building services team, which also includes Code for Sustainable Homes (CfSH), Standard Assessment Procedure (SAP), Energy Performance Certification (EPC) and Building Research Establishment Energy Assessment Method (BREEAM) assessors. The benefit of this integrated structure allows a holistic approach to be taken to the building services design, assessment and monitoring of low carbon homes. This gives a wealth of knowledge and experience within the construction industry, equally balanced between Housing

Association (HA) clients and construction contractors, with which to explore mass low carbon housing.

1.3 The Research Problem

This research has developed from the multidisciplinary and collaborative approach of the practice, and the close involvement with mass low carbon homes. Low carbon affordable housing has been driven by the government's commitment to reduce CO_2 emission levels by 20% across the EU by 2020, and 80% by 2050, which remains the target in the UK under law (HM Government, 2006). As a consequence of these targets there has been a raft of legislation and guidance within construction to establish and drive compliance. In new build housing, compliance has been incorporated into the Building Regulations 'Conservation of fuel and Power' Part LD1A. The SAP assessment, a standard performance criteria for each dwelling to demonstrate compliance, linked with the EPC, is issued on completion of each new home by law. This process is used to confirm compliance with the building regulations and inform residents that their new dwelling is a low carbon home.

In 2006/7 the government introduced the Code for Sustainable Homes (CfSH) to further drive performance standards for new dwellings. CfSH has been mandatory for affordable housing since its instigation and for all new homes, through the planning process, since 2010. This sustainability assessment method, based on whole dwelling construction and energy use, has formed the second compliance method for housing. The CfSH requires a SAP and EPC assessment to be incorporated within the assessment process. Therefore, from a construction perspective there are three clear assessment methods driving low carbon homes development, and as such, the industry should be performing effectively via compliance.

However, this is not seen in the ‘real world’ of the construction project. Performance of low carbon homes are failing on a number of levels, indicating that ‘design’ and ‘as built’ construction vary considerably (Zero Carbon Hub, 2011). Ozorhon (2013) identifies that quality and process are underperforming, giving a cause for concern in the construction industry’s response to housing low carbon challenges. This research investigates aspects of this underperformance witnessed through practitioner engagement on low carbon housing projects.

Prominent amongst the issues, seen in practice, is the fragmented nature of performance at installation and commissioning stages for low carbon technologies. With the Design and Build contract (D&B) being the leading contractual arrangement for new build homes, it does have a tendency to lead to fragmentation in design and installation quality. Griffiths (1999), has found that ‘cost, risk and responsibility’, are the main reasons for selecting the D&B contract, and that quality often suffers as a consequence of the cost and risk management (BRE, 2008). This is seen ‘first hand’ on current construction projects especially within the current boom in construction activities. The research presents a much-needed exploration of the barriers and possible interventions, which could bring change to this under researched area. This is further supported by the Zero Carbon Hub, which identified:

> *‘the development of appropriate testing, measuring and assessment techniques is urgently required to enable the '2020 Ambition' to be demonstrated’ (ibid, 2014:p12).*

This research aims to explore, through the practitioner experience, the installation and commissioning performance barriers with the aim to improve and develop new practice for low carbon homes. Therefore, with the current changes adopted by government to reduce assessment in low carbon housing, with the removal of the Code for Sustainable Homes;

this research comes as a timely investigation of performance and its effects on mass low carbon new build homes in the UK.

1.4 Research Question

To enable the research to address the issues of installation and commissioning of low carbon homes the following research question and subsidiary questions are to be investigated:

How can installation and commissioning strategies for low carbon homes be improved?

Subsidiary questions:

1. What are stakeholder perceptions of low carbon technologies in new construction developments?
2. How can the installation process of low carbon technologies be better communicated during construction?
3. How can the commissioning process be enhanced to improve performance?
4. What intervention processes can achieve an effective installation and commissioning strategy in new mass low carbon homes?

The primary research question has been formulated to better understand the installation and commissioning processes and what barriers deter the ability for change. As part of the research at the professional practice level, the aim is to explore new working practice through the instigation of observation and intervention. The subsidiary questions represent facets of the main research question, developing an incremental exploration through the research. Trafford and Lesham (2012) observe that research questions have a distinct

advantage over other ways of conveying the research intention. In asking the question there needs to be an answer, and from a practice perspective those answers lead to the process of change in professional practice. It is important that the questions have boundaries and explicitly state the nature of the research. In this way the questions identify the elements of installation and commissioning of low carbon technologies as the primary research area. Each question enables the investigation to explore the theory, literature and practice to lend a significant contribution to current and future knowledge and practice.

1.5 Research Scope

The performance of new build low carbon dwellings is a substantial subject area with a considerable quantity of literature and research concentrated on post occupancy behaviour and technology operation. There is much less research focused on installation and commissioning of the technologies at the construction stages, with most of the research based on commercial buildings. Hopkins et al (2015) point to the apparent silence on the subject for UK housing development, recognising the need for the capture of the link from installation and commissioning to handover of the development. This research represents not only an opportunity to bring new knowledge to this area, but to improve practice and performance.

Gill et al (2010) identify that Low and Zero Carbon (LZC) technologies are adversely influencing the quality of the built home, an issue also identified by professional practice. However, the extent to which poor installation and commissioning are contributing to the impact, as well as the role of the various construction stakeholders, is little researched, and as such, the thesis concentrates its scope on this area.

The social housing sector has been selected as a research area for two reasons. Firstly, this sector has been the most affected by the mandatory introduction of the Code for Sustainable Homes from its inception in 2006, through Homes and Community Agency Funding (HCA), (DCLG, 2006). Secondly, the professional practice is predominately engaged in the housing sector with 70% of the consultancy services focused on social housing schemes. Therefore, access and experience in this area are established, adding credibility to the research through close collaboration with industry.

The professional practice has an established link with low carbon housing going back to 2005/6, with consultancy services based on design and monitoring in collaboration with housing associations, developers and contractors. This 'insider research' perspective contributes to the research and gives an understanding of the 'culture, strengths and weaknesses of the organisation' (Gray, 2011:p402). The scope of the research has therefore, adopted the perspective of the practitioner research (Gray, 2011) making best use of access to the stakeholders, exploring new working practice to improve low carbon housing performance at the construction stages.

The scope of the research is limited to installation and commissioning activities, and does not investigate post occupancy or maintenance services responses. Whilst these are contributory factors the research wishes to concentrate on the construction stages, investigating the level of performance and what is happening pre resident operation.

1.6 Justification for the Research

In addition to adding to the limited knowledge currently available for installation and commissioning of mass low carbon homes, the research is justified through the need to meet three criteria. Firstly, to engage in a unique practitioner led research project, within the

professional practice. Exploring and highlighting the challenges and barrier experienced in the domestic housing sector to achieve low carbon performance. Secondly, through the use of 'real world' observations and interventions demonstrate what those barriers mean for the opportunities to improve low carbon performance. Finally, as part of a practitioner research project, use an action research methodology 'to improve and implement change as a result of the research' (Koshy et al, 2011:p146).

1.7 Summary of the Thesis

The research investigation uses the epistemology of pragmatism. It undertakes to explore existing literature and professional practice to implement the improvement to performance of low carbon housing. This is investigated utilising mixed methods within the action research methodology. The research cycles include stakeholder wide exploration surveys, followed by site observations and interventions, on three separate projects. The research has generated empirical data, which contribute to both the practical implementation and theoretical knowledge of low carbon technology performance in housing at the construction stages.

The thesis is organised into 9 chapters, structured as follows:

Chapter 1: Introduction. Introduces the thesis and details the structure and the focus of the research to be carried out

Chapter 2: Installation, Commissioning and handover process in Low carbon homes - Engaging with the Literature. Defines the body of knowledge surrounding the research topic and acknowledges the literature in the field of low carbon homes. Subjects covered include the history and growth of government regulation and assessment, design and

building contract review, construction site management, relationships with subcontractors, knowledge management and installation and commissioning of low carbon technologies.

Chapter 3: The Research Design. Explains the research methodology indicating the conceptual framework, research approach, data gathering methods and ethical considerations. The chapter give justification for the use of mixed methods within action research and reflects on the theoretical and practical applications of the research methodology.

Chapter 4: Exploring the Problem. Defines the research problem in the context of the practitioner research. It introduces the stakeholder and practice elements of the project and details the structure of the stakeholder survey undertaken as part of the reconnaissance phase of the action research. The chapter details the development and structure of the questionnaire and reviews the data gathered for use in the structure of the observations and interventions phase of the action research. The data is explored for meaning and triangulated to validate the information obtained. The chapter ends with a reflection on the data obtained and the direction for the next phase of the action cycle.

Chapter 5: The Action Research Cycles – Plan for the Site Observations and Interventions. Defines the plan for the observations and interventions cycles and details the engagement with the key stakeholders, selection of sample sites and the route to engagement with the main and subcontractors on the sample sites.

Chapter 6: The Action Research Cycles – The Site Observations. Explores the observations of installation and commissioning on three sample sites for low carbon technologies using air source heat pumps, communal heating with combined heat and

power (CHP) and photovoltaic (PV) panels. The chapter reviews each site in turn, brings all the data together at the end to review, compare and reflect on the information obtained.

Chapter 7: The Action Research Cycles – The Interventions and Reflection on Change. Explores the two intervention cycles for monitoring and knowledge sharing from the three sample construction sites. The chapter draws together the interventions data from the sample sites and compares and reflects on the information obtained.

Chapter 8: Discussion of Findings from the Research. Discusses the findings from the reconnaissance, observations and interventions stages of the action research and reflects on the comparisons at each stage of the action cycle. The chapter reflects on the outcomes from the action research cycles and outlines the new working process 'Commission2 Perform' for future low carbon housing projects.

Chapter 9: Conclusions. Addresses each of the research questions and draws conclusions from the findings for the implementation of a change process for installation and commissioning of low carbon homes. The chapter details the limitations of the research and critically reviews the research methodology used for the thesis. The chapter concludes with a review of future research opportunities and a reflection on the research journey.

1.8 Chapter Reflection

This chapter has introduced the thesis, including a background and context to the research, indicating the involvement and collaboration between professional practice and the stakeholders involved in mass low carbon homes. It has given an identification of the research problem, outlining the issues and barriers influencing installation and commissioning performance. A list of the research questions is given emanating from the

research problem and indicating the direction of the investigation during the action research cycles. A justification for the research subject is explained identifying the need both to add to knowledge and to improve and implement change in professional practice. Finally, a summary of the thesis is given to highlight each chapter and indicate the journey of discovery throughout the research. The next chapter will review the existing body of knowledge.

Chapter 2

Installation, Commissioning and Handover Process in Low Carbon Homes - Engaging with the Literature

2.1 Introduction

Having established the need for research for low carbon technologies this chapter explores a range of research possibilities from the perspective of the construction industry paradigm. This will define the gap in knowledge for the installation and construction process for mass low carbon homes. The extent to which a 'holistic' approach is taken to the installation and commissioning of low carbon technologies will be reviewed within current and past research. This is necessary in order to understand the construction industry practises, which may be contributing to the early stage performance issues with low carbon technologies within dwellings. Specifically construction activities will be reviewed within the social housing sector, where low carbon technologies are installed with a user group that has neither directly selected, nor chosen to use such technologies as part of their life style. The ability of the construction industry to deliver a functioning and efficient end product is important for the future development of low energy housing. There is also the potential to contribute to the required development of low energy installation, commissioning, construction integration and long term education within the construction industry. This chapter will concentrate on the literature from government and industry sources for low carbon homes, and as illustrated in figure 2.1 below, to achieve a perspective of regulation, assessment and construction activities relating to low carbon homes.

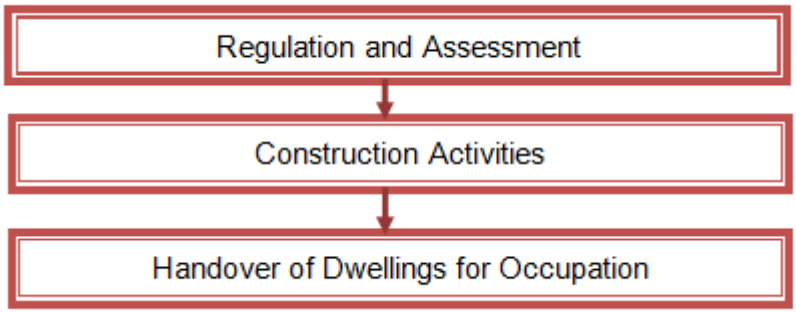


Figure 2.1 Engagement with the Literature

Understanding the connection across these areas gives rise to the identification of the gap in knowledge. It also highlights the confusion of messages given by Government, which feed into current construction activities and have an effect on the end product at the completion of the construction. It is seen that whilst there is a wealth of research on post occupancy monitoring and user interaction; there is little relevant research on construction activities for installation and commissioning of low carbon technologies in the domestic construction market.

2.2 The Recent History and Growth of Government Requirement, Regulations and Assessments

The Building Regulations Part L (LD1A) 'Conservation of Fuel and Power' is the primary compliance route for energy performance for new domestic buildings (DCLG, 2015). The Building Regulations were introduced into the UK, firstly in Scotland in 1964 and England in 1965 to replace local byelaws and bring national compliance (NHBC, 2015:23). The base of the Regulations in operation today came out of the 1984 Building Act with the intention of consolidating the hitherto fractured nature of the regulatory process (HM Government, 1984). The Act further streamlined local regulations and the London Building Acts, a set of regulations for building within London which came out of the great fire of London and were a legal requirement from 1667 (Watkins., 2014). This consolidation into a single piece of

legislation to govern building standards, as noted under Section 1 of the act, the Secretary of State was given powers to make Building Regulations:

'For the purposes of securing the health, safety, welfare and convenience of persons in or about buildings…, (and) furthering the conservation of fuel and power' (DCLG, 1984).

Part L 1985 underwent several revisions in 1995 and 2002, with the amendment in 2002 providing for a division of Part L into domestic and non-domestic sections ADL1 and ADL2 respectively. There was also the introduction of the European Energy Performance of Buildings Directive (EPBD) in 2003, designed to promote the improvement of energy performance in buildings within the EU (European Parliament, 2002) with four main policy objectives:

1. Establishing of a calculation methodology
2. Minimum energy performance requirements
3. Energy performance certification
4. Inspection of boilers and air-conditioning equipment

With the introduction of the EPBD, the UK Government implemented a substantial raft of changes to legislation to accommodate the EU requirements (Campbell, 2007). These included the 'Energy White Paper' published in 2003, followed by the 'Action Plan for Energy Efficiency in 2004'. The further consolidation of legislation came in 2006 with the adoption of the Climate Change and Sustainable Energy Act and the EU Energy Efficiency Action Plan. This had a target of reducing energy consumption by 20 per cent across the EU by 2020 and 80% by 2050, which remains the target in the UK under law (HM Government, 2006).

Part L 2006 marked a step change in the requirements for energy and CO_2 reductions from the domestic sector (Campbell, 2007). The elemental method of compliance, by energy

efficiency requirements, was replaced with target CO_2 emissions calculation and the requirement of the Standard Assessment Procedure (SAP) (DECC, 2015). This route to compliance, as stated by Davies (2013) 'out went compliance with elemental conditions and in came a small army of SAP assessors' to manage a calculated route required by the adoption of the EPBD 2003 directive.

In 2007 the publication of the 'Building a Greener Futures: Policy Statement' by the then Labour Government (DCLG, 2007), set in motion a route to net zero carbon homes by 2016, with incremental carbon reduction steps enshrined in the building regulations. Three steps were set out by Government with the first requiring a 25% reduction in CO_2 emissions over the 2006 Part L1A Building Regulations incorporated into the 2010 edition. A further 44% reduction incorporated into the 2013 regulations and finally net zero carbon incorporated into the 2016 Part L1A Building Regulations (DCLG, 2007). The policy statement brought into operation the Code for Sustainable Homes (CfSH) in December 2006. This was a Government created assessment scheme managed by the Building Research Establishment (BRE). Its structure is an assessment tool with 9 sections including Energy, Water, Materials, Health and Wellbeing, Management, Waste, pollution and Ecology, (DCLG, 2006). The Code has 6 compliance levels from 1 – 6 with 1 being the entry level and 6 being termed 'net zero carbon'.

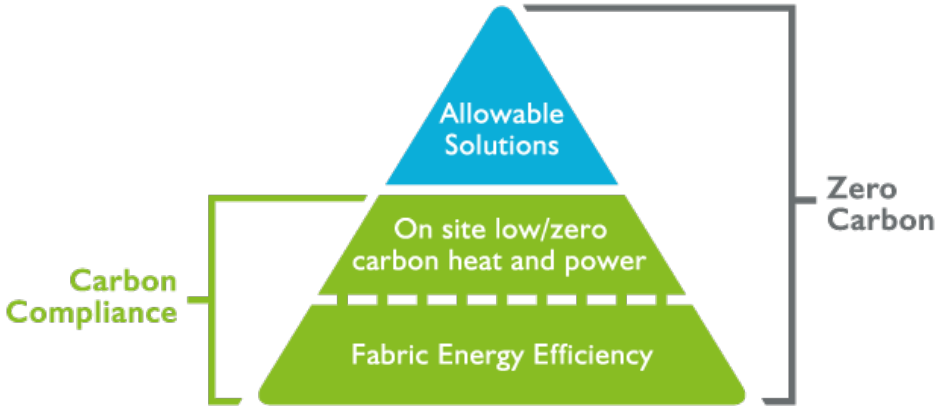
Levels 3 and 4 have been the most commonly achieved and required by planning, with the energy section (Ene1) of the Code being linked to the Building Regulations since 2010. Compliance certification for the Code is split into two phases with the first certification at the design stage called 'Design Stage Assessment', and at the completion of the project called 'Post Completion Assessment'. Although the assessment is called 'Post Completion' it is primarily a verification of the information used in the design stage and compliance on actual materials and processes used. There is however, no review of installation and

commissioning during construction, or monitoring of the dwelling in use, further, the certification is completed before occupation of the dwelling. Initially this was voluntary for private housing, but required for securing Housing and Communities Agency (HCA) funding for new Social Housing (DCLG, 2006) the Code is used both within the Building Regulations and as a conditional requirement in planning applications for new housing developments in England.

The Code link to Part L1A of the Building Regulations for CO_2 reductions was to drive 'continuous improvement, greater innovation and exemplary achievement in sustainable home building' (DCLG 2006:4). The 'Building Greener Futures' policy also heralded the creation of the 'Zero Carbon Hub' a non-profitmaking organisation set up by Government to deal with the on-going management of the Governments net zero carbon target for 2016 (Zero Carbon Hub; 2008). One of the early goals of the 'Zero Carbon Hub' was to review the definition of zero carbon, which up until 2008 was captured in the requirements of achieving Code for Sustainable Homes Level 6 from regulated (SAP calculated heating, lighting, cooling and ventilation) and unregulated (all other household energy, cooking and appliances) emissions through 'on-site' means. By 2009 both Government and the construction industry saw this as impractical and overtly costly on most if not all construction projects (Zero Carbon Hub, 2013). Therefore, in 2009 the concept of 'Allowable Solutions' was put forward by Government as a way of achieving net zero carbon emissions (HM Government, 2009).

The Allowable Solutions strategy seen in Figure 2.2 created a two stage approach to zero carbon, with the first stage of compliance tied to an emissions level set for the development (Code Level 4, 44% over 2006 Building Regulations). The second stage being an 'off set' through a funding strategy, paid by the developer, to be used locally for low carbon projects. There was a further additional change to the zero carbon definition in 2011 with the

Government removing the unregulated emissions element from the definition as part of the budget announcement (HM Government, 2011). This gave compliance for net zero carbon by calculation through SAP and the 'Allowable Solutions' combined route.



(Zero carbon hub, 2013)

Figure 2.2 Zero Carbon Definition with Allowable Solutions

There has since been a significant change in the Government's response to zero carbon for construction (UK-GCB, 2015). Changes to the UK Government in 2010, with the forming of a coalition of Conservative and Liberal Democrats, adopted the previous Labour Government target for Building Regulations and zero carbon. The regulations maintained their structure as set out in 2007 and, in the main, adhered to recommendations for zero carbon targets as set out by the Zero Carbon Hub (UK-GCB, 2015). However, there was a substantial departure from the structure for the 2013 edition. After consultation with industry, the targeted reductions in CO_2 was reduced from the previously agreed figure of a 44%, over 2010 Building Regulation, maintaining the link to the Code (Code Level 4 compliance), to a 31% reduction (DCLG, 2013). This review had its origin in the establishment of the Government 'Red Tape Challenge' that reviewed over 21,000 statutory rules and regulations including the Building Regulations between 2011 and 2013 (HM Government, 2013). The aim was to 'tackle unnecessary and inappropriate regulations, and the associated enforcement requirements, and remove or adapt the legislation to make compliance clear

and simple' (HM Government, 2013). The departure from the zero carbon route map was ostensibly taken to continue a slower rate of reductions in CO_2 and to assist industry, as stated by Baroness Hanham, in the House of Lords debate, by 'lowering costs and making regulation more clear and simple' (Lords Hansard, 2013). As a further part of the government 'Red Tape challenge' (Cabinet Office 2014) the Code for Sustainable Homes was set to be withdrawn in October 2015, with a number of assessment areas being either abandoned or transferred to the relevant Building Regulations. There is currently a crossover period, which will allow for schemes already granted planning permission to be completed under Code, but all new schemes will only be required to be Building Regulations compliant in future (DCLG, 2015). This change has been accompanied by an announcement through Government to scrap the 'Allowable Solution' strategy planned for Building Regulations Part L1A 2016. The new goal is to 'keep with existing measures and to keep under review the future of zero carbon' (HM Government, 2015:46). The reason given for this sudden departure from a net zero carbon target for 2016 is to:

'Increase productivity and to recognise that existing measures to increase energy efficiency of new buildings should be allowed time to become established' (HM Government, 2015:46).

This illustrates how, over the last 6 years, there has been a marked change to the projected goals of reaching net zero carbon for homes by 2016. The messages to industry have been confusing and have led to statements from the Energy Saving Trust and the UK Green Building Council stating 'Let us be in no doubt this announcement is the death knell for zero-carbon homes' (Guardian, 2015).

All of these changes have created an impact on the construction industry. Davis Langdon & Everest recognised as far back as 2001, in a cost study of regulation changes, that not only additional time was required in understanding regulations, but this would also 'knock on to

installation and commissioning activities (DLE. 2001). Dawson et al (2008) similarly identified in a later study the possible effects on the requirements of commissioning, noting that construction professionals responding to their survey on the changes to the 2006 Building Regulations, in particular for delivery and the incorporation of commissioning requirements, implied that more time would be required for commissioning activities.

However, it is not only the effects on the commissioning that have a 'knock on' effect from changes to the regulations. Cost, ability within the supply chain, construction educational needs and the step change in the nature of the regulations have been seen as potential barriers (Dawson et al, 2008). Whilst it is observed that regulations are 'major drivers of innovation in the construction sector', it has also been the case that the process for delivering low carbon projects is considered more complex and costly than traditional construction activities (Brandon and Lu; 2008). Blayse and Manly (2004) also point out an additional factor that has influenced delivery; the 'one off' nature of the construction process which limits the ability to develop innovation and to learn from the processes. Hakkiene and Belloni (2011) have recognised this disjointed nature of development in construction identifying that the discontinuous nature of 'on site' projects gives rise to a break down in learning, and subsequent learning feedback loops for future projects. It has been recognised that improvements in quality and the application of new processes within construction are needed to fully realise energy efficiency (Ozorhon, 2013). Osmani and O'Reilly identify in their study of house builders (2009) that regulation and legislation is seen as the most effective driver for low and net zero carbon homes. However, clarity of direction is necessary for implementation if industry is to maintain and develop the required standards (Goodchild and Walshaw 2011).

Therefore, there is a need to understand the implication of each change in the regulations for the construction industry to be able to deliver on the installation and commissioning

requirements. It is also clear that there is a need to consider the construction process and the impacts of regulation, management, training, installation and commissioning knowledge on low carbon domestic construction.

2.3 The Construction Process

To better understand why these issues arise it is necessary to identify the actual construction process from the typical design and build contract, through construction management and training to the installation, commissioning and eventual handover of new low carbon homes. As noted by the 'Zero Carbon Hub (2011) the need to derive compliance for energy performance from 'As Built' as opposed to 'As designed' is critical for the development of low carbon homes. Therefore, the significance of how the homes are constructed and commissioned is as important as both the design and use in ensuring long term low carbon homes. According to Bailey (2010) there is a real requirement to bridge the gap between design, installation, commissioning and 'real in-use performance' within housing schemes. Fundamental questions of complexity, construction quality, skills and communication need to be addressed to fully understand the performance gap in low carbon homes (NHBC, 2012).

2.3.1 The Use of the Design and Build Contract on Registered Provider (RP) New Build Housing Projects

The Design and Build Contract forms the primary route for procurement of housing projects in England, and is used extensively by Registered Providers (RP's) on all new build schemes (Fitzgerald. 1995).

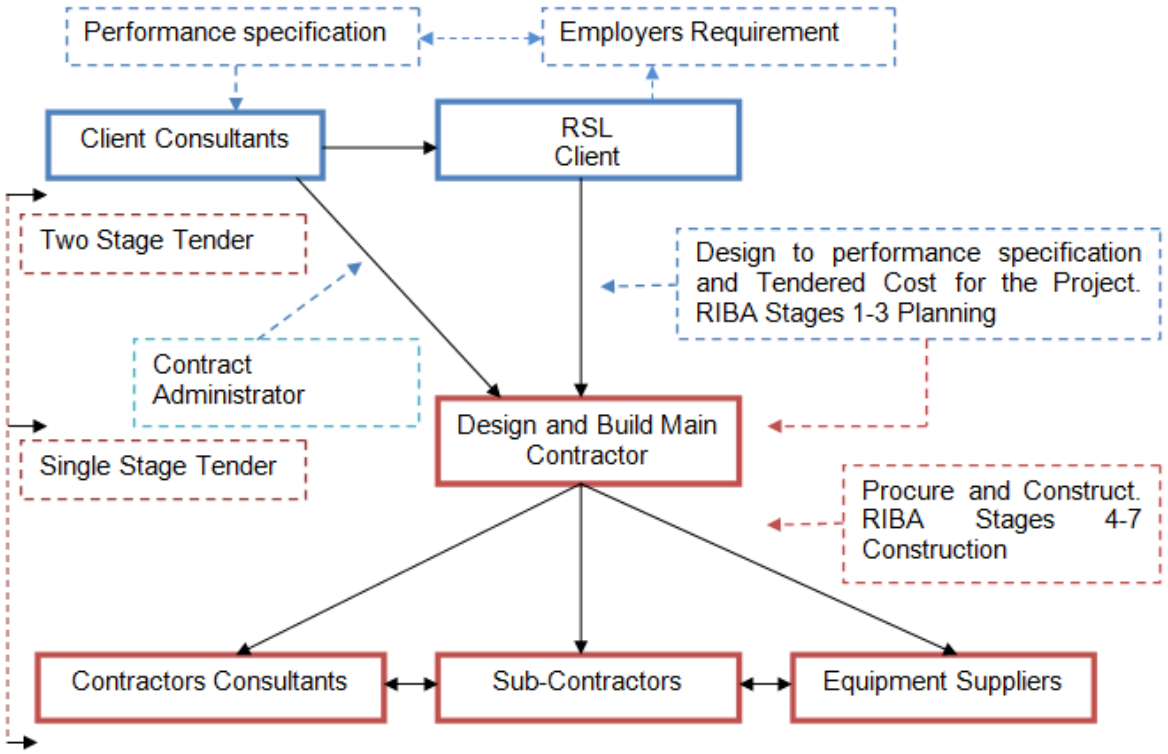


Figure 2.3 Design and Build Contractual Relationships and Structure (Adapted from Chan et al 2005)

Figure 2.3 illustrates the divide between client and contractor for the standard single stage Design and Build Contract, the contract most often used by RP's, which is entered into after the completion of the planning stage, Royal Institute of British Architects (RIBA) stage 3. From this point the scheme is tendered to a range of Main Contractors, often through a set framework (list of pre-selected contractors) or partnering (joint venture contractors) arrangements, to complete the project from RIBA stage 4 – 7. The information that informs the tender includes the planning consent, a set of Employer's Requirements (ER's), consultant's performance specifications and outline drawings completed to RIBA Stage 3. The structure of this procurement process and preference by RSL's has its basis in the work carried out by The Latham Report 'Constructing the Team' (HMSO, 1994) and the later Egan Report 'Rethinking Construction' (HMSO, 1998).

One of the key elements of these reports placed an emphasis on the role of the client as the driving force in the construction process along with the importance of the full brief, construction quality and mutual cooperation (Clamp et al, 2007). This is an area that has in no way been fully achieved within RSL new build housing construction. However, whilst a study by Liguori et al (2012) would indicate that 70% of RSL's engage in strategic long term partnering, with cost and quality as the specified benefit, this has still not greatly affected the quality outcome on housing projects associated with this study. The main driver for the RSL's has remained to achieve 'cost certainty' at the earliest stage of the contract and to pass risk onto the Main Contractor for the delivery of the scheme. This is backed up in a study of several RSL's in Liverpool by Griffiths (1999), which found 'cost, risk and responsibility', as the main procurement decisions used for the selection of Design and Build contracts. It was also noted in the study that there were instances of poor quality where the contractor had amended the design 'to achieve lower unit costs' and therefore affected the scheme final product and performance. It is this factor of cost and quality pressure to achieve lower production cost and increased profit which is observed to be a key initiator of subsequent installation and commissioning issues with house building. This is, to an extent, raised by Egan in his review of 'Rethinking Construction' taken 10 years on in which he states:

> *'I have to say, one segment of the industry which I really expected to do very well indeed was house building. They're in control. And yet, across the seven year period, from the statistics we've got, they made no cost improvements at all. Absolutely nothing….I just don't think they were trying'. (BRE, 2008:p2)*

His reason for the statement is the apparent lack of productivity on the construction site and the continuing drive to 'lowest cost tendering' and 'risk dumping' (BRE, 2008:p4), which is adversely affecting construction. His assertion that simple design and simple 'off site'

construction for the market place is, to an extent valid, however this would only satisfy a small area of the market where ‘off site’ construction could be achieved.

The experience of the changing requirements within new build low carbon homes, the planning constraints, risk transfer of the D&B contract and the number of dwellings required in the RSL market, has made ‘off site’ construction a niche market. Egan states that the construction process is a team effort with all parties, design, supply chain and construction working together. However, that lowest cost tendering affects the process by ‘starting them off as separate groups’ (BRE, 2008:p3-4). This is an effect that can be observed as part of the on-going process of the D&B contract, currently employed by RSL’s. However, the increased effects on low carbon homes and the associated installation and commissioning is lacking within the literature. Egan in his 10-year review gave his overall assessment of the construction industry giving 4 out of 10 ‘and that’s basically for trying’ (BRE, 2008:p4). With the increased construction of low carbon homes since his review was undertaken the actual score now could be far less.

To better understand the elements that affect the process it is necessary to review the relationships, which develop between the main contractor and the services subcontractor through the construction process, and how these have an effect on the end product delivered.

2.3.2 Construction Site Management and the Relationship between the Main Contractor and Services Sub-contractor

Subcontracting is a key element of the construction process with over 90% of the value of the contract emanating from labour, supply of materials or expertise (Hinze and Tracey, 1994). Therefore, the selection of the right subcontractors and developing the most effective

main contractor and subcontractor relationships are important in achieving a successful construction project (Hartmann and Caerteling, 2010).

The relationship between the main contractor and services subcontractor has always been, and continues to be at best, a fraught and confrontational affair influenced by cost, quality and workmanship (Arditi and Chotibhongs, 2005). Wong et al (2005) found that establishing trust amongst participants in construction partnering is a critical success factor, with 'performance' (competency and problem solving) and 'permeability' (openness to share information) key to a successful project outcome. Understanding the role that trust plays in the contractor partnering and management relationship has both academic and practical value, especially when looking at the complexity of the delivery of low carbon homes (Wong et al, 2005).

The Construction Statistics Annual Tables show the UK registered construction companies in the third quarter of 2014 (Office for National Statistics, 2015). These indicate that of the 66,533 Building Services construction companies, split into Electrical, Plumbing and Heating Ventilation and Air-conditioning (HVAC) operating within the UK, only 2% have more than 25 employees. A further 2.6% have between 14 – 24 employees. However, the majority are companies with 2 – 13 employees at 44% and sole trader and single employees at 52%. This illustrates that the building industry is reliant on small and single trader Building Services sub-contractors regardless the size of the construction project. This mix of small, and often, specialist subcontractors, within individual construction disciplines, does give flexibility to the main contractor for labour, and further generates cost competition. However, the management of quality control and communication at this level can be problematic and complex (Manu et al, 2015). Hseih (1998) observed that such small subcontracting companies can lack in internal processes for document management, quality control and staff management. Historically construction has a tendency for high staff mobility, and as a

consequence, inadequate staff training (Lin and Gibson, 2011). This does lead to issues of quality and performance, which negatively reflect on the main contractor – subcontractor relationships and supply chain. In addition the complexity of low carbon technology installation predominetly requires coordinated inputs from both electrical and mechanical subcontractors to achieve the required end product (NHBC, 2012).

The research confirms that electrical and mechanical installation and commissioning on a significant number of observed construction site come predominetly from separate companies. Therefore, the combined and collaborative role needed throughout the installation and commissioning is most often carried out as isolated and individual tasks (NHBC, 2012). A careful study of the avaliable literature reveals that the effects of the uncoordinated approach to the installation and commissioning of low carbon technologies has not been thoroughly investigated. Therefore, a clear understanding of the potential performance issues is essential to identify and develop more effective strategies for commissioning low carbon homes.

In a paper by Ng and Tang (2009) they argue that establishment of Critical Success Factors (CSF) is key to the construction industry. Rockart (1979) pioneered this form of analysis as an approach to define information required to achieve organisational goals. Liedecker and Bruno (1994) further developed it to research key factors for successful behaviour. The research does have its critics, Wagner et al (2006), suggest that it is over simplified and difficult to realise in practice due to context and interpretation. However, for the small size subcontracting company, as it has been demonstrated most services subcontractors are, there may be further oppotunity for research. The research by Ng and Tang (2009) puts forward a set of CSF's for labour intensive and equipment intensive subcontractors that have many similarities and common goals. It is however, interesting that they argue that a common set of CSF's cannot be applied to all areas of subcontracting (Ng and Tang, 2009),

as each discipline will differ. Whilst this is appreciated in the research, the common goals within building services subcontracting, especially the housing sector, could be developed to a set of construction success factors with discipline specifics being added.

Lu et al (2008) have suggested that subcontractors play an important role in the construction process, and that competency and experience are crucial elements for a successful project. Close working relationships on the construction site also play their part, and according to Kale and Arditi (2001), the embedded nature of the relationship serves to help in the selection of the subcontractor to be used. There is however, a difficult balance to achieve between long terms embedded relationships and the need to realise best value for the project (Hartmann and Caerteling, 2010). Briscoe and Dainty (2005) argue that there is a place at the subcontractor level for a more integrated supply chain which enhances collaborative working, and this is to an extent what takes place on construction sites especially with larger main contractors. However, the balance of cost, quality and trust are still firmly weighted in the need to achieve a competitive tender as found by Hartmann and Caerteling (2010) in their study of subcontractor selection for new build housing.

When reviewing criteria for selecting ‘known and unknown’ subcontractors, the main contractor only selected a previously known and used subcontractor when the price offered conformed to market requirements (Hartmann and Caerteling, 2010). This illustrates that price and market requirements remains a main driver for selection of the subcontractor, often to the detriment of a repeated relationship built on trust. It is suggested that this may be due to the need to arrive at a main contract price for the design and build contract at the early stage, with outline design to RIBA stage 3 (Planning Consent) completed. Therefore, this often only allows for the formulation of a speculative price from the subcontractor, for which, detailed design is still to be completed. In addition the ability to meet the project

expectations about future performance, cooperation and behaviour exerts less of an influence on the main contractor at this stage of the tender (Rousseau et al, 1998).

The study was also interesting, being based on 202 respondents across construction, it showed that the main contractor was willing to compromise on technical 'know-how' and co-operative skills if the quality of the work was viewed as 'acceptable' (Hartmann and Caerteling, 2010). This could be an indication why currently observed issues with installation and commissioning of low carbon technologies is presenting, not only a construction delivery problem, but a direct strain on the relationships between the main contractor and services subcontractor. Glass et al (2008) have also indicated, in their research into developing improved standards in new build construction, that the 'lack of know–how' and cooperation were significant barriers to delivering new construction and low carbon homes. Heffernan et al (2012) further reinforce this by identifying that skills gaps and lack of knowledge are the primary barriers to moving forward with low carbon homes. Eriksson and Laan (2007) suggested that reliance on the review of acceptable quality as part of the selection criteria, along with market value, is a reflection of the main contractor's relationship with the client and their own reputational goals. Therefore, this attempt to balance both quality and market value through management and control creates the constant struggle of cooperation between the construction teams (Eriksson and Laan, 2007).

It is argued by Kadefors (2004) that such central controls and monitoring by the main contractor is detrimental to the development of trust with the subcontractor. However, as suggested by Manu et al (2015) mutually agreed controls could actually provide the basis for trust that is then predicated on 'demonstrated trustworthiness' and a 'Trust Platform'. When taken that most of the subcontractor relationships will be predominently with small companies and often sole traders, a structured process with critical success factors could enhance the contractor relationships. With the knowledge development curve required to

keep pace with advances in low energy housing, the possibility for development of a mutually agreed structured process could have positive benefits for the main contractor/ subcontractor relationship and the delivery of low carbon homes (Manu et al., 2015). However, to understand and develop a structure the role of tacit (know how) and explicit (know what) knowledge management on construction projects need to be reviewed. This will give insight into the process of knowledge transfer and its effects on the low energy installation and commissioning process.

2.3.3 Knowledge Management and Transfer Levels for Low Carbon Homes Between Main Contractors and Services Contractors

Egan (1998) stated that:

> *"… much of construction does not yet recognise that its people are its greatest asset and treat them as such. Too much talent is simply wasted, particularly through failure to recognise the significant contribution …"*

The labour intensive nature of construction highlights the importance of the construction worker and their tacit knowledge, in the necessity of bringing together multiple skills to effectively complete a construction project (Druker & White, 1996). Due to the diverse makeup of the construction industry, site employees can come from a myriad of occupations including skilled, unskilled, managerial and professional positions (Druker & White, 1996), as well as from other nationalities (where translators are required for communication on the site). This creates the challenge to manage people effectively to ensure a successful project (Partirage et a., 2005). Knowledge and skills management and effective transfer of tacit 'know how' and explicit 'know what' knowledge (Smith, 2001) is of critical importance within low energy construction, especially when considering low carbon technologies and their

commissioning strategies. Nonaka (1991) expounds that there are four methods of creating knowledge:

- Tacit to tacit – learning by observing, practice and imitating – mentor learning
- Explicit to explicit – taking documented information and using in another document
- Tacit to explicit – taking discussions and descriptions and converting into a document
- Explicit to tacit – reinterpretation of a document from another person's perspective

The last two methods are the most problematic, being the basis of the dilemma of effective communication of ideas and practices within the construction project. This is further compounded on many construction sites where the makeup of the workforce is multinational (Tutt et al, 2011). Trajkovski and Loosemore (2006) argue that there is little examination of inter-cultural communication and learning issues, and that there 'were significant communication problems with migrant workers' (Oswald et al, 2015). The necessity for the main contractor, mechanical and electrical subcontractors to work closely together and exchange knowledge and information, in the installation and commissioning of low carbon technologies is clear. However, as this study has observed, the communication of this knowledge 'in the real world' is to the greater extent non-existent with little appreciable tangible knowledge transfer or sharing taking place. This issue has many parts including the 'trust factor' (Arditi and Chotibhongs, 2005) bound up in cost and quality, the increasing multinational nature of construction (Tutt et al, 2011) and perceptions of poor performance issues (Lin and Gibson, 2011), creating an effective barrier between the main contractor and subcontractor.

In their study of delivering zero carbon homes in the UK, Heffernan et al (2012) found that one of the major barriers was a skills shortage and the knowledge gap. Results from their study showed gaps in all areas of the construction industry, which concurred with a similar

study undertaken by Glass et al (2008). This indicated the concern that implementation of low carbon homes would be difficult with the lack of knowledge currently within the construction industry. It is argued by this research that the gap in knowledge is manifest within this communication and lack of knowledge transfer and sharing. The need for collaboration, flexibility in approach and the development of a context under which low carbon homes can be constructed (Heffernan, 2012) are seen as the main drivers to achieving low carbon homes. It can be seen that there is a real need to overcome these barriers if low carbon homes are to be constructed effectively.

It is estimated that upwards of 90% of knowledge in any organisation, and probably more within construction, is tacit in form and 'embedded and synthesized in people's heads' (Bonner, 2000; Lee, 2000). Within the shifting and changing workforce of the construction industry, coupled with the endemic short term nature of construction projects, this repository of tacit knowledge is repeatedly lost, not communicated or documented for future learning. Bakker et al (2011) have referred to the paradoxical nature of learning within construction. Firstly, the fluidity and multidisciplinary side gives creativity, however the short term and discontinuity of projects (Bresnen et al, 2003) restricts the use of the created knowledge for development or growth over time.

Hartmann and Doree (2013), when reviewing the nature of the transfer of knowledge from one construction project to another, argue that the 'sender/receiver' approach has limits to the effectiveness of learning and learning transfer. It is invariably seen as outside the day to day management and work flow of the project and is interpreted by the participants as an additional task. Hartmann and Doree (2013) see the potential hurdles, endemic to construction, of time constraints and codifying documenting data as feeding the potential failure of the knowledge transfer. The process is seen as 'additional work' to be carried out in the same time frame; therefore, unpopular and unlikely to be completed successfully or in

a form useful to the company in future. There are many studies which see this sender (completed project) to receiver (next project) (Noorderhaven and Harzing, 2009) process as a way of managing knowledge transfer through the creation of tools or channels such as post project meetings, IT infrastructure and face to face meetings (Paranagamage et al, 2012). However, all of these again look to a structure that potentially sits outside the day to day management of the project. Hartmann and Doree (2013) argue that it is not wholly the issue of the sender/receiver process, which is failing the transfer of knowledge, but that additional ways need to be found to capture and record the information, which can be seen as relevant to the project within the project process.

The nature of the construction industry relies on efficient communication by individuals, teams and organisations (Dainty et al, 2006). Chen and Kamara (2008) have suggested that the most efficient way of achieving this is to capture the information ‘at a point where they are and a time when it is needed’. Harstad et al (2015) see both positives and negatives to this form of use of technology and cite live drawing information, Building Information Modelling (BIM) and the use of tablet computers on construction sites as a way of capturing and communicating information during construction and installation. However, access to the technology, costs and training needs are barriers to smaller organisations, along with access and interpretation of data on a small handheld screen.

Hartmann and Doree (2013) in their paper see the attributes of social learning theory, not only occurring within the individual but as a consequence of interaction with others (Easterby-Smith et al, 2000). Knowledge emerges through collective actions (Hartmann and Doree, 2013) and therefore, becomes a shared experience, and as such, shared knowledge. This process is most commonly seen by this and other studies in problem solving and goal based tasks, where there is a shared responsibility to achieve the end result (Hartmann and Doree, 2013).

This process of social learning theory, as part of knowledge transfer, may have benefits for improved communication and learning between the main contractor and services subcontractor (Hartmann and Doree, 2013). Its potential weakness is in the method of capture of such varied, elusive and undefined knowledge, which is the very basis of tacit knowledge. As already seen most services subcontractors are small or sole trader companies where time constraints are imposed and information transfer capability, where not directly project related, are not often seen as culturally important. This tendency to concentrate on the delivery of the project at hand, managing the day to day fluctuation of demand and the commitments of staff to project tasks (Bishop et al, 2008), could therefore be used as a potential conduit to development and not as a barrier. This may be seen as trying to 'catch the butterfly' (Smith, 2001), alluding to the elusive nature of the knowledge to be mined. However, to effectively share 'face to face' and 'hands on' experience and document for future learning, will assist in the future positive outcomes of low energy housing projects (Smith, 2001).

Within the process of constructing low carbon homes there is a requirement on the construction team to deliver in accordance with regulations and assessment procedures. There needs to be an understanding of the process of delivery of low energy targets and how the construction team respond to achieving this within the context of regulation and planning.

2.3.4 The Assessment and Installation of Renewable and Low Carbon Technologies

It is a requirement from 2020 that all new buildings within the European Union will be 'nearly zero carbon buildings' (European Union, 2010). The term 'nearly zero-carbon building' is defined in the literature in Article 2 of the EPBD recast as:

> *"A building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby". (European Union, 2011)*

The Energy Performance in Buildings Directive (EPBD) gives the responsibility for delivering the requirement on each member state (Heffernan et al, 2015). Within the UK 'zero carbon homes' is the targeted response to this directive for all new dwellings. However, as observed by Mlecnik (2012) whilst flexibility is required for achieving the target of 'nearly zero carbon buildings', this very flexibility has created confusion within the European Union around the diversity of definition. Heffernan et al (2015) also point to the fact that there is little discussion in the academic literature for a clear definition of 'zero carbon homes'. The Zero Carbon Hub, a public/private partnership, has taken the lead in the on-going definition of zero carbon homes with the three main principles set as Fabric Energy Efficiency Standards (FEES); on-site use and generation of LZC and 'off site' allowable solutions (Zero Carbon Hub, 2014). However, with the recent change in emphases of the UK government away from 'allowable solutions' (HM Government, 2015:46) and the removal of the Code for Sustainable Homes from 2016, it is suggested that this confusion can only continue to increase and affect delivery of low carbon homes.

Within the UK ‘low and zero carbon technologies’ (LZC), used as part of the contribution to low energy and ‘zero carbon homes’ remain difficult to define beyond those used by the Zero Carbon Hub and therefore, mainly depends on the perspective taken (Bevan and Lu, 2012). There are several terms, which include:

> *‘Renewable sources of energy or technologies which are significantly more efficient than traditional solutions or which emit less carbon in providing heating, cooling or power’ (NHBC, 2010)*

Also:

> *‘Zero carbon in operation (powered by 100% renewable energy) and those that are considered to be low carbon in operation (powered at least in part by fossil fuels)’ (Energy Saving Trust, 2010).*

These terms cover the common range of renewable energy technologies including photovoltaic (PV) and solar thermal (ST) panels, biomass boilers, and ground and air source heat pumps. They also cover low carbon technologies such as Combined Heat and Power (CHP), also connected with communal heating systems, and Mechanical Ventilation with Heat Recovery (MVHR). This wide ranging selection of technologies and associated definitions presents an on-going challenge to the construction industry, working through their supply chain, to meet the constant changes of requirement and definition from the UK government (Peterman et al, 2012).

Probably the most significant driver for the use of LZC technologies, within new build housing, and especially RP housing, is the Code for Sustainable Homes (DECC, 2015). Used as part of the funding criteria for new building social housing by the Homes and Community Agency (HCA, 2015), Code for Sustainable Homes has substantially influenced

the use of low carbon technologies within construction (DCLG, 2006). The mandatory setting of Code at Level 3 or 4 (compliance with the current building regulations 2013 for Code Level 4 for energy conservation) for HCA funding of new build social housing projects has made all but essential the use of renewable or low carbon technologies and construction methods on all RP schemes.

The determination within the Code, for the energy used, is through the Government Standard Assessment Procedure (SAP) and the Energy Performance Certificate (EPC). SAP has been in place since 1992 and first used in the Building Regulations Part L in 1994 (DECC, 2014), with the EPC required whenever a building is built, sold or rented (DECC, 2014). The EPC certificate is issued at the handover of the dwelling to indicate the energy performance band (from A – G, with A being the best performing to G being the worst energy performing) for regulated energy. Regulated energy is class as energy used for heating, lighting and hot water. Current statistics (Energy Performance of Buildings Certificates Q1-2008 – Q4-2014), for EPC's in new dwellings indicates that 77% achieve an Energy Efficiency Rating (EER) of A or B, 22% achieve C or D and 1% achieve E, F or G. (DCLG, 2014).

Until its recent removal by the UK government in England and Wales, the code for sustainable homes formed the main assessment, in coordination with Part L of the Building Regulations, for achieving a holistic and graduated response to zero carbon homes (DCLG, 2006). Code will continue to be used for 'legacy projects' (DECC, 2015) , defined as those projects that historically received planning permission for Code compliance, or where funding criteria exist which sets a code level compliance for grant funding (HCA, 2015).

According to the DCLG Code for Sustainable Homes statistics, over the current lifetime of the Code 197,851 Post Construction certificates have been issued at completion of the

project, with 30% in the private and 70% in the public sector amongst RP affordable homes providers (DCLG, 2015). Completions for Code have grown from 65 per year in 2008/9 at the early stages of the scheme to 41,085 in 2013/14, with the vast majority being at Code Level 3 and 4 (energy requirements in line with Building Regulations 2010 and 2013) at 69% and 29% respectively (DCLG, 2015). It is seen within the DECC statistics that the delivery of Code Level 5 and 6 homes has remained constant at well below 1% (126 dwelling completions) since code introduction, apart from 2012-2013 when this peaked for one year only at just over 1% (359 dwellings) (DECC, 2015). The delivery of the majority of low carbon homes has been restricted to building regulations, funding and planning requirement with little appetite for zero carbon construction beyond 'one off' projects (Ganah et al,2015). Ganah et al (2015) identify the barriers of cost, technical competence and cultural change can be seen to be present in the DECC statistics. Their findings also showed that of the construction professionals questioned in their research, 50% were looking to develop higher than mandatory Code compliance, but none were looking to zero carbon as defined by Code 6 compliance.

Osmani and O'Reilly (2009) and Ganah et al (2015) have demonstrated that a primary effect of the Code, for the construction industry and RP's, has been in the change to design and construction to meet the requirements for carbon reduction and building performance. From a construction perspective there has been, and continues to be, challenges to installation, commissioning and subsequent maintenance and management of low carbon technologies (NHBC, 2012). The Code has introduced a wide range of low energy and renewable energy technologies into the home since its introduction in 2007 (NHBC, 2012)' some of which are not only little known to the RP's, but also to the design and build contractors undertaking the installation and commissioning (Ganah et al, 2015). Williams and Adair (2007) in their study of UK housing construction and adoption of low carbon technologies found that there were both cultural and technical barriers to the uptake of technologies. Cost, standard house type

design change and familiarity were amongst the main barriers (Williams and Adair, 2007), with an unwillingness to embrace change and adapt to innovation as a core construction industry attitude (Nelson et al, 2004). This is particularly evident within the housing sector and is borne out in evidence gathered at a range of construction developments at varying stages within the construction process (NHBC, 2012). These highlight further the inconsistency of approach to installation and lack of understanding of the technology and requirements for commissioning, which is proving to be commonplace throughout housing construction. In 2008 NHBC undertook a review of zero carbon delivery identifying that the supply chain skill and knowledge base was underdeveloped and needed considerable input and change to cope with zero carbon homes by 2016 (NHBC, 2008). It can be argued from this research project, that there is little change to that scenario currently in 2015. As illustrated by Ganah et al (2015) after code being in existence since 2007 fundamental issues with the understanding of installation and commissioning of low carbon technologies remain.

Bevan and Lu (2012) in their research of the literature on LZC technologies in housing have found that the initial selection of low carbon technologies is not solely based on the technical considerations. Their research found that there are a range of influences surrounding that initial selection that also have social-technical structures. These consist of technical and institutional considerations as well as the beliefs and interests of the 'players' involved in the construction development (Bevan and Lu, 2012). This balance between the requirements to use familiar and cost effective technologies alongside the requirement to achieve the institutional goals of regulation and assessment, create a dynamic where 'pieces of the jigsaw' can be missed (Bevan and Lu, 2012).

It is at the installation and commissioning stages of the project that this dynamic of 'missing pieces of the jigsaw' (Bevan and Lu, 2012) are feeding directly into the issues of poor

performance of technology, and a lack of a consolidated approach to delivery. The lack of consistency is directly contributing to the continual fragmentation of approach and commitment from the construction industry. This research project therefore, identifies and addresses these critical stages from a practioner perspective.

2.3.5 The Commissioning and Handover of Renewable and Low Carbon Technologies

Djuric and Novakovic (2007) define commissioning as 'a systematic process of ensuring that all building facility systems perform interactively in accordance with the design documentation and intent'. Noyne et al (2013) identify the five primary steps to the commissioning process as shown in figure 2.4 below.

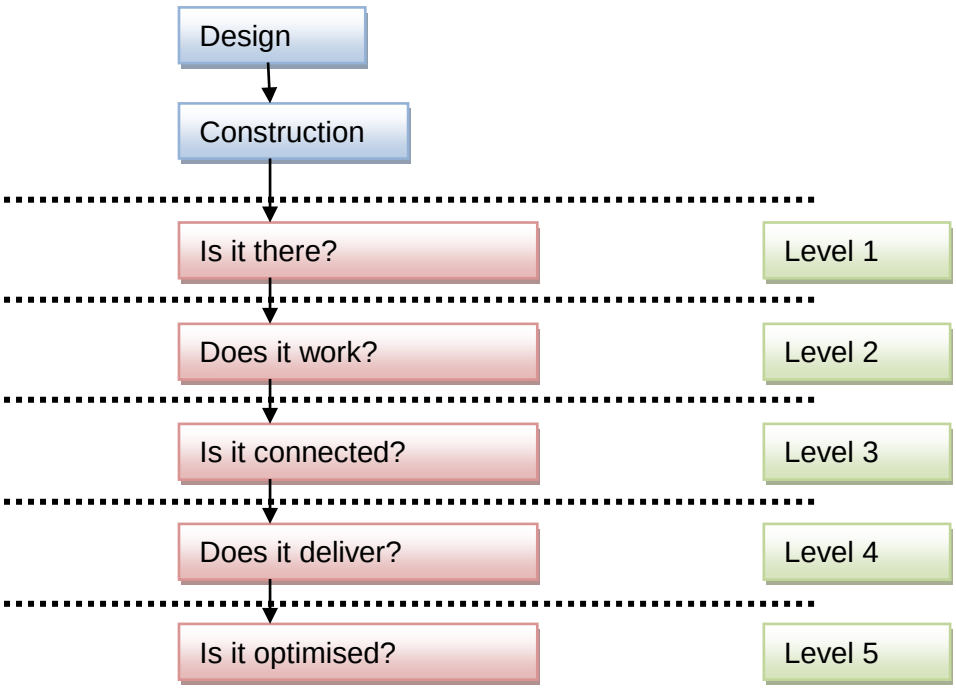


Figure 2.4 Five Primary Steps to the commissioning Process Adapted from (Noyne et al, 2013)

Noyne et al (2013) identify the varying degrees of success within the levels of commissioning and point to the fact that the process often only extends to level 3, with levels 4 and 5 often missed or not considered at all. They also recognise that unlike some other engineering applications, buildings are at the constant mercy of environmental change and therefore, the commissioning process needs to take this into consideration throughout the process.

The importance of commissioning within LZC housing, as with all other buildings, is paramount in achieving the required building performance (Noyne et al, 2013). It is however, found within the literature that most studies of the process and effects of commissioning are in non-domestic building, and are mainly centred on Commercial and Industrial developments. Few, if any, studies are available on commissioning within LZC domestic developments and the possible effects on the delivery of the low carbon technologies within the UK. In a study by Wray et al (2000) looking at commissioning literature for domestic and non-domestic buildings in the US, only 33 papers out of 469 reviewed (Wray et al, 2000 p1-4) considered domestic dwellings, with the majority not identifying dwellings as having complex systems to commission, or that any were related to low carbon homes.

The requirement on complexity has substantially changed with the advent of low carbon dwellings and the challenges faced by the construction industry in ensuring these systems are operating at their optimal level. The use of a varied range of LZC technologies, including heat pumps, heat recovery ventilation and district heating schemes, adopting combined heating and power (CHP), has seen a step change in the complexity of installation and commissioning for the domestic contractor. Achieving this level of complexity, and low carbon target, requires the link between design, installation and commissioning to be fully appreciated, and the need for systematic and accurate commissioning adopted by the contractor.

Mills (2009) recognises this and discusses four distinct areas of development including professionalism, value proposition, standardisation and reduced fragmentation to increase the effectiveness of commissioning. With professionalism Mills (2009) saw the endemic issues of an untrained workforce and poor communication giving a sporadic quality to the level of achievement of the commissioning process. He also identifies the requirements of standardisation and reduction in fragmentation of the workforce in delivering effective commissioning, although he did not offer further discussion on these areas. Within value proposition he raises an interesting point from the client's perspective on commissioning for optimum energy saving when the ultimate savings may be 'enjoyed by a third party' (Mills, 2009 p55). This is seen in the UK where the benefits of energy savings are for the resident and not the landlord, however when dealing with RP's this is not so much the case. This balance of the technical process and the value of optimal performance is an area seen in the Low carbon domestic sector. Therefore, although attributed to commissioning within commercial buildings, these distinct areas of concern raised by Mills and Noyne are seen to be true for domestic development.

Mills (2009) identifies in his study that commissioning can have a noticeable benefit in the reduction in carbon emissions in buildings. He states that commissioning can be the single most cost effective strategy in reducing energy use and carbon emissions suggesting a 13% reduction in energy use in the first year of building operation. Altwies and McIntosh (2001) also identify the cost benefits of commissioning offering a calculation for Avoided Costs (AC) on commercial projects as a method of calculating the commissioning impact. Figure 2.5 indicates the calculation showing the elements used:

Issues Resolution Cost (IRC)	Description
Repair Costs (Rep)	The total costs to fix systems, subsystems or components
Replacement Costs (Repl)	The total cost to replace systems, subsystems or components
Installation Costs (Inst)	The total cost to purchase, transport and install systems, subsystems or components
Professional Costs (Prof)	The total cost of professional time

Issue Effect Cost (IEC)	Description
Energy cost (Ener)	The total costs due to higher energy consumption
Depreciation cost (Depr)	The total costs due to an increase in the rate depreciation of systems, subsystems, and components.
Maintenance cost (Maint)	The total costs due to an increase in maintenance of systems, subsystems and components.
Revenue loss cost (Rev)	The total income lost due to decrease in sales
Productivity loss cost (Prod)	The total income lost due to the decrease in employees' work performance and output

AC = IRC + IEC

where,

IRC = Rep + Repl + Inst + Prof

and,

IEC = Rev + Prod + Ener + Depr + Maint

Figure 2.5 Commissioning Cost Calculation Model (Altwies and McIntosh, 2001)

Both studies are based within the commercial sector, however with the increasing use of communal heating systems for large scale developments, the learning and structure from the commercial field becomes increasingly relevant to current housing projects. In particular the Altwies and McIntosh 'avoid cost calculation' could be amended to accommodate the domestic sector by removing the productivity loss cost and changing the revenue to an RP attendance cost.

The effects of the commissioning process are also evident within the ensuing ‘snagging’ and ‘defects’ process. These processes entail the checking and acceptance of the installation for compliance with standards and workmanship ‘snagging’, and the monitoring of the installation after completion for ‘defects’. These activities running concurrent and subsequent to the commissioning process highlighting potential issue prior to handover, in the case of snagging, and in the following year after handover in the case of defects. Hopkins et al (2015) in their study of defects in new UK housing point to the growing pressure on the construction industry as a result of the low carbon regulation derived in Part L of the Building Regulations. This is also supported by Lohne et al (2015) in the ‘fuzzy commissioning’ process when commissioning is continuing, rightly or wrongly, long after the building is handed over by way of defect rectification. Therefore, the possible effects of poor installation and commissioning, through long-term repeated defect management, compounds the reduction in energy savings throughout the life of the technology. This can also be seen in research undertaken by (Lofthouse and Lilley, 2006) looking at user centered research methods for design. Their research indicated that people find a way around failing or flawed technology to achieve a comfort level in the home, thereby compounding the issues at the construction stage affecting the long term use of the technology due to error. It is also found in ‘Closing the Gap’ (Carbon Trust, 2012:p22) that most commissioning, even where carried out, is often not undertaken in seasonal conditions, or repeated in the correct season. This suggests that even when the certification is given it is often not based on the actual performance even at handover. This raises the implication that the impact of poor installation and commissioning compounded by defects issues within the first year of occupation is feeding into the long term performance, and where unchecked, is reducing the potential for carbon reductions.

Hopkins et al (2015) suggest that whilst the literature covers pathology and statistical analysis of defects for construction, there is little study on how the construction industry

learns from defects in order to reduce the occurrence on future scheme, especially when those defects are concerned with low carbon homes. The literature also suggests that the growing use of new technology, especially those required for low carbon homes is adversely impacting on the quality and end product home (Gill et al, 2010). Additional evidence of the increase in defects has come from the recent Home Builders Federation report (HBF, 2015), which indicates that 93% of homes in 2015 had reported defects, an increase for the second year in a row. Hopkins et al (2015) identified a number of recommendations from the current literature regarding the potential reductions in defects. These included training for trades, standardisation and predefined quality criteria all of which have degrees of influence, but without apparent success at substantially reducing the instance or number of defects. With regards to the process of learning from defects and the approach the construction industry takes to analyse and put in place learning process 'the literature is silent' (Hopkins et al, 2015).

A common thread that runs through all of these key areas is centred on the technical knowledge to carry out commissioning, and the value judgements based around the benefits and incentives of achieving the levels of performance required to reduce carbon emissions. Lohne et al (2015) in a study of the Norwegian construction industry and its ethics regarding commissioning have also found that there is a social as well as technical dynamic enacted during the commissioning process. The research suggests that there is a continual 'power play' between the client and contractor; with the requirements of project completion, dates and incomplete installation creating a 'fuzzy commissioning' process (Lohne et al, 2015). This process being neither systematic nor accurate in its approach to commissioning delivery can be seen in a majority of cases observed in the 'real world', and by this research project..

One way of understanding the ‘power play’ behaviour during the construction process can be seen from research carried out by Taylor (2004), in which he introduces the idea of ‘social imagery’. The term denotes what is and is not acceptable behaviour within social communities. Taylor’s central argument is that individual’s actions can be better understood when taken alongside the function and role of these individual’s in the wider context. When applied to understanding actions within construction this can be used as a form of tool to understand judgements made and actions taken (Lohne et al, 2015). Where this is applied to commissioning, especially when looking at specific actions to complete the process with low carbon homes, this may shed light on why particular decisions are made and why there is often a disconnect between what is expected and what is actually delivered. This therefore, opens further understanding within the UK domestic construction industry where this view has not been investigated fully.

Hopkins et al (2015) point to the possible tools of Organisational Learning (OL) as a potential method to analyse the construction learning process. They cite Berkhout et al (2006) and their cycle of learning constructs based on four areas including signal recognition and interpretation, experimentation and search, knowledge articulation and codification and feedback. They suggest that this approach of recognising a new process, experimenting via trial and error, codifying the knowledge to form explicit information and feeding back into the process has a place within the construction industry. It is however, argued from the literature that the construction industry is a project based construct (Gunn and salter, 2000) and that the knowledge creation is mainly tacit and applied to meet specific needs for an individual client (Winch, 1998) therefore, difficult to translate and use effectively (Barlow and Jashapara, 1998). It can also be seen that for the construction industry to progress in the ‘real world’, the link between the inherently tacit nature of the knowledge base and the need to explicitly record that knowledge must find a more coherent way to develop. Knauseder et al (2007) argue that the link can be found through organisational memory (OM). This is

defined as “the means by which knowledge from the past is brought to bear on present activities” (Stein and Zwass, 1995:89). Berkhout et al (2006) argue that a codifying process can be set up within the company to ‘enable the transmission of new routines’ and practices. Ozorhon et al (2005) identify the need for construction organisation to develop the skills and systems to generate explicit knowledge through OM to use for future projects. Hopkins et al (2015) point to the apparent silence on the subject for UK housing development and the need to capture the link from installation and commissioning to handover of the development, which will offer valuable insight into the potential future practices for domestic housing construction. This was borne out in research by the Zero Carbon Hub (2014) which identified ‘the development of appropriate testing, measuring and assessment techniques is urgently required to enable the '2020 Ambition' to be demonstrated’. The engagement with the literature clearly demonstrates that there is a gap in the development of learning and knowledge transfer for low carbon homes at the construction stages.

2.3.6 Summary

The journey through the literature has illustrated the development of regulation and the environment of continual change that the construction industry operates within. It has shown how that change process has informed the processes that construction has adapted to keep pace with the change, and how that adaption has created a degree of confusion and reticence towards constructing low carbon homes. The chapter has examined the contractual arrangements and how the Design and Build Contract has created a risk adverse client and a mistrust of the contractor on cost and quality delivery, with Egan giving only 4 out of 10 for performance in the industry. That same mistrust is seen between the main contractor and subcontractor in the forms of relationships developed on site. The balance of cost and quality on delivery is seen as the main barrier between the two with little or no effective communication for achieving common goals. The structure of M&E subcontractors

with 2% having less than 13 employees and 52% being sole traders, indicates the real difficulties that exist in generating structured teams and communicating effective explicit knowledge on and across developments. It also illustrates the nature and structure of the construction industry; demonstrating how the knowledge base is inherently tacit in form with little or no bridging structure to allow that knowledge to be codified to an explicit form to inform future development.

At the level of installation and commissioning the high degree of inherent tacit knowledge has an effect on the ability to have effective commissioning and optimum operation of the technology. Construction reality is at best a hurried installation, lack of understanding and training, with last minute commissioning at the basic level of 'switch on and walk away'. The effect on the finished product is one of increasing defects and poor performance of poorly installed and barely commissioned services. These cumulative issues give rise to the effects on the end state technology and the handover to the resident, where a loss of faith in the technology through poor performance, initiates a lack of trust in operation. That lack of trust and faith in the technology during early engagement is acting as a contributory factor to the poor performance of many low carbon schemes, contributing to the gap in performance.

2.4 Identifying the Gap in Knowledge and Reason for the Research

It has been demonstrated that there is a gap in knowledge in terms of the flow between the installation and commissioning processes for low carbon homes in the UK, and how this has an effect within Code compliant dwelling. The gap in knowledge exists in understanding the learning and communication process at each stage of the installation and commissioning for low carbon dwellings. Better understanding is required of how each stage is communicated, and how that communication may be formed into a bridge between tacit (silent) knowledge

and explicit (documented) knowledge to inform future developments. There is a need to have a 'whole process' approach to delivering low carbon technologies to give the best chance of delivering sustainable homes in the UK. In short, it demonstrates a gap in knowledge for an approach for effective construction and commissioning of low carbon homes in order to create, through professional practice, an approach to low carbon technology during the construction phase.

2.5 Chapter Reflection

This chapter has engaged with the literature to understand the development of the approach to installation and commissioning of low carbon technologies in new mass housing. That development has been traced through institutional practice and the expansion and growth of regulations guidance and assessment. It has been possible to define the issues that impair the fulfilment of the design intentions for low carbon homes creating a gap in knowledge. The engagement with the literature has indicated the gap in knowledge based around the main and subcontractor understanding and communication during the installation and commissioning of low carbon homes. It has indicated that there is a need to develop knowledge of how low carbon technologies are being installed and commissioned and how this is affecting the performance of the technology during the early defects period. The next chapter will define the research design to be used to investigate the gap in knowledge, and how this research design can be used as a tool to illuminate this gap in the knowledge.

Chapter 3

The Research Design

3.1 Introduction

This Chapter will explore the paradigms, research approach, methodology and methods for the research to be undertaken into installation and commissioning of low carbon homes. The chapter will journey through the identification and description of the research paradigm, the development of the theoretical perspective and the review and selection of the methodology best suited for the research design in professional practice. The research data collection methods will be identified and discussed demonstrating their suitability for a professional doctorate research project undertaken in a 'real world' environment. A conceptual framework mapping the key relationships, associations and boundaries for the design and execution of the research are also discussed to delineate the scope of the study. It is intended to demonstrate, through a discussion of the design and structure of the research, the reason for the methodology selected, and how this has assisted the selection of data gathered for evidence. Figure 3.1 illustrates the connection of the paradigm, approach, methodology and research methods to be used for the research.

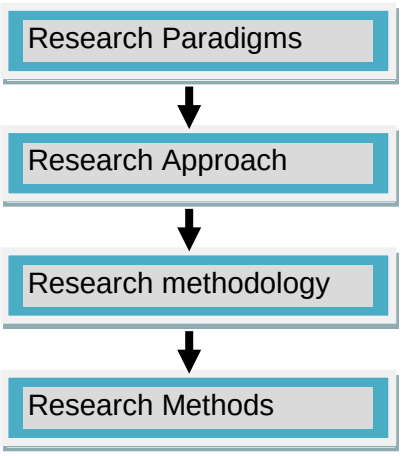


Figure 3.1 Process of Research (Adapted: Vernon and Lesham, 2012)

The research explores and contributes to the existing body of research based on carbon use within the domestic sector, being specifically centred on social housing and the effects of the installation and commissioning of low carbon technologies. The social housing sector is of particular importance to this research for two reasons: Firstly social housing and the RP sector have been used as a test bed in the development of mass low carbon homes. The government sponsored Homes and Community Agency (HCA) funding has required defined levels of low carbon development as a prerequisite for grant funding, and compliance with code for sustainable homes level 3 and 4 as a mandatory requirement. Secondly, the investigation of professional practice is at the core of professional doctorate research, and this research focus enables an 'insider researcher' perspective to explore problems arising from low carbon housing projects (Hopkins, 2002). The 'insider perspective' enables a unique opportunity to view the development and transition of construction working practice along side the effects of the code for sustainable homes. It allows the research to obtain a 'real world' view of installation and commissioning of low carbon technologies in this defined area, and gain insight from a construction industry perspective.

The ethical perspective is reviewed to establish the importance of a protective and controlled environment in which the research is conducted. The insider research approach does create ethical implications when conducted within the work place and these need to be considered and addressed as part of the research design. The research makes and develops contacts with a wide range of construction professionals and therefore, the need to protect and treat all respondents sensitively, is of importance in achieving the research results.

3.2 Conceptual Framework and Research Boundaries

It is necessary, before commencing any research project, to establish the conceptual framework and research boundaries. Miles and Huberman (1994:p18) define a conceptual framework as a visual or written presentation which 'explains either graphically, or in narrative form, the main things to be studied – the key factors, concepts or variables'. This gives a framework on which to develop the key influences and variables within the study, exploring the relationship developed through the theory (Miles & Huberman, 1994; Robson, 2011). A graphical representation of the study areas has been selected to indicate the interrelationships for the installation and commissioning activities on new construction sites. It has enabled the examination of the interactions of different influences in the research area, illustrating the complexity of the construction environment and the interdependency of the site professional roles (Figure 3.2).

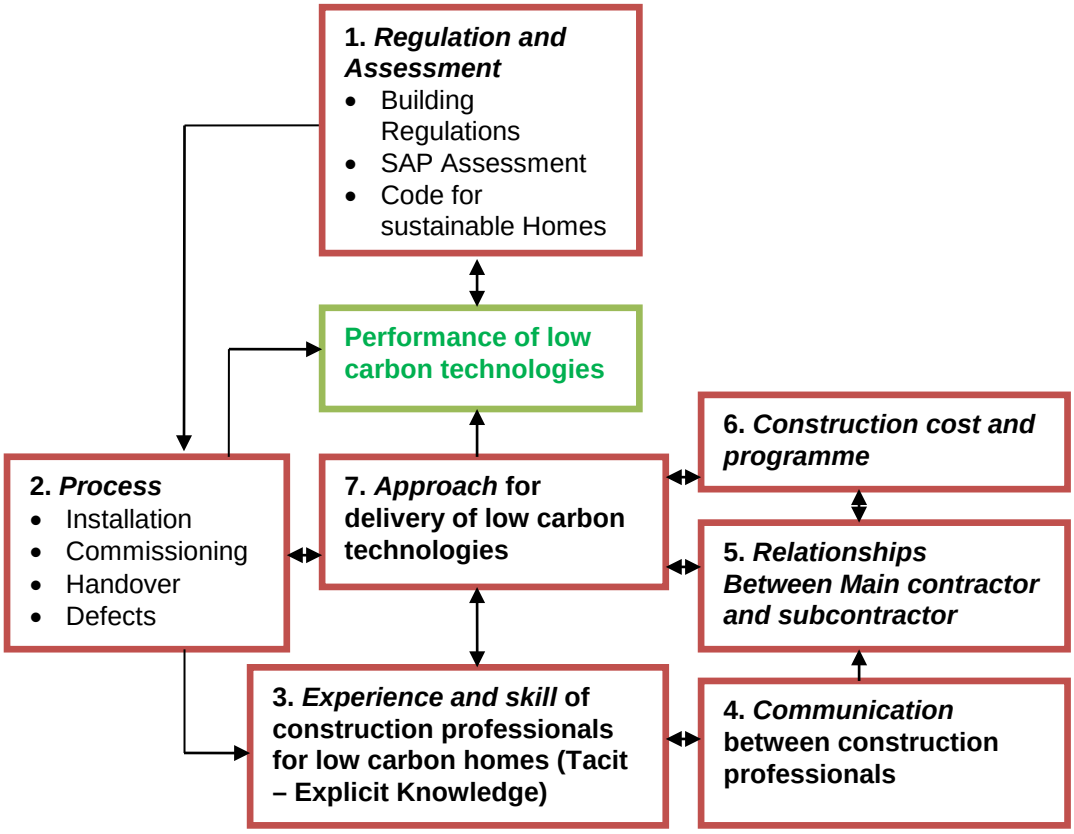


Figure 3.2 Conceptual Framework Adapted from (Miles and Huberman, 1994)

The conceptual framework presents seven variables that affect the interactions on the construction site when exploring the performance of low carbon technologies. Each variable has an influence on the performance criteria. However, the interrelationships of the seven areas combined illustrate the complex nature of the construction environment, giving an appreciation of the subject to be researched and explained. As Trafford and Leshem (2012) point out the conceptual framework gives the focus to the research and provides a basis for the determination of the research design.

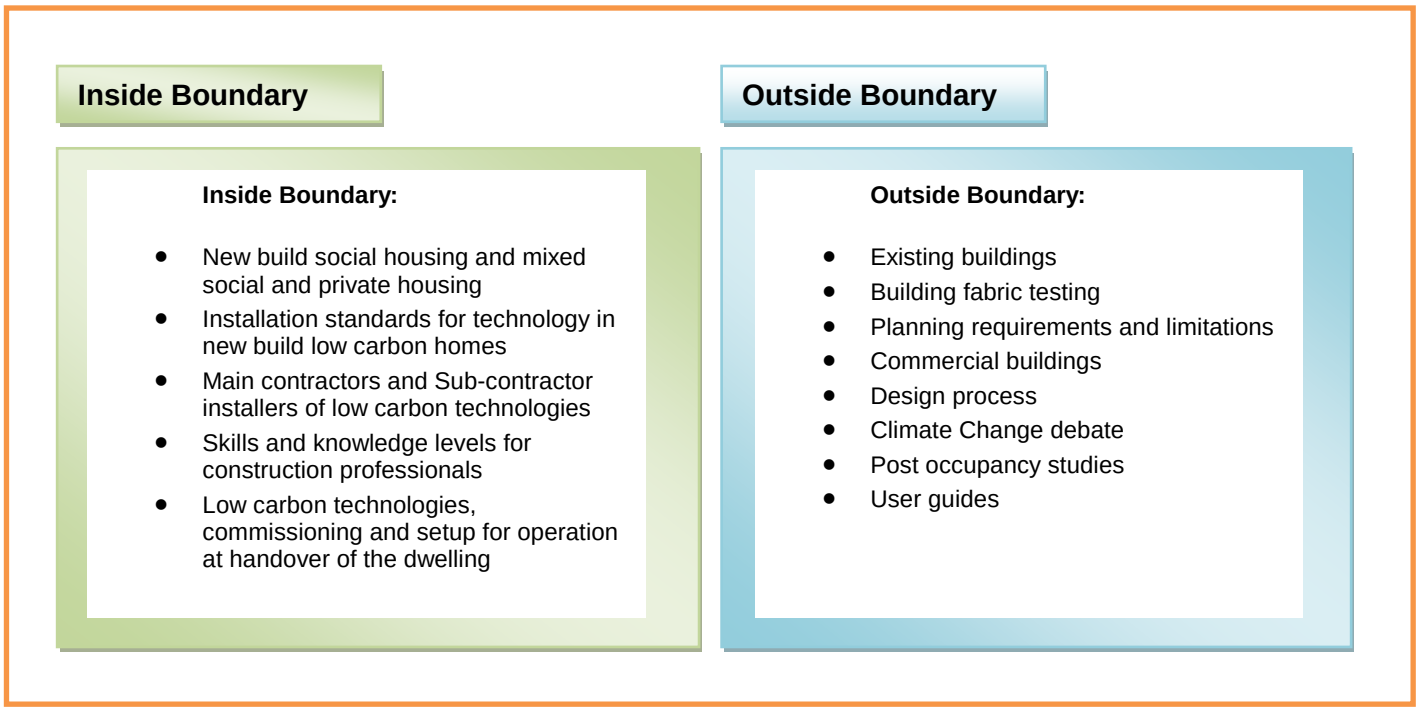


Figure 3.3 Research Boundaries

Gray (2011) suggests that the conceptual framework also identifies exclusions from the study, setting an explicit boundary for the research (Figure 3.3). These have been identified to set limits on the scope of the research. In this research the boundaries have been set around new low carbon housing projects and specifically those carried out for RP clients. Installation and commissioning activities, along with communication and knowledge levels are included, these being central to the pre-occupation performance of the low carbon technologies. Miles and Huberman (1994) identify that the framework is an iterative process; the conceptual model is continually revisited throughout the research to check validity and direction. This promotes the continual assessment of the boundaries, identifying emerging themes from theory and practice, and revaluating the focus of the research. Those aspects that fall outside the research boundaries may be considered in later studies

3.3 Research Question

Having established the conceptual framework and research boundaries it is then necessary to define the research question that distils the various questions that have been identified within the conceptual framework, into one overarching research question. Trafford and Lesham (2012) observe that research questions have a distinct advantage over other ways of conveying the research intention. In posing research questions the researcher has to provide answers, and thereby demonstrate 'closure to the research quest'. As O' Leary (2004) suggests research questions must be 'researchable and explicit' and include the definition of the investigation, establishment of boundaries and provide direction to the research.

Following this reasoning, it is possible to define the main research question as:

How can installation and commissioning strategies for low carbon homes be improved?

Subsidiary questions:

1. What are stakeholder perceptions of low carbon technologies in new construction developments?
2. How can the installation process of low carbon technologies be better communicated during construction?
3. How can the commissioning process be enhanced to improve performance
4. What intervention processes can achieve an effective installation and commissioning strategy in new mass low carbon homes?

It is envisaged that the insider perspective approach taken from professional practice will enable each of these questions to be investigated from the standpoint of 'real world'

housing delivery, using the appropriate research paradigm.

3.4 Research Paradigm

The whole process of this research is governed by the research paradigm. A paradigm is defined as - 'the entire constellation of beliefs, values, techniques shared by members of a given scientific community' (Kuhn, 1970). Therefore, facts and phenomena are viewed and interpreted by researchers based on their own given paradigm framework to generate knowledge and understanding. According to Mackenzie and Knipe (2006) without establishing the research paradigm at the start of the research project, there is no real basis for choices of methodology, methods or research design. In Table 3.1 Creswell indicates the four paradigms, or as he suggests 'world views' defined as a 'basic set of beliefs that guide action' (Guba, 1990 p.17).

Table 3.1 Four Worldviews (Creswell, 2009)

Positivism **Quantitative (Deductive)**	**Constructivism and Interpretivism** **Mainly Qualitative (Inductive)**
❖ Determination ❖ Reductionism ❖ Empirical observation & measurement ❖ Theory verification	❖ Understanding ❖ Multiple participant meanings ❖ Social & historical construction ❖ Theory generation
Advocacy/Participatory **Mainly Qualitative (Inductive)**	**Pragmatism** **Mixed Methods (Deductive and Inductive)**
❖ Political ❖ Empowerment issue-orientated ❖ Collaborative ❖ Change-oriented	❖ Consequences of actions ❖ Problem-centred ❖ Pluralistic ❖ Real-world practice oriented

These world views are shaped and directed by the researchers experience, beliefs and environment and lead to the methodology selected by the researcher (Creswell, 2009).

This research is to be undertaken within the sphere of a professional doctorate, and as such, the subject is founded in professional practice. This therefore, places the research in a social setting and one which is conducted in the real world (Bryman, 2004). The perspective of professional practice is key to the investigation of the research problem being undertaken, and gives an insider researcher angle to understanding the effects installation and commissioning have on the performance of mass low carbon homes. This professional paradigm allows the lens of a real world view to be applied to the subject and to the problems to be addressed (Gray, 2011). It also puts the exploration of human knowledge and activities at the core of the research question, leading to a pragmatic paradigm centred on the consequences of actions and real world practice (Creswell, 2009; Rylander, 2012)

Pragmatism is concerned with actions, situation and consequences rather than antecedent conditions and is centred in the application of problem solving (Creswell, 2009). Action has, as Dewey (1931) states, 'the role of an intermediary', he suggest that action is the way to change existence. Therefore, to perform change in a preferred way, the action must be guided by purpose and knowledge. The world is seen to change through reason and action displaying an inseparable connection between human knowing and human action (Creswell, 2009). The Pragmatist approach is pluralistic, not committed to any one system of philosophy and does not see the world as an absolute unity. It looks to many approaches for collecting and analysing data rather than subscribing to only one way in order to deal effectively with the full richness of a real world problem (Creswell, 2009). Creswell also argues that pragmatism uses findings in a positive manner in harmony with the value system held by the researcher, linking the choice of approach directly to the research questions posed. Therefore, pragmatism gives the ability to research subjects that are of interest by embracing the methods that are appropriate to the study (Armitage, 2003). Creswell (2003:p11) identifies that pragmatism places the research problem at the centre of the study

and ‘applies all approaches to understanding the problem’. It is primarily focused on the ‘what’, ‘how’ and ‘why’ of the problem with data collection and analysis methods being chosen from those which provide insight into the research question (Tashakori and Teddlie, 2009).

Pragmatism can be seen to ‘fully acknowledge the mutual permeation of knowledge and action’ (Goldkuhl, 2004). However, Rylander (2012) argues that the researcher needs to be wary of accepting the ideas of pragmatism too uncritically. She identifies that pragmatic ideas need to be used as tools for further inquiry; that the ‘explanation of phenomena’ should not only come from ‘surprising’ new information, but from tested theory based on the logic of deductive and inductive research. In addressing and solving the real world practice problem care needs to be exercised to ensure rigor and method are applied to the research methods to gain validity (Tonkinwise, 2011).

With the above in mind, the research is to be viewed within this professional paradigm exploring why installation and commissioning of low carbon technologies affects performance targets, and how commissioning processes may be developed to improve performance (Vernon and Lesham, 2012). The Installation and commissioning process is the development through which technologies in new homes are installed and tested to ensure performance against design criteria. It is also a process whereby several construction professionals coordinate activities and communicate to achieve the performance of the end product. The investigation is to be conducted within the ‘real world’ (Gray, 2011), engaging with a variety of stakeholders to solve the research problem using both deductive and inductive research methods. Therefore, the construction professional paradigm, centered in the real world environment, is supported epistemologically by the pragmatic paradigm, with the additional rigor of qualiatitive and quantatitive data gathering for this research.

3.5 Research Approach

In establishing the appropriate research approach based on the examination of the construction industry at the installation and commissioning stages, it is necessary to design the process of the research activities to achieve the outcomes required. Easterby-Smith et al (2002) advocate the requirement to establish the epistemological basis of the research, understanding what types of knowledge are legitimate and relevant for the study. Crotty (1998) also suggests a close interrelationship between 'the theoretical stance adopted by the researcher, the methodology and methods used, and the researcher's view of the epistemology'. Therefore, building on the theoretical perspective, research paradigm and development of the research questions, the research approach is further explored to consider methodology and data gathering methods.

This research addresses the process of installation and commissioning of low carbon technologies on new build construction sites for RP housing. The research seeks to understand what is currently happening, why it is happening in this way and how it can be developed and improved to advance professional practice. It is focused within the philosophy of pragmatism, combining both the empiric (knowledge from experience) and rational (knowledge from scientific reasoning) processes (Ivankova, 2015:p54). This combination of empiric and rational approaches accommodate the view point of 'what works' pragmatic problem solving, and uses a mixed methods approach within the research (Johnson et al, 2007). Ivankova similarly proposes that pragmatism is able to function as a 'philosophical foundation for mixed methods research'(ibid, 2015:p53); using both the inductive and deductive approaches to find and understand the answers to the posed research questions (Maxcy, 2003). Johnson and Onwuegbuzie (2004) also propose that pragmatic research using mixed methods should entail selecting 'the combination or mixture of methods that works best for answering your research question' (ibid, 2004:p17).

Therefore, this mixture of methods to address the research problem is discussed further in order to identify the research best suited for this study.

3.5.1 Mixed Methods

Consideration has to be given to the use of the mixed methods approach for this type of research. Greene et al (1989) identify five main purposes for applying mixed methods research over mono research methodologies; these include triangulation, complementary, development, initiation and expansion. (Table 3.2).

Table 3.2 Five Purposes for Mixed Methods. Adapted (Greene et al, 1989; Ivankova, 2015;p11)

Purpose	Description
Triangulation	Convergence and corroboration of results from different methods
Complementary	Enhancement and clarification from the use of both deductive and inductive results
Development	Using results from one method to develop and inform results from another method
Initiation	Discovering new perspectives and allowing questions and results to be recast from one method to another
Expansion	Extend the breadth and range of research by using facets of inquiry from both the deductive and inductive approaches

Teddlie and Tashakkori (2009) also describe three situations where the mixed methods approach can be more advantageous than using deductive and inductive approaches alone. They suggest firstly that both confirmatory and exploratory questions can be answered in the same study. Secondly, that mixed methods provides 'more stronger and credible inferences from the data' (Ibid), enabling a more complete picture of the research. Thirdly, the researcher can explore and develop divergent viewpoints from both the inductive and deductive approaches, thereby extracting more rich information than from single methods (Ivankova, 2012). Hanson et al (2005) similarly identifies that mixed methods allows for the

development of rich data through the simultaneous use of both deductive and inductive research, suggesting that research gives 'contextual understanding' (ibid) to the phenomena being researched. It is this richness of data streams and the ability to triangulate the results from the research which gives the process a greatly reduced level of uncertainty when interpreting the data (Webb et al, 2000). This approach has benefits for the research within construction as installation and commissioning are, to an extent, collaborative processes. They require not only the ability to achieve recordable and repeatable results, but to do this practically within a pragmatic paradigm of social interaction and the variable response this can give. Gray (2011) suggests that taking this pragmatic paradigm removes the dogmatic approach and assumptions that flow from either deductive or inductive methods alone. The approach allows the research to flow from the research question, providing the 'best chance of obtaining useful and workable answers' (ibid). Lohne et al (2015) supported this approach, in their study of the construction industry and its ethics regarding commissioning. They found that there is a social as well as technical dynamic enacted during the commissioning process, and that this needs to be identified to fully understand the process (ibid). Therefore, when approaching this research study the actions of installation and commissioning and the results achieved, along with reflection on the process, are important outcomes. Understanding the dynamic of how this is achieved, why a process is conducted and what changes may be enacted to bring improvement add descriptive richness to the research outcomes for professional practice.

By using mixed methods research approach there is a focus for exploring the installation and commissioning processes during the delivery of new low carbon homes. The structure and design of the mixed methods approach needs to be carefully considered to ensure that the data is collected as required for the research (Gray, 2011). Creswell and Clark (2011) and Teddlie and Tashakkori (2009) propose that there are characteristics related to the design and implementation of mixed methods research. Creswell and Clark (2011:p63) refer to

these characteristics as 'key decisions' (ibid) that the research should make when selecting the appropriate mixed methods design.

Teddlie and Tashakkori (2009) argue that they believe there is no true mixed methodology without integration, Morse and Niehaus (2009) and Creswell and Clark (2011) also see integration as an essential strategy for mixed methods study. According to Yin (2006) and as suggested by Ivankova (2015) integration can occur at different stages of the research from 'conceptualisation, structuring the research questions, through to data collection and interpretation of the results'. A merging of the two approaches, as opposed to the development of one or the other as a pure approach, has enhanced the data collected and its subsequent value in understanding the research outcomes (Ivankova, 2015). This also gives validity to the professional doctorate and enables, through the understanding of the installation and commissioning process, the changes that can be enacted to move professional practice forward. The merging of the quantitative and qualitative methods to answer the research question as observed by (Guba and Lincoln., 1994) shows that there are consistencies between the two paradigms, which allow for the two approaches to be used as complementary enquiries research. Creswell (2012) asserts that the action researcher uses the data to construct a set of detailed and rigorous conclusions and therefore, validity through the triangulation of the data gives support for a combination of both methods as complimentary.

Mixed methods, like all research approaches, needs to be reviewed through the critical lens (Mackenzie and Knipe, 2006). Fielding and Fielding (1986) argue that mixed methods should not always be assumed to be of benefit to the research. As Bryman (2007) states, the end product of the research should be more than 'the sum of it individual quantitative and qualitative parts'. Care and attention need to be paid to the gathering of data and the blending to ensure well integrated interpretation (Krahn et al, 1995). In defence of mixed

methods Guba and Lincoln (1988) stress that the internal consistency between quantitative and qualitative research approaches, their 'associated logic, and paradigm location' mitigates against methodological mixing of different enquiry modes. Tashakori and Teddlie (2010) also suggest that eclectic data collection strategies cannot be dismissed, stating 'we cannot ignore the practical imperatives that necessitate the practical research endeavour'. To this end Johnson and Turner (2003) refer to the advantages of this data collection method as a 'fundamental principle of mixed methods research' with the methods selected as having a 'complementary strengths and non-overlapping weaknesses'. Johnson and Onwuegbuzie encapsulate the philosophical position of mixed method researchers when they make the following statement:

> 'We agree with others in the mixed methods research movement that consideration and discussion of pragmatism by research methodologists and empirical researchers will be productive because it offers an immediate and useful middle position philosophically and methodologically; it offers a practical and outcome-orientated method of inquiry that is based on action and leads, iteratively, to further action and the elimination of doubt; and it offers a method for selecting methodological mixes that can help researchers better answer many of their research questions'.(ibid, 2004:p17)

With this statement in mind this research study uses the combining and merging of deductive and inductive approaches to explore installation and commissioning test data, and the reasoning and actions of the research participants. This mixed methods approach when taken in the context of the pragmatist paradigm gives the tools to the research approach to investigate the real world problem within construction. Considering the professional practice based nature of the research area, and the unique position as an insider researcher, an

action based methodology connected with mixed methods will be best suited to the research design. Action research is therefore, considered for this research and is further discussed to investigate the research approach.

3.5.2 Action Research

Stringer defines action research as ‘a systematic approach to investigation that enables people to find effective solutions to problems they confront in their everyday lives’ (Stringer, 2014). The term action research, first used by Kurt Lewins in 1946 (Burnes, 2004), is viewed as a tool to understanding social systems and organisational learning (Lewin, 1946). In emphasizing the connection between theory and practice Lewins argued ‘no action without research; no research without action’ (Adelman, 1993). Kemmis (1982) suggests that actions and interventions are fundamental to the process of action research, requiring a cycle of actions to develop and evaluate inputs to improve professional practice. As a consequence of observing and reflecting on the cycles of intervention Ivankova (2015) observes that the practical researcher gains empowerment to make improvements to their working environment. Ivankova goes on to argue that the primary purpose of action research is to produce practical knowledge that both strengthens and progresses professional practice. This emphasis on the creation of practical knowledge to benefit professional practice, through intervention and action, is the primary reason for the selection of action research as the methodological approach for this study.

Herr and Anderson (2005) suggest that a primary goal of action research is to ‘generate local knowledge that is fed back into the setting’. For this reason, the presence of the professional practitioner within the research allows for knowledge that is relevant to the professional community to be used to improve practice (Teram et al, 2005). Kemmis and Mc Taggart (2007) identifies that the emphasis is on the practitioners own professional practice, exploring and clarifying the problem and creating conditions to remove the obstacles to

improvement. Similarly Hopkins (2002) refers to the 'insider perspective', one in which there is 'disciplined enquiry with a personal attempt to understand practice while engaging, improving and reforming it' (ibid). In this way, action research gives a practical methodological approach to the study of construction site activities. It enables the insider perspective to gain a deeper insight of the complex interactions between the construction professionals during the installation and commissioning of low carbon technologies. It also recognises the degree of rapport and collaboration required in action research, as identified by Herr and Anderson (2005), to gain the perspective and initiate change.

3.5.3 Action Research Model

Lewins (1948) conceptually regarded action research as a cyclical progression of four distinct phases namely planning, acting, observation and reflection (Figure 3.4).

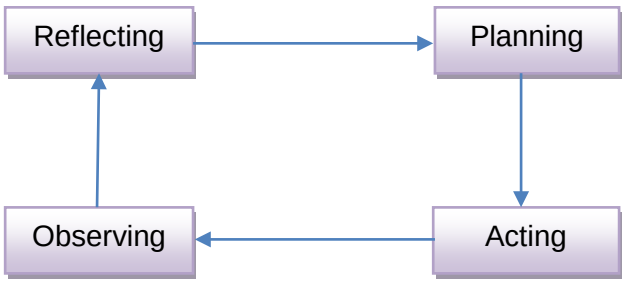


Figure 3.4 Based on Lewins (1948)

According to Ivankova (2015) the cycle begins with the professional practitioner identifying a problem that requires a solution within the practice setting. The researcher reflects on the facets of the problem and identifies what is known about its structure and impact. Next a plan is developed on how to proceed and the actions to be undertaken. These actions and results are then observed and reflected on to identify improvement and change. The cycle can then be continued through the four phases a number of times until the problem is resolved (ibid). Stringer (2014) has taken a similar approach to this cycle based on three

iterations he identifies as ‘look, think and act’ with the look element integrating observation and reflection. This model of action research has been adopted within the current research, to explore the scope of the problem centred on effective installation and commissioning of low carbon technologies.

The cyclical model suits the investigation by enabling the insider researcher to identify the issues within the construction site processes from professional experience. Through the cycle of phases, the process invites the discovery of emergent themes in practice, which after reflection, can be used as part of the route to change (Ivankova, 2015). The model for this research study has been developed and is illustrated in Figure 3.5. The model has emerged from the practical considerations for engaging in the research from an action research with mixed methods design perspective.

McNiff (2010) suggests that when engaging in the research cycle the first stages of the process must identify the issue to be investigated and state why this is an issue for the researcher. From this stance the cycles flow in iterative steps of looking, thinking, acting and reflecting (Stringer, 2014) therefore developing naturally and progressively through a continual interrogation of the process.

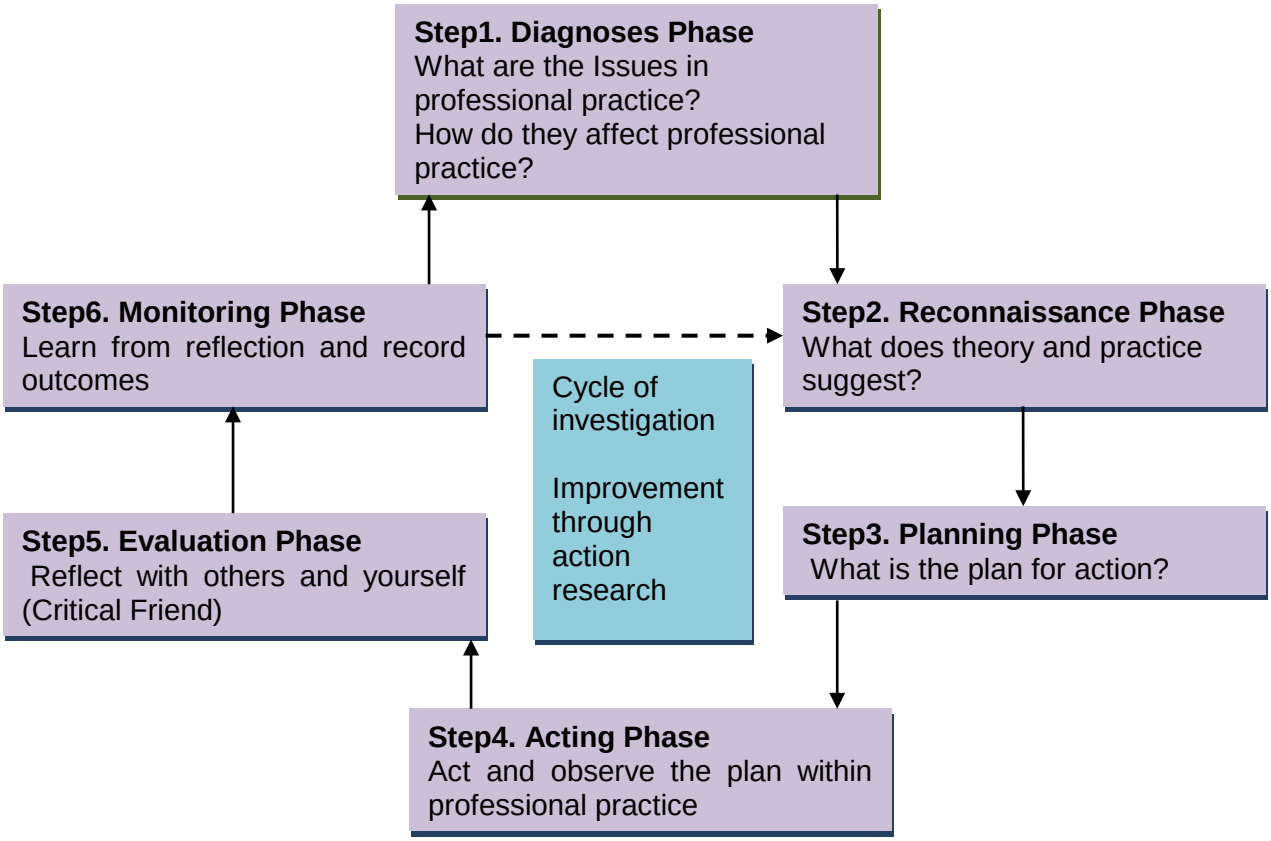


Figure 3.5 Action Research Cycle Adopted for the Research Project (Ivankova, 2015:p90)

At each step of the cycle the research engages with the participants within the study. Insight is gained from these interactions which enables the unique position of the insider research, central to a professional doctorate, to develop and improve practice from within (Gray, 2011). These exchanges permit the development of a research perspective using both academic Mode 1 knowledge and practical deliberations from professional practice using Mode 2 knowledge as explained by Gibbons et al (1994). The research perspective is continually assisted by the intervention of a 'critical friend' to critique and challenge the research findings (Huberman, 1994).

A mixed methods approach has been used within the action research model as described by Ivanakova (2015). Mixed methods and action research are complementary in their

approaches and also allow a sound theoretical frame work to carry out the action research process. The deductive and inductive elements combined within mixed methods approach enhance the action cycle, and allows a structure for verification of the research findings during the reflection and monitoring phases (Ivanakova, 2015). Creswell and Tashakkori (2007) propose that the 'practice perspective' influences investigators to use mixed methods in other research approaches including action research. McNiff and Whitehead (2011) advance this view by suggesting that as action research is a 'broad methodological approach' it can and should include a range of methods from other approaches (ibid). The steps within the model have, therefore been designed using an integration of deductive and inductive approaches within mixed methods throughout the action research cycle. As emphasised by Herr and Anderson (2005:p58) mixed methods within action research has established a research approach that has built on the 'meaningful integration' of deductive and inductive methods. Therefore, creating 'new and more enhanced ways of learning about the problem of interest' (ibid). The following phases indicate the research cycle for the research project:

Step1. The **Diagnosing Phase** initiates the research cycle by investigating professional practice and asking the 'what' and 'how' questions associated with the problem and its effect on practice (Ivankova, 2015). (Tashakori and Teddlie, 2009) suggest this is fundamental to the pragmatic approach and gives foundation to the research questions to be framed for the study. The research study has looked at a number of low carbon new build construction sites, where the professional practice is actively engaged, to observe the current practice for installation and commissioning. Data collections methods including a focus group to test ideas and assumptions, and a questionnaire to develop the themes of the study, are proposed to establish the issues in professional practice. The focus group has also been used to pilot the questionnaire before circulating to construction professionals.

Step2. The **Reconnaissance Phase** takes the investigation of the problems identified in the diagnostic phase and examines theory and professional practice before engaging in action. This phase identifies potential areas of change and improvement, and informs the development of the planning stage for actions and interventions (Ivankova, 2015). During this phase exploration of the literature is one of constant engagement based on the research problem, ensuring that a theoretical perspective is formed and that literature is not seen in isolation from, but more in connection to, the study (Rugg and Petrie, 2004; Trafford and Leshem, 2012). Consultation with both theory and professional practice has permitted the development of a viewpoint from the experience of others within practice and in the research field. McNiff (2010) suggests that integration between practice and theory is an important element of action research, Herr and Anderson (2005) also point out that it lays the foundation of 'new ways of knowing' (ibid).

Step3. The **Planning Phase** reflects the exploration through the engagement with theory and professional practice (Ivankova, 2015). McNiff et al (1996) suggests that the key to the planning phase is identifying a focus with a 'sense of commitment to improvement'. Unlike experimental research, exploring causal relationships between variables, action research at the planning phase is considering actions that can lead to change within practice (Gray, 2011). This phase continues with the interaction and consultation with practice to establish the framework of the plan that engages all parties within the research (Munford, 2001). This process deals with the plan of action to introduce change and improvement, and as described by Cowan (2006) becomes the 'reflection for action' before action is engaged.

Step4. **The Action Phase** requires the action plan to be put into operation and to observe and record data produced. Gray (2011) observes that data collection should be as comprehensive as possible as important data and insights may only emerge once the data is analysed. Stringer (2007) also advises that the researcher should ensure diversity in the

study so that a full interpretation of the setting and actions undertaken can be represented. It is to be recognised that there are challenges to the implementation and success of the action phase, Stringer (2014) and Hinchey (2008) both respectively identify the issues of stakeholder engagement in the action and interventions cycle. Mills (2011) also points out the concerns of the reluctance to change and the fear of the unknown within the action phases which have the potential to threaten research outcomes. Tomal (2010) guides that an understanding of the change process to be undertaken is essential when conducting action research, as the research implies the aim of solving problems and instigating change. The research project has elicited many of the issues raised by Mills, Stringer and Hinchey and as a consequence engagement with both the research subjects and the 'critical friend' has assisted in creating an understanding of the data under these constraints.

Step5. **The Evaluation Phase** as argued by Tomal (2010) is critical to the practitioner researcher, as without evaluation of the actions one never knows if the 'results of the action were successful or that the problem was resolved'. Stringer (2014) also suggests that the evaluation acts as a 'tool of empowerment' as it allows the researcher to reflect on the direction of the action and the efficacy of the desired outcomes. Ivankova (2015) also argues that evaluation also helps inform monitoring of the actions and interventions and assists in promoting the 'sustainability of the change efforts'. It has been important at this stage of the research to also engage with others within professional practice thereby reflecting from the construction site perspective as well as those views of colleagues and the critical friend. The professional practice has acted as a focus group for the research, which has allowed the testing and review of ideas from the researcher, the research subject, but also from wider professional practice.

Evaluation and reflection of varied perspectives and data have permitted a triangulation of the evidence gathered with the information drawn from more than one source. This has

been important in demonstrating validity within the action research as identified by Gray (2011). Where further actions have been identified, through reflection, this has enabled a return to step2 and to repeat the action phase with inform adjustments to effect further change and improvement.

Step6. **Monitoring Phase** calls for the sharing and dissemination of knowledge created from the research cycle; Koshy et al (2011) see the purpose of the research cycle to 'improve practice or to implement change' and to sustain that change by bridging the gap between theory and practice (Mertler, 2012). Hacker (2013) states that the monitoring phase 'jump starts' (ibid) the process of translation of new generated evidence into adopted professional practice. The research process has seen this as lessons learn activity in practice that has generated new approaches to installation and commissioning with low carbon technologies. The sustainability of the processes put in place as a result of the action research project are evident in current practice, but as experienced in construction activities the research cycle will be continual.

3.5.4 Justification for Action Research using Mixed Methods

The interaction of the mixed methods approach with action research is considered to form a good fit with the aims of this research, where an insider practitioner perspective is used to solve a practice problem. The research is carried out whilst working within the practitioners own environment to observe and support the change process within the work place (Ivankova, 2015). This type of action research has precedent within construction, with the literature indicating projects undertaken in several construction fields since 1997. Seymour et al. (1997) for example conducted research within local government organisations in the area of urban renewal, whilst Cushman (2001) researched information systems within construction using action research. Azhar (2007) and Rezgui (2007) have also used this

research methodology for the study and development of IT related systems within construction projects. They emphasize the approach of the ‘established’ methods of action research using the 4 or 5 step cycles common to research in the social science fields (Connaughton and Weller, 2013), and adopted on this research project.

From a critical perspective Connaughton and Weller (2013) have identified 4 key themes that are important within construction action research. These are:

- The formality of the approach
- Methodological issues
- Definition of the researcher/participate roles
- Management of interventions

They argue that adherence to the established action research cyclical approach is required to achieve ‘objectivity and rigour from involving researchers in the problem/solution axis’ (Ibid). They further stress that the steps of observation, action, reflection and learning are explicit to the research to enable the process of intervention and emergence of new knowledge to be understood.

Ivankova (2015) suggests that Mixed methods can give a ‘rigorous methodological’ foundation for action research. Equally Johnson et al (2004) consider that qualitative data fits with action research, however goes on to state that in many cases quantitative data can also be used where appropriate to strengthen the validity of the research. McNiff and Whithead (2011) also observe that mixed methods can be effective within a collaborative process with ‘joint problem solving by stake holders’. However, Herr and Anderson (2005) argue that the situation of multiple stake holders in the research can affect the position of the researcher shifting views from insider to outsider. This they say can create challenges with the balance of power, ownership of data and accuracy of the problem. Ivankova (2015)

suggests overcoming this ‘insider, outsider conundrum’, the action research project should always be collaborative regardless of whether the researcher is inside or outside the study setting. It is therefore, suggested by Ivankova that integration of the two approaches of research provide support and validity for the research methodology. Action research has been chosen as the research approach for two reasons. Firstly, it is epistemologically consistent with the investigation, its aims and objectives. Secondly because it seeks to both facilitate change within a construction environment and enable theory to be developed from empirical evidence gathered as a result of the change intervention (Garnett, 2001). Considering the intention of the research project to understand the construction events through a range of methods including focus groups, questionnaires, interviews and observation; this synergy of mixed methods and action research are used as the methodology for the research.

3.6 Research Data Gathering Method

Within current professional practice there is a level of tacit based ‘common knowledge’ understanding concerning the issues involved in installation and commissioning of new low carbon homes. Actual research data is not easily forthcoming in this area, and what is available is taken from supporting sources, not primary or secondary sources, and is of an anecdotal nature at best (Trafford and Leshem, 2012). Therefore, the development of an action research approach using mixed methods, both deductive and inductive data, permits a systematic, organised and methodologically sound process of investigation to produce credible and practical knowledge (Stringer, 2014).

Creswell (2012) equally identifies that action research follows a systematic procedure of ‘problem identification, data collection, analysis and interpretation’ which generates reliable knowledge to inform improvement in practice (Ivankova, 2015). Triangulation of the

information, by gathering data from multiple sources, increases the level of validity and reliability (Greene et al, 1989). This approach allows the deductive and inductive data to be reviewed together and created a feedback loop to continually test, compare and reflect on the data produced. The use of Methodological Triangulation (Denzin, 1989) offers the researcher this ability to collate and interpret varied data streams between different methods. Therefore, the Triangulation of the research information permits data sets to be combined, compared and corroborated from a varied range of methods (Greene et al, 1989).

3.6.1 Structure for Data Gathering

To gather evidence during the action research cycle, exploring installation and commissioning approaches, both deductive and inductive data collection methods are to be used. Gray (2011) proposes that data gathering is systematic and that a permanent record is taken of the research undertaken. Gray states that in action research it is important to use a varied range of methods to enrich the data and allow for triangulation of results. The research uses an integrated approach to data collection with both deductive and inductive combined throughout the study (Gray, 2011). The strategy for data collection for the research uses the following methods in table 3.3:

Table 3.3 Data Gathering Process

Inductive Data Gathering	**Action**
➢ Focus Groups	Test the initial ideas for the research area. Also use for reflection on research outcomes and modifications
➢ Observation	Look at Current active sites to see the extent of the problem 'in the real world' Look at the actual commissioning data to see if it corresponds with information from site activities
➢ Semi Structured Interviews	'In depth' interviews with a selection of construction professionals to gain further understanding beyond the questionnaire responses
➢ Participant Reflection	Communication during each phase of the action research to gain insight from participants on planning and interventions
➢ **Deductive Data Gathering**	**Action**
➢ Questionnaires	Ask questions about the 'real world experience on installation and commissioning on current projects
➢ Construction Documentation	Reviewing commissioning data gathered before and after interventions

Greene et al (1989) indicate the strength of mixed methods to give 'coverage and corroboration' when considering the validity of the research findings.

The data gathering process must be controlled to focus the research area (Stringer, 2007). Therefore, as part of the focus group and in depth interviews an approach was adopted to create a concept map for the defined data areas, as seen in Figure 3.6 below:

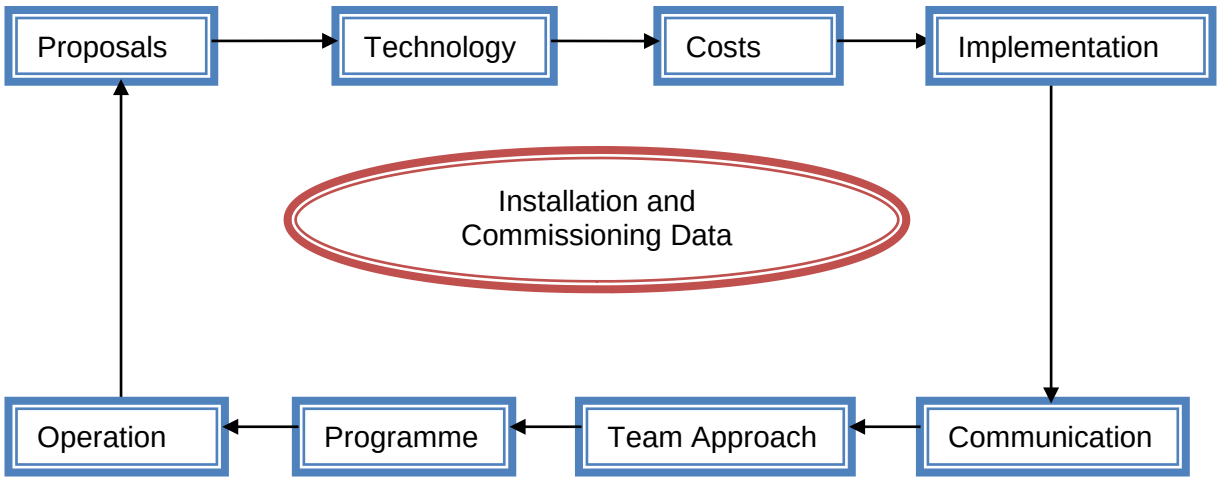


Figure 3.6 Data Gathering Concept Map (Adapted from Gray, 2011, p17)

Figure 3.7 illustrates the research tools at each stage of the action cycle, these are reviewed in turn and form the basis of the initial exploration of the research problem using questionnaires and interview strategies. This early strategy has been selected to identify the key construction issues from a range of professional perspectives in this field. At these diagnostic and reconnaissance phases the deductive questionnaires and inductive semi structure interviews allow feedback into the view of the problem from other prespectives. Herr and Anderson (2005) argue that multiple stakeholders give rise to the challenge of ownership and accuracy of data. They suggest that collaboration and participation in the research can overcome the 'insider-outsider' split. The research therefore engages at the earliest point in the cycle to investigate other perspectives before engaging in planning and action. McNiff (2010) suggests a number of 'research tools' to be used and further points out that the criteria for use is related to the appropriateness to answer the research question.

A focus group has been used to critique issues emanating from the action cycles. They have been used throughout the cycle to examine varying perspectives of the research and to engage open and honest discussion on reflection of the research (Creswell, 2013). As

identified by Ivankova (2015) and Teddlie and Tashakkori (2009) the focus group can be used at the diagnosis and reconnaissance phases to explore the relevance and usefulness of actions and interventions. The focus group structure was informal in construction and used as part of the critical friend analysis throughout the research.

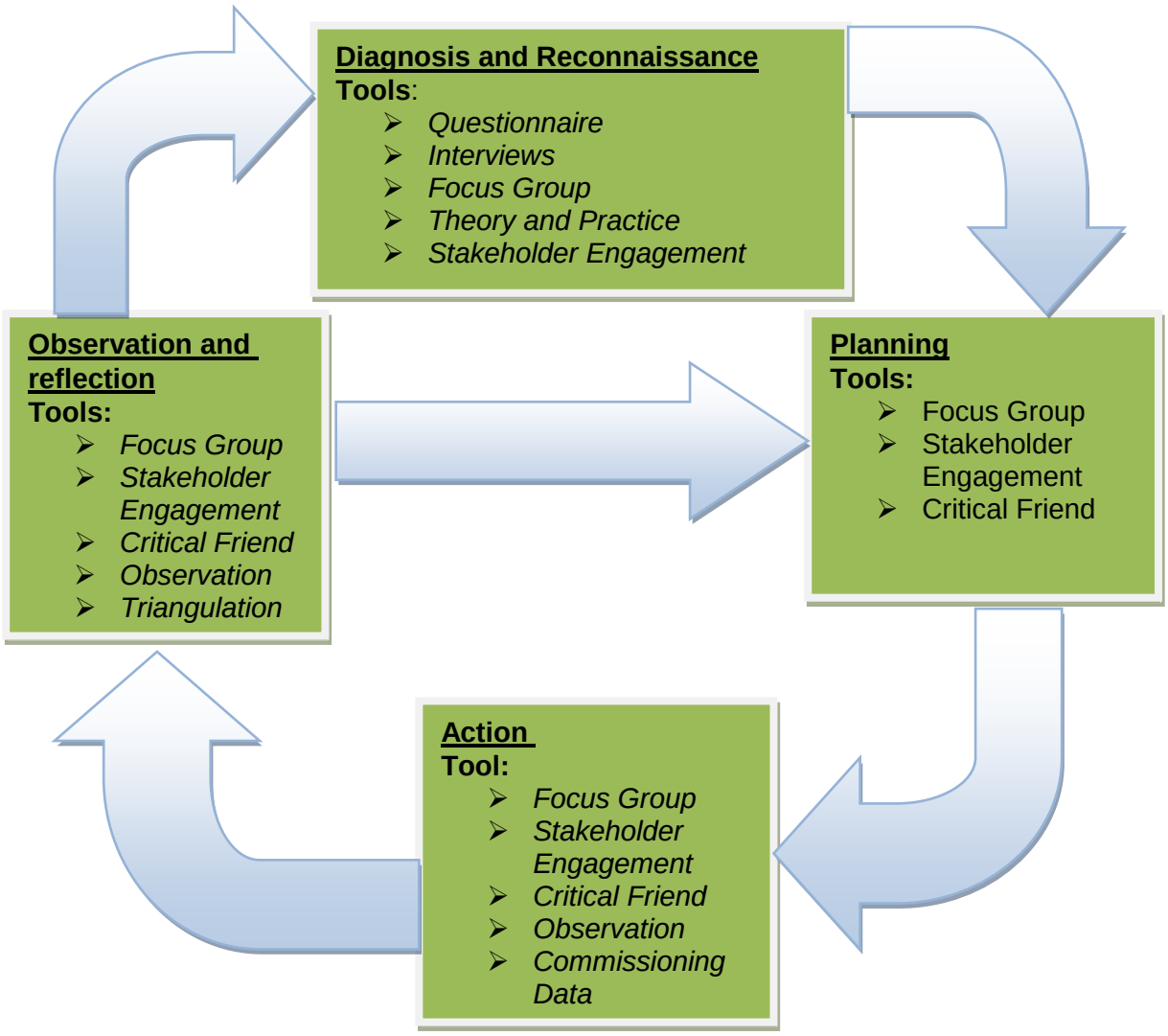


Figure 3.7 Research Tools for Action Research Cycles

3.6.2 Focus Groups

From the early stages of the research a focus group has been utilised to test, review and reflect on information and data that has been created. As put forward by (Bryman and Bell, 2007) this group was selected as experts in the field of construction, ranging from designers, developers, main contractors and sub-contractors. Their expertise has been used as part of the reflection process, and as observed by Coghlan (2001), can assist in achieving a structure of outcomes from the research to be used in professional practice.

As part of the first stage of the research the focus group was involved in a pilot study, which as identified by Gillham (2000) is essential to ensure information is accurate when collected. This information is used to create initial perspective from current construction experience of low carbon homes at three developments to explore the key element of the research problem. Informal interviews with designers at the planning stage are used to investigate the disconnect between the design considerations and the 'on site' activities of installation and commissioning. It also indicated that early design concepts for planning consent are potentially enshrined in planning conditions, therefore creating the possibility of compromises at an early stage in the construction process.

Creswell (2013 and Koshy et al (2011) recognize the use of the focus group as an efficient method of exploring the experiences and perspectives of different stakeholders. Attention must be paid to attendance and participation and to the power dynamic within the group ensuring equal opportunity to contribute and discuss (Ivankova, 2015:p203).

3.6.3 Questionnaires

The questionnaires have been constructed using a web based survey and marketing software ‘Dotmailer’. This is used as it is familiar in the professional practice engaged in the research study, flexible to use, data gather and access was simple for the respondents to reply via e-mail or Facebook. As observed by (Gillham., 2000) questionnaires need to be piloted to ensure understanding, therefore the questionnaire was repeatedly trialled with the main focus group who commented on question content, instructions and relevance. Test questionnaires were also sent out to the same group to sample the final content and software action after formal ethics approval, ensuring the main questionnaire had the highest probability of completion.

The questionnaires were designed to gather opinions on the delivery of technologies within low carbon homes. Arksey and Knight (1999) identify a number of areas to avoid when constructing questionnaires; these include prejudicial language, leading questions, assumptive and hypothetical questions. The questions used were predominately closed questions (Oppenheim, 1992) using ‘Rank’ and ‘Scale’ type questions designed on the Likert scale for ease of answering and reviewing data. There was a range of open and closed questions throughout the questionnaire, and these were arranged in subject groups to assist completion.

3.6.4 Interviews

Whilst questionnaires have their place, Arksey and Knight (1999: 32) find interviews have the opportunity to ‘help people to make explicit things that have hitherto been implicit’. Interviews have been used within the research to extend the meaning and understanding of the initial questionnaire and look for added richness of information beyond the restriction of the closed questions. A semi-structured interview process was adopted as a method to gain

more in-depth data from the initial questionnaires. The semi-structured approach, as opposed to the more formal and rigid structured approach, gave the opportunity to gain that rich information from the interviewee in the form of explicit and tacit knowledge, values, preferences and attitudes (Cohen and Manion 2000). As the research uses an action research approach the need to understand the meaning behind the actions during the installation and commissioning activities contributes to exploring the gap in knowledge. However, as found by (Arksey and Knight, 1999) to achieve strengthened validity there must be a robust structure to the interview session with the opportunity to build rapport, use questions drawn from theory and practice, ensuring sufficient time to explore the subject in-depth. As part of the interviews with the construction professional's, validity was further developed, firstly by selecting volunteers from a wide range of construction disciplines (many who had also answered the initial questionnaire). Secondly, interview sample sizes were increased until no new viewpoints were detected in the data (Arksey and Knight, 1999). Lastly, interview bias needed to be addressed to ensure the respondent was not influenced in their comments and as suggested by (Oppenheim, 1992). All interviews therefore, had a set of instructions, which along with the questions, were sent to the respondent before the interview. The interviews were also recorded to provide a record of the interview and to allow accurate transcription of the data. A set of instructions were given at the start to ensure the candidate understood the process and order of questions that were to be followed.

3.6.5 Observation

To explore the issues emerging from the focus group a selected range of site observations were carried out on current construction projects to gain a greater insight into the delivery of technologies within low carbon homes. According to (Bailey, 1996) overcoming the difficulties to gaining access to the research setting is vital and that building relationship with stakeholders and gatekeepers is key to success. Within the research a wide level of access

was requested and gained to a number to construction site through long establish professional relationships. This enhances the role of the insider researcher and has given access to data key to role of the professional doctorate researcher (Gray, 2011). Ellen (1987) identifies that observational studies involve researchers in very close proximity to the subject of the study, and as a consequence ethical issues can arise. Power and authority also need to be considered as this practice research reviews elements of the company practice (Herr and Anderson, 2005). Action researchers work towards improvement and change as the research objective, and as such, must acknowledge the effects of their presence on the research (ibid). Ivankova (2015) points out that keeping the participant informed and involving them in the process should be a fundamental part of the research method. Gray (2011) also advises that written approval for access is given to all the research areas used to ensure ethical consent. Participant observation (Saunders et al, 2007) has been used for the observations conducted overtly as part of the installation and commissioning process. The 'real world' setting was based within the construction activities on a small number of sites, but with a large number of properties, to attempt to understand the prevailing issues for the delivery of low carbon homes.

3.6.6 Stakeholder Engagement

As cautioned by (McNiff, 1996) there needs to be a very realistic idea of what action research can achieve in the 'real world'. Success of the research is very often inextricably linked to the relationships and working with other people. As (Stringer, 2007) indicates the role of action research is not to 'present finalised answers' but to bring groups with divergent views together to collectively form a solution to the research area (Gray, 2011:318). To effect the change, a holistic change process will be developed to assist collaboration on new developments, to bring together the observed disparate sections of installation and commissioning to contribution towards new low carbon homes (Mumford, 2001). This

process acts as an ‘action warrant’ (Avison et al, 2001) to build the collaborative process between the team to continuously review the progress made on each development. There is recognition of two outcomes that can come from the change process, firstly the co-ordinated approach of the installation and commissioning activities, but also to start to develop a record of low energy construction technical collaboration against recorded outcomes of defects recorded in the first year of occupation.

3.6.7 The Reflective Practitioner Process

Reflection on the process of action research is an important part of the process. Ensuring that evidence is gathered as suggested by (Coghlan, 2001) to have elements of how the researcher engaged, challenges assumptions, interprets and critically reviews contradictory interpretations.

It is shown that the range of evidence and information from both the qualitative and quantitative research data gives indication of a pattern of interaction with low carbon technologies directly related to installation and commissioning. The action research has formulated a model for a collaborative working process for the installation and commissioning stages which has built on the evidence from the research and also recognises the requirements for the construction industry going forward (Zero carbon Hub, 2014).

The research has been undertaken in close cooperation with RP’s and key construction professionals. Cooperation was maintained throughout the research including the investigation of professional practice change and overt observation and participation. Approval had been obtained for these research elements through the university ethics committee before the action research began.

The research exploring installation and commissioning of low carbon technologies is to be undertaken on several construction sites using the same processes at each site. The research reporting structure will therefore take the form of a case study of the action research cycles (Tripp, 2005) across the sites investigated. This will incorporate the research methods into a narrative of the action research cycles, investigating not only an account of the 'what' and 'who' questions, but importantly for action research the 'how' and why' to (Gray, 2011).

3.6.8 Thematic Analysis

Thematic analysis is a process of reducing qualitative data into meaningful groupings which is primarily concerned with the identification of patterns within the data (Naoum, 1998). Holloway and Todres (2003) identify thematic analysis as a core method used across qualitative research and suggest it is used as a 'foundation' to qualitative analysis. Braun and Clarke (2006) point out that thematic analysis lends a flexible approach to analysing data such as interviews and observations however, argue that the method should be undertaken to ensure the analysis is 'theoretically and methodologically sound'. As a consequence they suggest a 6 point guide (see table 3.4) to the analysis to ensure that it is carried out in a 'deliberate and rigorous way' (ibid). Significant points are raised within interviews and observations are identified and collated both in a thematic grid, constructed using an excel spread sheet (Naoum, 1998) and analysis of statements made throughout the interviews and observations. This facilitates the identification of repeated words or statements and can be used to categorise and extract themes from the data (Braun and Clarke, 2006). This method was used to analyse data from the semi structured interviews and observations, therefore enabling the research to build up a richer understanding of the subject through the narrative data.

Table 3.4 6 Point Guide to Thematic Analysis (adapted Braun and Clarke, 2006)

Phase of Analysis	Description of Analysis for each Phase
1. Familiarisation with the data	Transcribing data, reading and rereading the data, noting down initial ideas. Information from interviews and observations both on and off the construction sites forming part of the research
2. Generate initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes	Checking in the themes work in relation to the coded extracts; generating a thematic map of the analysis.
5. Defining and naming themes	On-going analysis to refine the specifics of each theme, and the overall story the analysis tells; generating clear definitions and names for each theme.
6. Producing findings	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back to the analysis to the research question and literature.

3.6.9 Statistical Analysis – Descriptive

Statistical analysis is concerned with the interpretation of data, usually in numerical format, in order to summarise and describe a collection of data 'descriptive statistics' (Gray, 2011). Descriptive statistics are used to summarise data from the questionnaires, including means for continuous data types and frequencies and percentages for categorical data types. Nominal and ordinal data has been extracted from the questionnaires designed using the Likert scales to explore the opinions and perspective of the stakeholder groups in the diagnoses phase. The data, gathered via the internet survey, using a proprietary survey software system 'Dotmailer', has been coded and arranged within excel to enable analysis. Frequency distribution data analysis is used to analyse the Likert data and information is displayed using bar and pie charts.

3.6.10 Triangulation of Data

Fellows & Liu (2003) observe that validation of research findings is an important process for research and should be considered at the outset of the project design process. Validation for this research is to be achieved by the combination of research methods, as part of the action research using mixed methods, in an approach centred on the principals of triangulation. Triangulation (Campbell and Fiske, 1957) represents the process of converging upon a particular finding by using different types of data and data gathering techniques to cross-check the research findings (Shaw, 2010). Denzin (1978) further explored how triangulation of methods should be used in practice by defining 'within methods' and 'between methods', distinguishing multiple data collected in one method, or multiple data collected between methods respectively. Denzin goes on to suggest that 'between methods' is potentially the most powerful as it takes data from 'different paradigms to balance bias' when interpreting the research data. Webb et al (2000) also argue that the process of using two or more independent measuring processes reduce the 'uncertainty in interpreting data' (Gray, 2011). Between Methods Triangulation (BMT) is to be undertaken in this research project by comparing the questionnaire and commissioning data with and observations and focus group findings discovered through the action cycles. Combining these research methods their data collection techniques adds depth, reliability and validity to the research findings, which in turn enables accurate conclusions and recommendations to be drawn.

Table 3.5 illustrates the various methods which were applied at each stage of the action cycle. The table, adapted from Shaw (2010), enables the research strategy to be illustrated in a clear and concise manner. It assists in graphically defining the research methods to be undertaken against the main research and subsidiary questions, and also indicates their use, contribution and data collection method within the action research cycle. This visual

representation of the research design and data collection methods has proved invaluable throughout the action research phase, both to maintain focus on the research questions, and link together the data gathering tools used for analysis. The table indicates the aim, based on the main research question, running through all of the activities throughout the research project, with the objectives and secondary research questions forming the structure for the action research cycle. The notes section at the bottom of the table gives the list of data collection methods used, as shown within the main body of the table.

Table 3.5 – Research Design and Data Collection (adapted Shaw, 2010)

Aim	Objectives	Action Research Cycle	Research Questions	Data collection Methods Used					
				Q	CD	OB & SE	FG & CF	SSI	TR
How can installation and commissioning strategies for low carbon homes be improved?	To explore the current understanding and practice of installation and commissioning of low carbon technologies in new mass low carbon homes	Diagnose and Planning Phase	What are stakeholder perceptions of low carbon technologies in new construction developments?						
	To develop interventions to improve installation and commissioning of low carbon technologies in new mass low carbon homes	Action Phase	How can the installation of low carbon technologies be better communicated during the construction?						
			How can the commissioning process be enhanced to improve performance?						
	To critically evaluate the intervention processes and its impacts on effective installation and commissioning of low carbon technologies in new mass low carbon homes	Reflection and Evaluation Phase	What intervention processes can achieve an effective installation and commissioning strategy for technologies in mass low carbon homes?						

Note:
Q = Questionnaires; CD = Commissioning Data; OB = Observations; SE = Stakeholder Engagement FG = Focus Group; CF = Critical Friend; SSI = Semi Structure Interviews; TR = Triangulation

3.6.11 Justification for Research Methods

As noted by Zikmund et al (2010; p112) ‘A problem occurs when there is a difference between the current condition and a more preferable set of conditions’. This gap in the difference between the known condition and the preferred condition or ‘problem discovery’ is the critical start point from which the research project design has flowed.

As a professional doctorate study based in business and professional practice, the gap which has been identified in the delivery of low carbon homes, is expected to open a new and deeper understanding around installation and commissioning activities which will lead to further research around the impact on new housing developments. From a practice perspective this research work will give real benefit to an important business sector. It has the potential to enable developers and RP’s to develop a long term construction strategy, not only for the benefit of future development, but also to work towards reducing earlier stage issues with low carbon technologies. It is intended that this research will assist in improving the way low carbon homes are delivered and managed within the social housing sector, and change practice approach to installation, commissioning across the construction sector.

3.7 Ethical Considerations

Before undertaking any research the ethical perspective of the research project has been investigated and offered for approval. The research project has been conducted using the methodology of a mixed methods approach with action research, which has sourced both qualitative and quantitative information. The method for the qualitative research element required the need to gather evidence from participants, some of whom were colleagues in professional practice, therefore the ethical dimensions was explored within the research structure. The nature of questions to be asked in a controlled circulation of a questionnaire, and the level of information used from a structured interview was carefully considered to

ensure evidence was obtained in a constructive and safe environment. However, this was not the only consideration; the need to ensure that information obtained did not cause harm or involve deception to the participant was of paramount importance to ensure the research had a defensible moral stand point (Gray, 2011).

A normative approach has been taken to the research project, one in which the moral actions are considered, and how a researcher should act from a moral perspective (Gray, 2011:69). Within the normative approach a deontological perspective (Broad, 1930), which looks from the stand point that the ends should never justify the means of the research has been the basis of the ethical approach. In other words regardless of the outcomes required or desired, the gathering of information should always be guided by, and rooted in a moral principle. Such principles therefore ensure the participants in the research project are fully respected and informed throughout their individual or collective involvement.

Therefore, developing the research structure the principals and considerations of the deontological perspective four key areas were considered when gathering evidence in a moral way. These key areas are made up of the following elements (Grey, 2011:73):

- To avoid harming persons involved in the research
- Respect the privacy of the participants
- Obtain informed consent from all persons involved in the research
- To avoid deception and ensure there is complete open communication

These consideration have been embodied within the questionnaires and interviews employed to obtain qualitative evidence from participants to the research. Such

considerations have assisted in the validity of the research making any information obtained, open and transparent and also ensuring a responsible and morally defensible position was taken and can be adequately defended. This is of importance as the research undertaken required questionnaires and interviews, which seek opinion and evidence to indicate that current construction activities and practices are not achieving the end results often claimed. Such information, was handled and recorded to ensure that if evidence obtained could have implications for particular individuals, and or companies, that all such information is given and treated anonymously. No information has been recorded which identified the person or organisation, or give details regarding specific construction projects unless full consent was given, and with the knowledge of how the information has been used within the research project.

The questionnaires and interviews did not require any identification names or specific locations, and all identifying material was removed from any information recorded in the research project. Information was stored in compliance with the Data Protection Act 1996 and has been stored in such a manner as to be accessible only to the researcher. A letter outlining the research proposal, level of research conducted and a full description of the requirements for participation had been sent to each participant, and signed confirmation of consent had been required before the research was undertaken. Application for research ethics approval was sought from the university and an appropriate approval was given before the main research commences.

3.8 Chapter Reflection

This chapter has explored the research design and identified the research within the theoretical perspective of pragmatism. Justification has been established for action research with mixed methods approach as the methodological stance. It will combine a cycle of

exploration through the research which will examine, plan, act and reflect on collaborative interventions to find improvement to the research question. A selection of data gathering methods will be used throughout the action research cycle facilitating integration with practice and theory which lays the foundation of ‘new ways of knowing’ (Herr and Anderson, 2005). The next chapter investigates the start of the action research project and examines the diagnosis and reconnaissance phases for the beginning of the research cycle.

Part 2 Action Research Cycle

Chapter 4

Exploring the Problem

4.1 Introduction

This chapter is concerned with the instigation of the action research cycle for the research project as discussed in the previous chapter. It describes the initial diagnoses and reconnaissance phases critical to giving direction to the action cycle. The context of the research is explored and the key elements and participants are identified, along with their interdependences and influences, within the construction process. A definition of the research problem is given, identifying historic issues within the installation and commissioning of low carbon technologies in mass low carbon homes. The problem is described through the lens of current professional practice, based on experience from recent construction projects within London and the Southeast of England. The structure, extent of influence and perception of the problem are investigated using a variety of research tools including a focus group, questionnaires and semi structured interviews. These have been distributed to a wide circle of construction professional stakeholders to explore their understanding and perception of the problem, and to gain insight into the complexity of the research topic. Data obtained from the investigation will be triangulated to allow themes to converge from the deductive and inductive methods, giving an interpretation to the findings and the basis for the planning and action phase of the action research cycle. Within the action research cycles reference will be made to the research being undertaken within the researchers professional practice, where this is recorded it will be referred to as 'The professional practice' or 'the researcher's professional practice'.

4.2 Context

The context of the research is based in professional practice and the experience of repeated problems centred on the installation and commissioning of low energy technologies in new mass low carbon homes within the social housing sector. The perspective of professional practice has given a unique insight into the current and past site processes through continual engagement and observation since 2007, on an extensive range of low carbon homes. This long term view point, gained through close working professional relationships within construction, has enabled access to the research problem from a wide range of stakeholder involvement. Therefore, this has allowed the research problem to be addressed in a real world setting, permitting the insider view to be balanced against the wider stakeholder perspective (Gray, 2011).

The research draws from theory and builds on past research to explore the increasingly complex environment confronting the domestic housing construction professions (Li et al, 2001). Stakeholder engagement is seen as an effective tool for this research within professional practice in identifying barriers to engagement in sustainable development (Wilson and Rezgui, 2013). Direct access, gained by the approach of insider researcher, to construction projects adds a further dimension to the engagement process, facilitating the environment for close observation and recording of the research problem (Gray, 2011). It engages both with a deductive and inductive means of enquiry to understand the rich level of data that is available in professional practice, and uses this to take action and reflect on the solutions to advance knowledge and future practice.

4.2.1 The Stakeholders

Wilson and Rezgui (2013:p289-309) observe that there is a necessity for the engagement of key stakeholders in low carbon construction to address ‘major drawbacks’ in meeting government targets for carbon reductions. They identify a wide range of fragmentation in the knowledge levels in construction, and indicate barriers in organisation and individual information sharing that obstruct sustainable development. Williams and Dair (2006) also suggest that stakeholder commitment is fundamental to overcoming barriers to low carbon construction. They argue that the devolvement of powers amongst stakeholders, both at the local and governmental levels, is critical to improve construction expertise and experience (ibid). In conclusion to their paper on sustainable construction in the UK, they state that ‘practical solutions’ to implementing sustainable construction development are required or ‘a sustainable built environment is unlikely to be delivered’ (Williams and Dair, 2006: p146).

From the insider researcher perspective the research has had the opportunity to engage with a wide range of stakeholders, investigating their opinions on the problems in low carbon new housing, and their perception of the practical solutions. A stated boundary of the research is to explore new mass constructed low carbon homes, and as such social housing projects and housing association schemes in particular are the focus for the study. Table 4.1 identifies the stakeholders engaged in the research and their involvement in the quantitative and qualitative elements of the investigation.

Table 4.1 Stakeholder Engagement

Stakeholder	Quantitative Investigation	Qualitative Investigation
Client Engagement	**Internet Based**	**Office and Site based**
Housing Association	Questionnaire	Focus Group/Interviews
Developers	Questionnaire	Focus Group/Interviews
Employers Agent	Questionnaire	Focus Group/Interviews
Project Managers	Questionnaire	Focus Group/Interviews
Surveyors	Questionnaire	Focus Group/Interviews
Construction Engagement	**Internet and Site based**	**Site based**
Main Contractors	Questionnaire/Commissioning Data	Focus Group / Observation/Interviews
Electrical Subcontractors	Questionnaire/Commissioning Data	Focus Group / Observation/Interviews
Mechanical Subcontractors	Questionnaire/Commissioning Data	Focus Group / Observation/Interviews
Building Contractors	Questionnaire/Commissioning Data	Focus Group / Observation/Interviews
Design Engagement	**Internet and Site based**	**Office and Site based**
Architects	Questionnaire	Focus Group/Interviews
Building Services Engineers	Questionnaire/Commissioning Data	Focus Group / Observation/Interviews
Structural Engineers	Questionnaire	Focus Group/Interviews

In defining stakeholder engagement within the research for low carbon construction Mathur et al (2008) contend that there are three distinct approaches for conceptualising the level and effect of engagement. They investigate stakeholder engagement as ‘a management technique; an ethical requirement; or a forum for dialogue to facilitate mutual social learning’. Mathur et al (2008) argue that engagement should be seen from the concept of social learning, suggesting that dialog can be effective in increasing ‘awareness, changing attitudes and affecting behaviours’. As part of the action cycle the perspective of social learning will be seen as the basis of engagement with the construction industry stakeholders. This concurs with the paradigm for the research and is supported by the theory and methodological standpoint for a mixed methods approach within action research.

For each of the research methods used the stakeholders have been engaged through varying approaches and at selected points in the action cycle. This includes face to face engagement for interviews, observations and focus groups. Remote access has been used for internet based questionnaires using 'Dotmailer' software. Where commissioning data is gathered as part of the research this has been investigated, both as an exploration of the documentation produced for commissioning results, and as part of observational data. Engagement with stakeholders has also been used at the planning and action stages, as well as a tool for reflection on interventions, forming a 'feedback' loop for the action research cycle.

4.2.2 The Construction Site

The construction site activities for installation and commissioning of low carbon technologies are the main areas of interest within the research. That said, the investigation of stakeholder involvement and external influences on the site construction processes, as detailed in the conceptual framework in chapter 3, are also to be explored. Therefore, a perspective of the construction site and how the individual stakeholders engage in the construction process will give context to the problem to be explored and addressed.

Dawson (1996:p17) defines an organisation as a 'formal group of people with individual or collective objectives'. This definition frames the construction site and the structure of the site activities. Li et al (2001:p171-172) observe that 'the market and organisational structure of the construction industry is highly fragmented and divisive'. The step change in complexity of domestic construction projects, through low carbon construction, has also increased this fragmentation and diversity on the construction site (Connaughton and Weller, 2013). It has accentuated the environment for conflict and a reduction in communication and cooperation as identified by (Mitkus and Mitkus, 2014) with lack of knowledge, coordination and

management playing a prominent role in poor performance at the installation and commissioning stages of the project (Toor and Ofori, 2008). This is evident on construction sites throughout the UK.

Whilst a site contains various professionals from the same industry engaged in the apparent single goal of construction, it quickly becomes clear that their diverse roles contribute to a wider range of objects and individual goals, which can often be conflicting and create 'adversarial relationships' (Li et al, 2001:p171-172). Accordingly Acharya and Lee, (2006) suggest that 'conflicts do not exist in the ideal world of construction, but the ideal world of constructions does not exist itself'. It is therefore, against this background of the 'site construction process' that the research is conducted recognising, as observed by Yiu and Cheung (2006), the inevitability of conflict based on the diverse level of construction participant interests.

4.2.3 The Installation and Commissioning Process

Mills (2009:p1) proposes that the aim of installation and commissioning of new low carbon buildings is to ensure 'they deliver, if not exceed, the performance and energy saving promised by their design'. He goes on to suggest, in his study of installation and commissioning with commercial buildings, that whilst commissioning would appear to be standard practice, buildings are 'rarely' (ibid) commissioned with almost no commissioning for energy efficiency. Lohne et al (2015) in their study of commissioning commercial buildings in Norway observed that there was a 'general consensus' amongst the construction professionals that buildings would never function at their optimum level. It was seen as more important to meet local issues for the client as opposed to installing and commissioning the building as designed. This leads the focus to the consideration of the ethical approach to the installation and commissioning process on the part of the contractor.

Taylor (2009) refers to ‘social imagery’ as defining what is acceptable and unacceptable behaviour; Lohne et al (2015) consider that this view of behaviour acceptance plays an important part in the attitude towards commissioning. However, as there is limited research in the area of installation and commissioning Lohne et al suggest that further research is required to explore the process from a range of viewpoints.

From a domestic construction perspective there is limited research on the impact of installation and commissioning of mass low carbon new homes. NHBC (2008:p106) identify a ‘high level’ of concern amongst the construction industry for the availability of a skilled supply chain especially for low carbon technologies. They suggest that industry wide specialist training is required to deliver on the requirements for zero carbon homes by 2016. The effect of this gap in the skill level is observed by Mills (2009) to have ‘rework cost’ for defective installation and commissioning on residential schemes of typically 3.15% to 4% of the contract value respectively. This is also without considering the long term energy and carbon reduction losses from a poorly installed and commissioned scheme.

Noye et al (2013) observed, again in the commercial field, that time constraints and budget overruns also have an effect on the installation and commissioning. They contend that in the majority of cases only cursory attention is given to the process with ‘practical completion’ of the project being the main concern of the construction team. They argue that historically commissioning has been seen as a primary objective of achieving a ‘safe and good environment’ for the building (Noye et al, 2013:p1), and not perceived in the wider context of design and extended carbon performance aims. Therefore, installation and commissioning for carbon performance has little or no part to play with the main target centred on contract completion and handover (ibid).

The context for the research illustrates the issues that are experienced within the construction process. It highlights the complex nature of the installation and commissioning process and the interrelated connections of stakeholders, construction activities and performance criteria. It also indicates that much of the research for installation and, in particular, commissioning is within the commercial construction leaving the low carbon domestic housing market relativity under investigated. This therefore, raises an important area to be researched and for the practical implications to be understood to enable the exploration of change through the action cycle.

4.3 Definition of the Problem

Currently 18% of the housing stock in the UK is owned and managed by local authorities or Registered Providers (RP) and is referred to as social or affordable housing. This equates to some 4.7 million homes (NHBC, 2014:p4). NHBC (2014) indicate that on an average of the last four decades approximately 153,000 new homes are built each year with 30,000 homes constructed for social housing. Since 2007 all of this new social housing stock has been built to at least code for sustainable homes level 3, with code level 4 following on after 2010 (DECC, 2015). There have also been numerous exemplar schemes building a small number of homes to code level 5 and 6 for zero net carbon emissions. This has therefore; put low carbon construction at the forefront of the domestic construction market, and since 2007 additional compliance with code targets. The technologies used are diverse in their installation methods and complexity of commissioning and operation. However, none have required mandatory training or certification before installation or commissioning by the sub-contractor team. Further to this, many of the technologies have not been selected by the design and building contractor, but are pre-selected at the planning stage or required by planning obligation. Added to this complexity, Heffernan et al (2012); Glass et al (2008) and Ganah et al (2015) have observed that there is a distinct lack of knowledge, know-how and

cooperation around low carbon technologies, creating a significant barrier to delivering low carbon homes (Heffernan et al, 2012).

The unique position of the insider researcher, in this instance, has given substantial access to observe the effects as indicated by researchers such as Heffernan, Glass, Ganah. It is the nature of the professional doctorate that it relies comprehensively on the actual experiences of professional practice (Defoe, 2007:p108), and as such, every commission obtained within the research area adds to the depth of the data gathered on the subject. It is inevitable, as a consequence of these direct experiences as observed by Defoe, that this will link directly to the research problem and data to be collected. Therefore, the practice historic records reviewed as part of the research diagnosis give a basis of the problem from observations on a number of construction projects over the last 5 years (as shown in Table 4.2). This indicates the key factors identified by the construction team, at the completion of the scheme, which had some impact on the project outcome. All projects recorded are taken from schemes with social housing involvement and completion of code for sustainable homes assessment to at least code level 3. Projects have been selected based on involvement in the construction process from a design or monitoring perspective, so that observational and record data can be gathered and reviewed.

Table 4.2 represents approximately 40% of new build low carbon projects undertaken in the period within the pratice, and are representative of the common issues experienced by the researcher's professional practice. The column headings have been selected to illustrate the main installation and commissioning themes, and identify where monitoring or review has been undertaken. Technologies have been identified based on the issues of complexity, they have also been limited for practical research considerations, and to concentrate on the technologies seen by the industry as being more 'technically challenging' (NHBC, 2013).

The comments section has been taken from the correspondence and observations from the project and from information given by the project manager, client or main contractor.

Notes for the Table:

The table illustrates a representative section of projects undertaken by the practice mechanical and electrical department, either as design appointment or for monitoring of site activities, over the last 5 years. The projects are a mixture of small and large scale housing developments using a diverse range of technologies, construction companies and client teams. All of the projects have been design in accordance with the Code for Sustainable Homes and range from Code 3 – 6.

The roles within the table are defined as:

• **Monitoring –**	Where overseeing of the installation and commissioning has been required by the social housing client or D&B contractor. This is not a controlling or lead role, but observation and report only (responsibility for compliance remains with the subcontractor)
• **Design –**	Where commissioned to carryout design only with no Monitoring requirements
• **Design/Monitoring –**	Where both design and monitoring are required (as described above)
• **Client Review –**	Where the client has requested a review of the project after completion to review issues with the scheme from independent perspective
Project Type/Units/Date -	Mixed Use (Social and Private) – M; Social Only S Code Level – 3 – 6 Number of Units Date: 2011 – 2016 – (11 – 16) Phased scheme completion - P **Example – M/3/55/11/P =** **Mixed development/Code3/55 units/Year completed 2011/Phased completion**

Table 4.2 Key Observations at a Selection of Schemes within Professional Practice over the Last 5 Years

Project Type/Units/ Date:	Role: M=Monitor D=Design DM=Both CR=Client Review	Technology Used:	Installation Monitoring: Y / N	Commissioning Programme: Y / N	Commissioning Monitoring: Y / N	Commissioning Reviewed by: Technical – Engineer Non-Technical – Employers Agent (Surveyor)	Construction Issues
M/3/105/11	D	CHP Communal Heating/ MVHR	N	N	N	Non-Technical	Installation/commissioning issues - Defects to 2016 on heating and MVHR system installation
S/3/95/11	M	Biomass Communal Heating/ MVHR	N	N	N	Non-Technical	Installation/commissioning issues. Poor insulation of pipe work, MVHR and systems setup
M/4/40/11	D	Communal ASHP	N	N	Y	Technical	Installation issues affected commissioning stage. Unable to change therefore, affected final performance of ASHP
M/4/330/12	CR	Individual exhaust ASHP	N	N	Y	Technical	Commissioning skills poor, repeated errors with commissioning activities. Lack of understanding how the system worked. No response to commissioning suggestions
S/4/125/12 /P	CR	CHP Communal Heating/ MVHR	N	N	Y	Technical	Poor installation of pipe work created water quality/HIU issues. Defect on going for water quality, MVHR and overheating. No response to commissioning suggestions
S/6/8/12	CR	PV/MVHR/ Boilers/Rain Water harvesting	N	N	Y	Technical	Poor installation; lack of understanding of the technology to commission. Defects on going
M/4/220/13	CR	CHP Communal Heating/ MVHR	N	N	N	Non-Technical	Site needed to be completely re-commissioned. Heating system failures. Poor water quality

Project Type/Units/ Date:	Role: M=Monitor D=Design DM=Both CR=Client Review	Technology Used:	Installation Monitoring: Y / N	Commissioning Programme: Y / N	Commissioning Monitoring: Y / N	Commissioning Reviewed by: Technical – Engineer Non-Technical – Employers Agent (Surveyor)	Construction Issues
M/4/250/13	CR	River water Heat Pump / MVHR	N	N	N	Non-Technical	Poor water quality. Poor control of HIU within each dwelling
M/4/350/13 /P	DM	CHP Communal Heating MVHR	N	N	Y	Technical	MVHR commissioning not carried out. Distribution pipe work installation poor. Communal heating not commissioned just set up to run.
M/4/750/14 /P	DM	CHP Communal Heating MVHR	N	N	Y	Technical	Installation quality is poor causing issues at the commissioning stages with performance of pipe work and insulation. System set up for low carbon performance not undertaken
S/4/1/14	CR	Exhaust ASHP	N	N	N	Non-Technical	Installation removed and re-installed due to poor installation
M/4/88/15	CR	CHP Communal Heating MVHR	N	N	Y	Technical	Installation quality is poor, commissioning basic and rushed by contractor for handover. Poor performance of the system, still in defects
M/4/110/15	CR	CHP Communal Heating MVHR	Y	N	Y	Technical	Contractor did not follow installation or commissioning advice. Major system defects under review

Table 4.2 demonstrates a re-occurring theme of unmonitored installation and repeated issues with both installation and commissioning across the projects reviewed. It also indicates the lack of monitoring at the installation stages, and the uncoordinated approach and apparent absence of control at the commissioning stages, leaving little or no time before handover for remediation of the problems encountered. The table concurs with suggestions from Ganah et al (2015) that there are still fundamental issues with the construction industry understanding of effective installation and commissioning, especially for low carbon homes. These do need to be overcome for the industry as a whole to move forward with low carbon developments (Ganah et al, 2015).

Evidence from the past projects review have indicated a number of issues at the installation and commissioning stages indicating that the actual installation and commissioning practice does not reflect the design conditions. In a majority of the cases it is apparent that the low carbon technologies have been put into operation without a co-ordinated approach to meet the design requirements or to meet a commissioning standard.

4.3.1 Practical Consideration for Research

The practical considerations for the research need to be investigated to ensure the research project can be achieved. These considerations also need to be balanced against the theoretical necessities of the research to enable the appropriate underlying principles to be adopted as part of the interventions strategies (Garnett, 2001). Firstly, the pragmatist perspective requires an open and collaborative approach to the research action cycle utilising all practical options for investigation. Secondly, the interventions need to be designed to support the mixed methods analysis, and as such, the approach to the data gathering needs to be considered.

Taking these theoretical perspectives into consideration the practical characteristics of the research should:

- Be collaborative in design
- Make effective use of the practical insider research approach
- Collect qualitative and quantitative data as part of the interventions process

Based on the review of historic project information collected in professional practice, as illustrated in table 4.2, the research will be confined to the following technologies:

- Low carbon communal heating systems
- Mechanical Ventilation with Heat Recovery (MVHR)
- Exhaust Air Source Heat Pumps

These technologies have been selected as the implications of their complexity of installation and commissioning are comparatively new to mass low carbon housing (NHBC, 2013). They also represent the source of the majority of issues observed in the professional practice. The practical implications of time, construction site access and stakeholder access also limit the investigation and subsequent interventions. It is therefore suggested that the investigation of these technologies will enable an understanding of the current challenges facing low carbon domestic construction, from actual real world observations and interventions.

To investigate this further the research was opened up to the wider stakeholder perspective to enable the understanding, views and interpretation of current construction activities to be gathered and analysed. This therefore, builds on the historic practice knowledge and experience, giving an additional dimension to the action cycle, thereby adding further context and validity to the research.

4.4 Focusing on the Issues and Engaging in Collaboration

Engagement with the wider construction stakeholder community is essential to gain context and understanding for the research. This is recognised by Wilson and Rezgui (2013) who observe that engagement with stakeholders is vital for the improvement for the longer term achievement of government low carbon targets. As discussed earlier, Mathur et al (2008:P110) see stakeholder engagement as a concept for social learning, 'changing attitudes and affecting behaviours'. However, it is also the product of this social learning which gives an indicator to the needs and expectations of the stakeholder group. Stakeholders have the capability to influence a project and the project team and consequently, the perceived success of the project is dependent on their expectation and the level of collaboration(Bal, 2014). Early engagement at this diagnoses stage gives the research the opportunity to take the wider perspective, and to offer challenge to planning concepts for the action and intervention cycles. It also allows the comparison with the historic observations, seeing these in a context outside of initial insider researcher experience.

The data collection process for the diagnosis stage takes the form of engagement with a focus group, an internet based questionnaire and follow up semi structure interviews to gain perspective and depth to the research problem. The data was gathered using both qualitative and quantitative data sets as indicated earlier in table 4.1. Each of the data collection methods have been selected and used as complimentary methods with information gathered and triangulated to explore interpretation and validation of the content. A small number of stakeholders have also been engaged in all three data gathering areas to give a level of consistency to the information and permit feed back to the process for the planning stages of the research.

4.4.1 The Focus Group

Coghlan (2001) observed that focus groups can assist in achieving a structure of outcomes from the research to be used in professional practice. The involvement of other professional participants, acting as experts in their field, develops the exploration of ideas and group experiences to feed into the collaboration process, informing the action phase of the research cycle. When structured positively Brewerton & Millward (2001) suggest that the focus group dynamic permits important issues to be raised that would otherwise be left silent. They go on to state that it encourages a collaborative interpretation of ideas through a shared understanding of their meaning and relevance to the research questions. Ivankova (2015:p202-203) indicates some of the potential draw backs to the focus group setting suggesting that attendance can be difficult, and where engaging with a group, the underlining 'power play' needs to be controlled to ensure equal opportunity for contribution. This control of 'power play' can be compounded when the focus group is made up of experts with established opinions. Therefore, particular attention has been paid to the structure to minimise dominant opinion through a range of structured questions and equal weighted responses.

Within this research the focus group structure has provided an important access into the collective expertise of the practice and within the wider construction industry. This approach has gain collaborative input from the group which has enable a rich source of data to be explored both at this diagnoses phase and throughout each cycle of the research. The structure of the group has facilitated the stimulation of a new perspective for the research question, and as observed by Gray (2011), these perspectives have been able to feed into the large scale questionnaire distributed to the wider construction industry.

The actual focus group consisted of 6 members representing the researcher's professional practice, a construction developer and housing association representative. The group was kept small to facilitate access and open discussion, and as observed by Creswell (2013), limited numbers assisted in managing the discussion and group participation. Membership was based on good access links within the practice, expertise in the research area and a willingness to take part and contribute to the study. Discussions were recorded by taking notes on issues raised from a set of open structured questions based on the main research question and subsidiary questions. A meeting was convened for the initial discussion and subsequent conversations where then engaged either by email or in telephone dialogues throughout the research. Within Appendix 1, there is a transcript of the initial meeting and Table 4.3 indicates the main areas of discussion within the group at the first meeting designed to understand construction experiences from the expert's perspective.

Both the table and the transcript indicate an open and free discussion amongst the group with no apparent dominance from any one member. However, what was apparent from the start of the discussions was a general reservation towards renewable technologies for heating and hot water systems, especially the more complex forms of district heating and heat pumps. The discussion ranged from the effects of the planning decision, made before construction involvement, to the implications of site communication and programme, following the questions posed to the group. From the discussion it became clear that there is an issue with communication, training and programming during the installation and commissioning of low carbon technologies. Each of the experts within the group suggested that there were gaps within the process for delivery of new homes and low carbon technologies form part of the gap.

The focus group discussion, along with the historic data, demonstrates the validity of the research area and assisted in informing the next step of the diagnostic phase. This step

seeks to take the questions of the construction process for low carbon technology out to the wider stakeholder community to further examine the responses of professionals across the construction sector.

Table 4.3 Initial Discussion for the Focus Group

Question	Practice Member 1 Mechanical Eng	Practice Member 2 Mechanical Eng	Practice Member 3 Electrical Eng	Practice Member 4 Project Manager	Construction Member 1	Housing Association Member 1
What are stakeholder perceptions of low carbon technologies in new construction developments?	Only used because of planning. Some better than others; PV most effective and have had some good experiences using the technology	New district heating used in London, not convinced it's working. Reductions in CO_2 are important and we need to develop	Code and planning lead the discussions not the technology PV used communally and not connected to dwellings in flats	I have seen more defects with district systems and heat pumps. What about 'fabric first' too much concentration on technology	D&B we are often given the solution from planning Not much training on technologies, but have to use them for Code	Funding states we have to use 'renewables'. PV seems ok, but has many issues for heating systems and MVHR. Hard to know which one is good and bad
How do construction professionals communicate best practice when installing and commissioning low carbon technologies?	Don't see an awful lot of communication on site. More like get it in as quickly as possible and move on. Post mortems are sometimes carried out, but there is little continuity on the next scheme	Depends on the site. Some are good, some bad. Training is an issue both design and installation. Bit of blind leading the blind	Don't get involved on many sites. Design and then contractor handles scheme without our input RFI often shows that 'they' are not following design	Management communication is normally good. However the lower down you go the less communication.	Sites are good and bad and depend on the teams. Site Managers are rare at the moment so some difficulty in management of subcontractors. Money is an issue, and getting M&E bias	Management level is normally good, but I do not have much communication at the subcontractor level. It does appear to depend on the team used
How is the commissioning of low carbon technologies co-ordinated within the construction programme?	When we are on site there is very rarely a programme for commissioning. It's all pretty ad hoc	I find the same. Commissioning happened somewhere at the end, very rarely programmed and often not completed	I have seen one or two programmes at the start of the scheme, but these are not updated or followed through to allow coordination	Construction programmes are updated at each meeting, however the M&E bit is just allocated a space and it's often late. We often do not have expertise to challenge M&E issues or commissioning results	We do get programmes off all our suppliers; however the commissioning section is always hard to define with all trades in at the end. Commissioning certs are always completed as required	Programmes are discussed at every meeting, but somehow it's nearly always a rush at the end for handover. Not seen the M&E programme, but that is a specialist area

4.4.2 Questionnaire Design

One of the outcomes of the focus group discussion has been to set the basis for the development of a questionnaire to the wider construction stakeholder community. The questionnaire design has been selected to investigate the opinions and experience of construction stakeholders, and build further validity for the research subject and approach. Arksey and Knight (1999) observe that questionnaires can generate insightful data when the people questioned have direct knowledge or experience of the research area. In this case the questionnaire was circulated to a wider range of construction professionals linked directly and indirectly with the professional practice.

To reach the widest possible audience the questionnaire was designed for a web based circulation using a marketing internet site and questionnaire design software familiar to the researcher's professional practice called 'Dotmailer'. The software enables the data to be collected, which can then be downloaded in a 'CSV' file to review and develop on Microsoft Excel. The software also facilitates the construction of a scale type ordinal questionnaire using the Likert scales (Gray, 2011), which solicit opinions ranked on a range of scales for each question. This type of questionnaire enables opinions to be examined against a range of set questions to extract an overall opinion of the question asked. However, to achieve this, as suggested by Arksey and Knight (1999) the questions must be clear, concise and unambiguous and avoid leading, assumptive or double meaning questions (Gray, 2011:p340). Therefore, as observed by Foddy (1993) and Gray (2011:p346) the questionnaire must 'cover the research issues that have been specified', and allow the respondent to interpret the question in the way the researcher intended. Regrettably, as Foddy (1999) has commented, the process can break down in several areas which can threaten the validity of the questions asked. It has therefore, been important to trial the

questions and review the list of respondents on the questionnaire circulation list. Gray (2011) suggests that this increases confidence that the respondents know what they are responding to and are willing to undertake and provide appropriate answers to the research.

4.4.3 Testing and Reflecting on the Pilot Questionnaires

Appendix 3 contains a copy of the final draft of the questionnaire circulated; however, as suggested by Gillham (2000) the structure and question content went through several pilot tests within the practice to sample opinions of the question type, length, instruction details and text layout. The focus group was also utilised to pilot the questionnaire before sending to the wider professional groups.

An early issue with the questionnaire extracted from the pilot test was the length of the questionnaire and the relevance of the questions asked. This initiated the early test criteria, as suggested by Gray (2011:p346) 'is the question necessary? Just how will it be useful'? There was a tendency in the early drafts to ask numerous questions on low carbon design and construction issues without knowing how the information would be used. Responses from the pilot test enabled changes to the questions which could then be re-circulated for further responses. The format was also explored to enable the questionnaire to be answered easily, and as importantly, for the data to be gathered in a suitable manner to permit detailed analysis without lengthy data sorting. The early questionnaires were constructed using Microsoft 'Word', whilst these were easy to construct (see Appendix 2), methods for data collection and analysis quickly proved time intensive and impractical. This was due to the fact that each questionnaire response needed to be sorted, transcribed for results and converted to an Excel document to enable analysis. Hard copies were also difficult to sort and store with returns by post or PDF on email being slow in return and difficult to interpret

dependant on writing style and quality of copy. These issues with the early designs led to the trial of a web based platform for the questionnaires. This form of information and data gathering, as observed by Dillman (2007), gives a more effective way of distributing and collating data than the paper based design format. However, as with all questionnaire design the web based format still needs to be carefully considered to ensure the required response and return rates. Dillman (2007) and Gray (2011) suggest that a wide range of techniques are used to increase the effectiveness of the questionnaire. These include personalising the email containing the questionnaire, keeping introductions and explanatory text brief and concise and setting limits to text on each page to increase the likelihood of a return.

To assist with these techniques an internet marketing website was found to be the most appropriate for the construction and distribution of the questionnaires. The selection of the site was based on access and familiarity with a marketing product used by the professional practice called ‘Dotmailer’. This software allows for the construction of Likert type questions with the additional function of being able to collect user defined responses where given. Likert type questions were used to enable a closed set of questions to be measured and compared against the opinions of the different stakeholders. There are advantages and disadvantages to this type of closed question structure, and as observed by Oppenheim (1992) advantages include ease for group comparisons, processing and time constraints. However, closed questions do lose the ‘spontaneous response’ and can lead to bias in the answer categories (Oppenheim, 1992 and Gray, 2011). In an attempt to balance the response structure ‘free form’ answer boxes were included within the questionnaire to enable respondents to add additional information. The Likert type used was predominately 4 and 5 point Likert response with the use of the selection of ‘Don’t Know’ and not applicable (N/A) also used (Colosi, 2005).

This online questionnaire was circulated to a small selection of staff within the professional practice, and to the focus group to test the ease of completion and the ability to extract data from the responses. All responses to the online questionnaire were downloaded into a 'CSV' file to enable further detailed analysis via Excel, which was found to be easy to undertake and offered effective analysis. The welcome email hosting the access to the questionnaire was also tested and feedback on the instructions and welcome text fed into the main survey structure.

Reflecting on the pilot testing it is considered that more time should have been spent on reducing the question numbers. After the pilot there were still 28 questions, and this in reality could have possibly been reduce by half and as a consequence could have raised the response rate, adding further richness and detail to the research. The benefits from the pilot trial have been the use of the online questionnaire and the wealth of feedback from the focus group that shaped the structure and direction of the survey. Gillham (2000) and Grey (2011:p359) observe that the questionnaire is a 'one shot' attempt at data gathering' and as such the pilot study has assisted in improving the quality of the content, and therefore, assisted in the eventual response rate to the main questionnaire.

4.4.4 Main Questionnaire Structure

The distribution list for the online questionnaire was derived from an extensive contacts list of construction professionals taken from the professional practice. This permitted the benefits of the insider research approach, as suggested by Gray (2011), not only to reach familiar and targeted stakeholder groups, but to widen the research to secondary contacts from the primary list by respondents sharing the online link. The list included Housing Association clients, Consultants, Developers, Main and Sub-contractors. The list also

included all of the professional staff from the professional practice, including the focus group members. The questionnaire was split into 4 colour coded sections for roles and experience, design and installation, commissioning and handover and personal information. It was considered important to capture the roles and responsibilities of the stakeholders at the early stage of the questionnaire, this helped to 'ease' the respondents into the questions and allow later data analysis to be undertaken based on the respondents role and responsibility in the low carbon construction process.

The questionnaires were circulated to over 600 contacts with a return of 255 respondents giving a return rate of 42.5%. Of the returns, 45 were discounted as they were not completed and no contact could be made to verify the possible errors in response, therefore the response rate was reduced to 35%. Gray (2011) observes that there are several ways to deal with missing data including coding as 'missing data', trying to determine the answer or re-contacting the respondent. The decision to discount the partially completed questionnaires was to reduce possible misleading responses where questions were either part completed or not answered in any way. Gray argues that there are 'two threats to the validity of questionnaires' Gray (2011:p363), namely accurate completion and non-respondents. Oppenheim (1992) also suggests that the best approach to dealing with missing data is 'not to have any at all' Gray (2011:p456). To improve the validity of the research therefore, these issues were dealt with by removal of non-completed responses, and the use of follow up interviews to test the general responses given. On reflection it is considered that the response rate could have been higher if the number of questions had been reduced. Despite this the response rate from the construction industry was encouraging and reflected the positive position of the professional practice within the industry.

The welcome e-mail containing the online link to the questionnaire was the same for all contacts and a screen shot of the welcome page is shown in Figure 4.1 below.

Design, Construction and Handover of Low Energy Homes Questionnaire

My name is **Terry Keech** I'm a Partner at Calfordseaden, and I'm currently completing my **Professional Doctorate** on Low Energy Homes in the UK. The following brief questionnaire has been designed to collect information from construction professionals involved in 'Low Energy Homes', to understand the approach to the Construction at the planning, design, installation, site construction and handover stages of the project.

The definition of Low Energy Homes for the questionnaire is based on homes that have been built to at least Code for Sustainable homes Level 3 or Ecohomes 'Very Good'.

All information collected is confidential, and names / addresses are not required and will not be used as part of the research. The Information gathered is to be used to gain an understanding of the opinions and approaches to the design, construction and handover of low energy homes, taken from your professional perspective. It also seeks to understand, where information is available, what processes are affecting delivery of low energy homes such as design, installation, communication and commissioning, and what effects this may have, if any on the outcome of the project. This information will be used as part of my thesis for my Professional Doctorate titled:

'The construction industry approach to delivering mass low energy homes'.

The questionnaire is divided into four colour coded sections aimed to guide you through the questions:

Role and Experience
Design and Installation Stage
Completion and Handover
Personal Information

Click Here to Complete the Survey

Please complete all questions and, wherever possible, give brief additional information in the text boxes provided at the end of each question, as it will help to further interpret your valuable responses. The questionnaire should take no more than approximately **15 to 20 minutes to complete**

Thank you for your time in completing this survey and £50 will be donanted to Cancer Research UK when all surveys are completed and returned.

CANCER RESEARCH UK

KEEP CALM AND SUPPORT CANCER RESEARCH

Unsubscribe from this email

Figure 4.1 Screen Shot of E-mail welcome page for the questionnaire

This initial contact page was an important element of the circulation strategy and was discussed in detail during the piloting stage to ensure as many respondents as possible opened the e-mail to increase the chance of a completed questionnaire return. This is also observed by Cohen and Manion (2000) and Gray (2011) who suggest that clear and concise instructions throughout the questionnaire greatly increase the probability of response. This strategy was therefore, developed throughout the questionnaire with instructions on question completion and information return forming a detailed part of the questionnaire construction phase. The initial instructions set out at the beginning of the online questionnaire, once opened after the welcome page, are indicated in Figure 4.2 below:

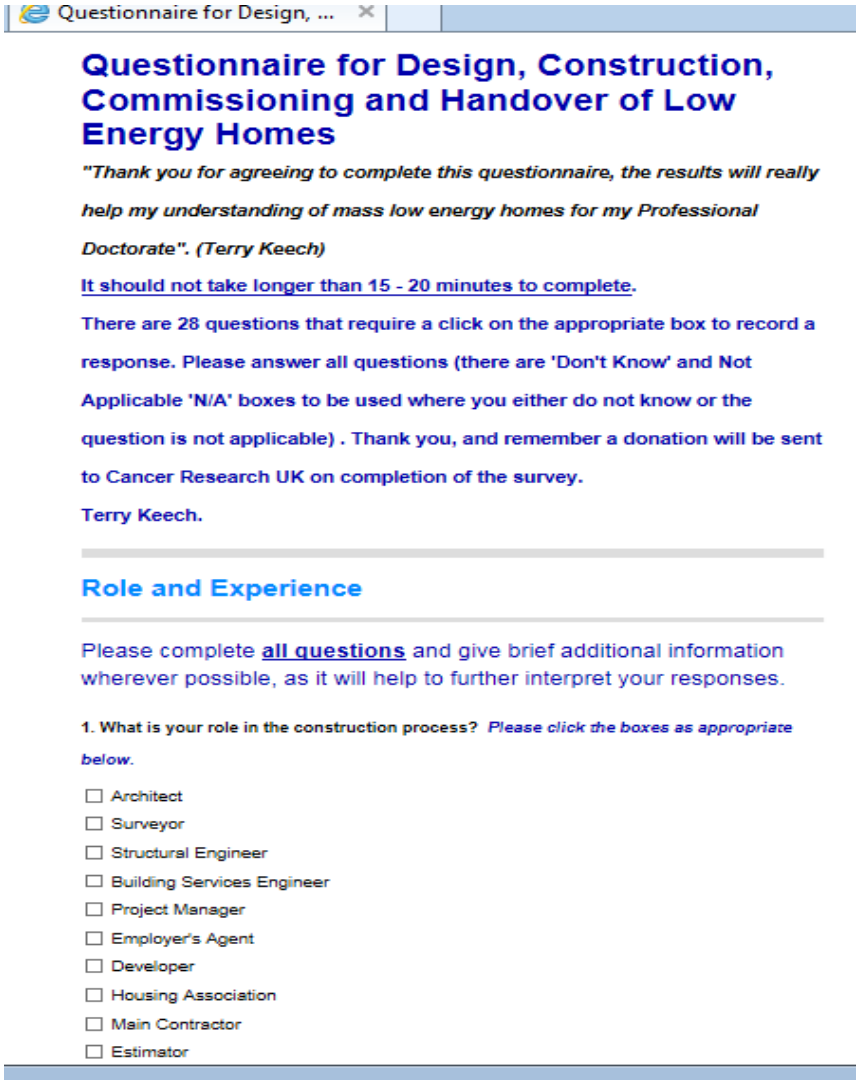


Figure 4.2 Initial Instruction page at the start of the Querstionnaire

The questionnaires were sent out to all the stakeholder groups at the same time and a two month period was given for the responses. Saunders et al (2007) lists six techniques for improving questionnaire response rates including clear instructions, follow up communication and additional follow ups if response rates are low. Therefore, during the distribution and response period several emails were sent to enquire if any further information was required and as a prompt for questionnaires to be returned. A final e-mail was sent (See Appendix 3) to close the response process and to thank all the respondents for the information received. This had a positive effect on the following interview phase, with a number of respondents suggesting they would be avaliable for follow up interviews. All of the responses received were automatically converted via the 'Dotmailer' software to a 'CSV' file and were then arranged for reviewed and anaylsed through Excel (See sample excel data sheets in Appendix 3).

4.5 Questionnaire Data Gathered and Results

4.5.1 Method for Data Analysis for the Questionnaires

Data analysis was carried out over several weeks post completion of the questionnaire response period. Data has been arranged into tables, bar and pie charts to enable the responses to be illustrated, and to carry out nominal and ordinal descriptive statistical analysis on the data gathered. Black (1999) observes that descriptive statistics show what the data collected is and allows comparison to be described in terms of percentages and median and mode correlation. Jamieson (2004) also argues that it is valid to display such data in the form of bar and pie charts for an understanding of the research, and that mean values should be avoid if the data is not interval type data.

The questionnaire is based on Likert type questions which comprise an ordering and ranking of values and opinions based on a selection of pre-set questions (Blaikie, 2003). However, it must be stated that these values and opinions (e.g. very satisfied, satisfied, unsatisfied, very unsatisfied and not applicable) are not intended to be of equal value, and as such, as observed by Gray (2011) there is no suggestion that there is a set interval between the terms. Blaikie (2003) warns against categorising Likert type data as interval type data possessing equal value in the response given. Kuzon et al have gone further in suggesting that the use of Likert type categories as an interval scale is 'the first of the seven deadly sins of statistical analysis' (Kuzon et al, 1996:p265-272). It is argued by Jamieson that 'the legitimacy of assuming an interval scale for Likert-type categories is an important issue' (Jamieson, 2004:p1217), as the incorrect selection of the statistical analysis can lead to the wrong conclusions from the data. Jamieson states that 'methodological and statistical texts are clear' (Jamieson, 2004:p1217) that for ordinal data, such as Likert type questionnaires, the frequencies / percentages are used for description of response categories. Within the responses both 'Not known' and 'Not Applicable' were included as the key stakeholder groups spanned all the construction disciplines, and a blank or missing response may have been misread when analysing the data.

The purpose within the research is to illustrate the responses from the questionnaire to give a basis for the planning and action phase of the action research cycle. The questionnaire analysis also gives the opportunity to compare the responses, through triangulation, from the smaller focus group and historic data, with the views and opinions of the wider stakeholder groups. The questionnaire data was also used for further comparisons during the action cycle to review against observations and during the reflection stage to contribute to the response to the research questions. The importance of the stakeholder engagement has been argued by Williams and Dair (2006) as fundamental in overcoming resistance to

low carbon development. Therefore, capturing the stakeholder viewpoints through the initial surveyed opinions, at the early stage of the action cycle, gives further validity to the development of the action investigation within the research.

From the diagnosis and reconnaissance stage of the action cycle several key questions have been selected to contribute to the planning and action phases. These have been chosen from the four questionnaire categories to represent key information for roles and experience, installation, commissioning and handover process. Creswell (2013) and Lincoln and Guba (1995) observe that reflection through triangulation of the research helps to enhance the credibility of the data gathered and further assists with the interpretation of results. Hinchey (2008) and Stringer (2014) also refer to the iterative nature of the action cycle and suggest that interpretation of additional data helps create a ‘wider and deeper picture’ for the research (Koshy et al, 2011:p121). It is therefore, important for the research to have a ‘layered approach’ to data interpretation, continually referring to the different strands of investigation to support to overall action cycle and research outcomes.

4.5.2 Respondent Roles and Experience

The return of responses demonstrated a wide coverage of construction industry stakeholders for the survey. Figure 4.3 below illustrates the response rate and the respondent categories based on roles and responsibilities within the construction field as identified in section 1 of the questionnaire. It was noted that there were no responses from commissioning engineers as most, if not all, residential schemes do not use specialist commissioning companies in addition to the M&E subcontractor.

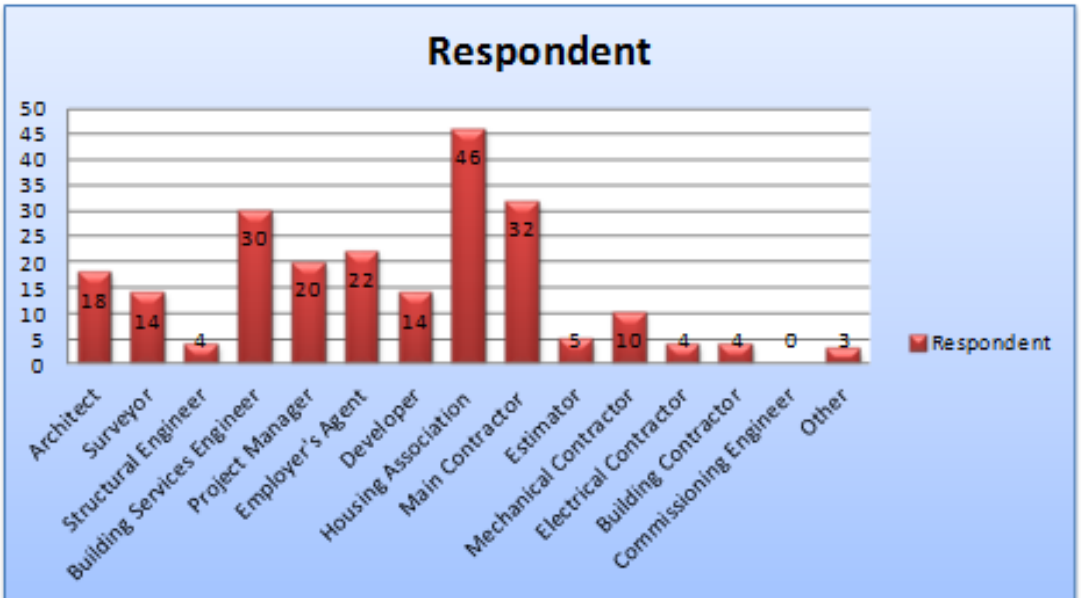


Figure 4.3 Survey Respondents

To enable analysis throughout the questionnaire these stakeholder response categories were further reduced to three main groups, Designers/Project Management, Development/Housing Association/Project Management and Constructors. This reduction in categories permitted comparisons of responses by the separate groups to investigate variances of perception across the different construction stage involvement. The grouping was selected to indicate perceptions from three distinct stakeholder viewpoints; those of the design, development and the construction processes. These three areas represent the stages when key decisions are made on the low carbon building journey, and the varied response perspective give insight into the construction process. Displaying these comparisons assisted in identifying where issues were raised within the stakeholder groups, and how importantly they were seen at each of the three key construction processes. Figure 4.4 and 4.5 gives the breakdown of the three groups both in number and percentage of respondents for the survey.

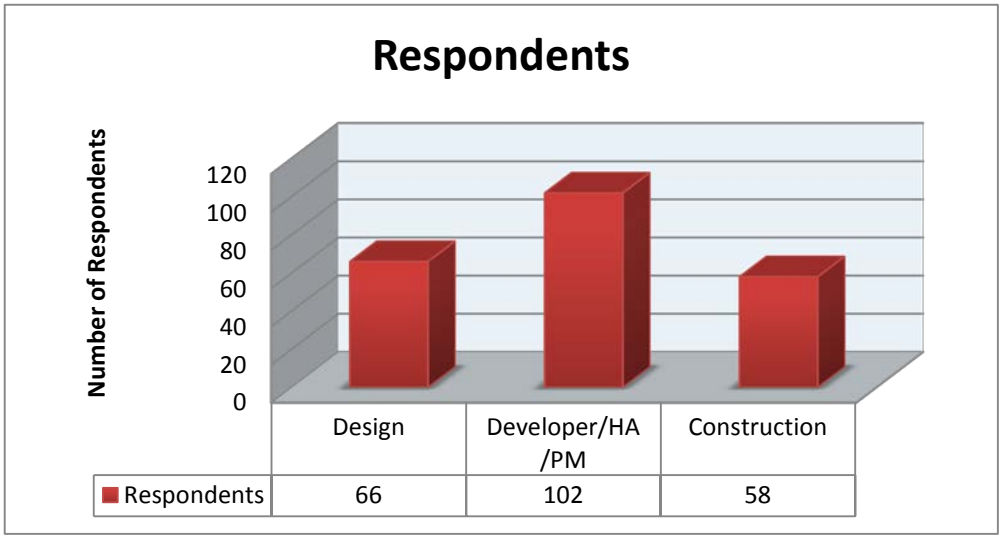


Figure 4.4 Numbers of Respondents

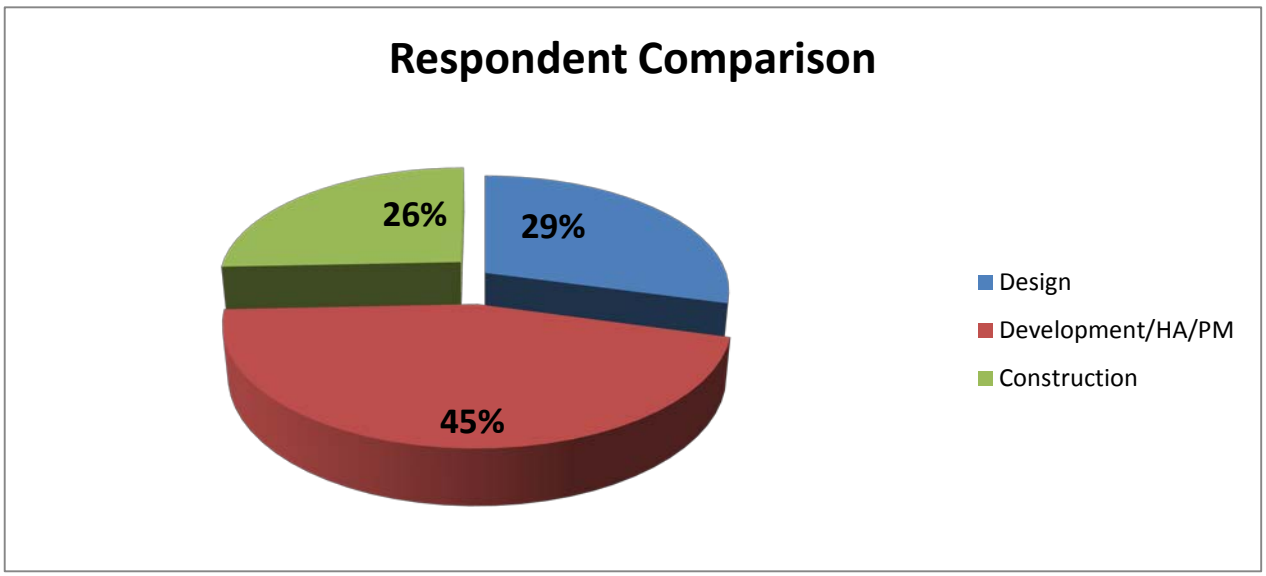


Figure 4.5 Comparisons of Respondents

The distribution between the three main groups is numerically balanced, with the Development/Housing Association/Project Management group (Development/HA/PM) having a balance of numbers within the group. This therefore, allows some comparisons to be made between the respondents to feed into the planning and action phases of the research. Within the questionnaire section on roles and responsibilities several questions

were posed to gain data on the level of knowledge and involvement the respondents had within low carbon homes construction. These questions had two purposes for the research, firstly to understand the level of involvement of the respondents, and also to identify any themes within the respondent knowledge and experience.

Figures 4.6 and 4.7 gives the level of responsibility and age groups for each of the respondents to the questionnaire; Figure 4.6 indicates that senior level staff are the most represented in the response levels. This is further supported in Figure 4.7, which suggests the majority of the respondents are in the age range of 31 – 60, with 9% between 16 – 30.

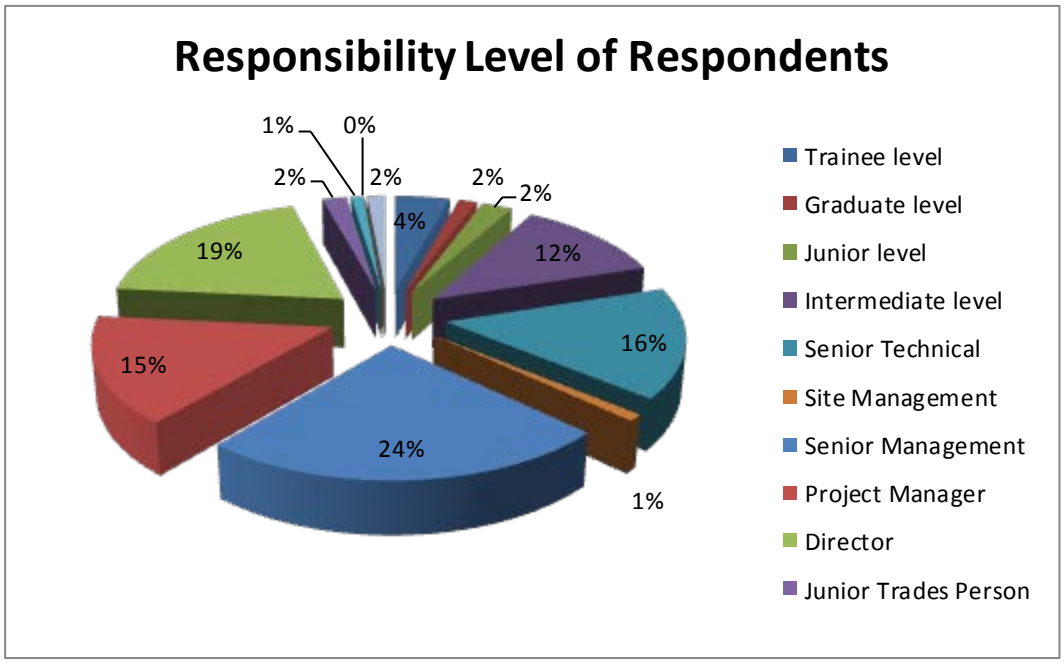


Figure 4.6 Responsibility Level for Respondents

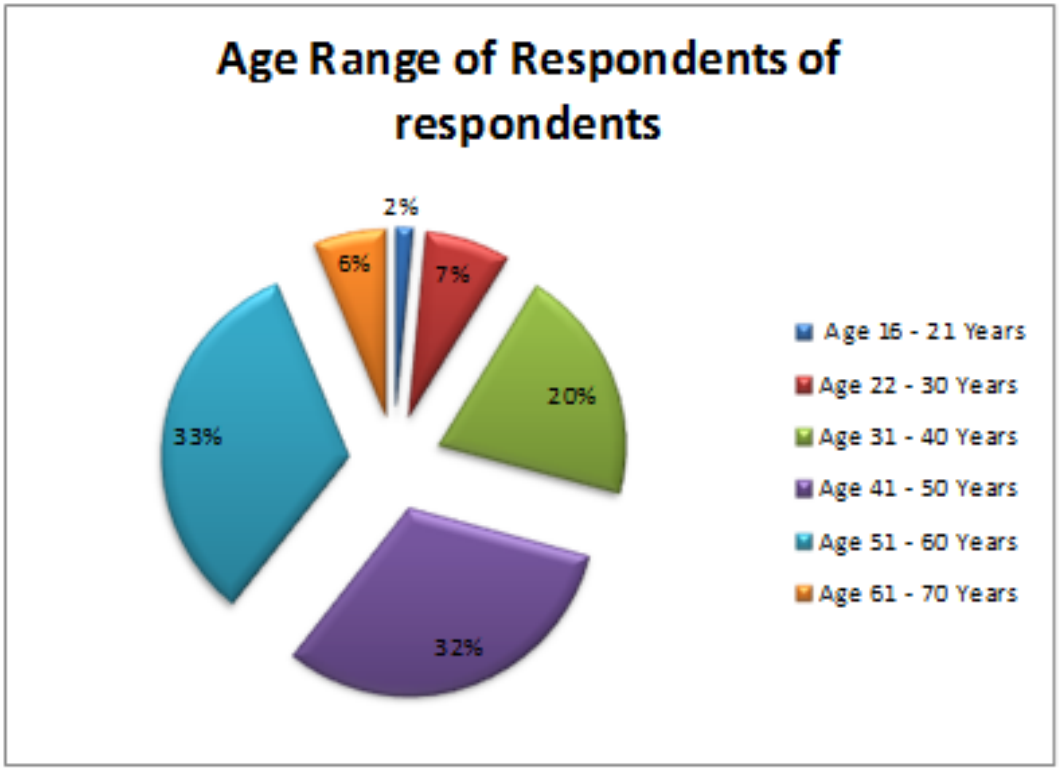


Figure 4.7 Age Range of Respondents

When reviewing the return rates for the respondents it was noticed that manual trades and junior construction professionals were lowest on the return rates. It was also the case that several returns from the same construction groups were rejected in the data review for partial or incomplete information without follow up responses. This tendency to lower response rates is recognised by Gray (2011) and Saunders et al (2007) and is also apparent in this survey. Therefore, later site observation data was specifically targeted on construction site staff to increase the balance of data and vilidity of the final results.

It was recognised that during the action cycle of the research, age level and experience would need to form part of the observations to compare back to the reconnaissance stage when reflecting on each cycle.

Figure 4.8 and 4.9 gives an indication of the formal and informal training and education undertaken by the respondents, particularly for low carbon construction. These questions were posed to understand what actual training and education forms part of the respondent's knowledge base, and how prevalent was low carbon training within the general training process and within the construction process for the respondent group.

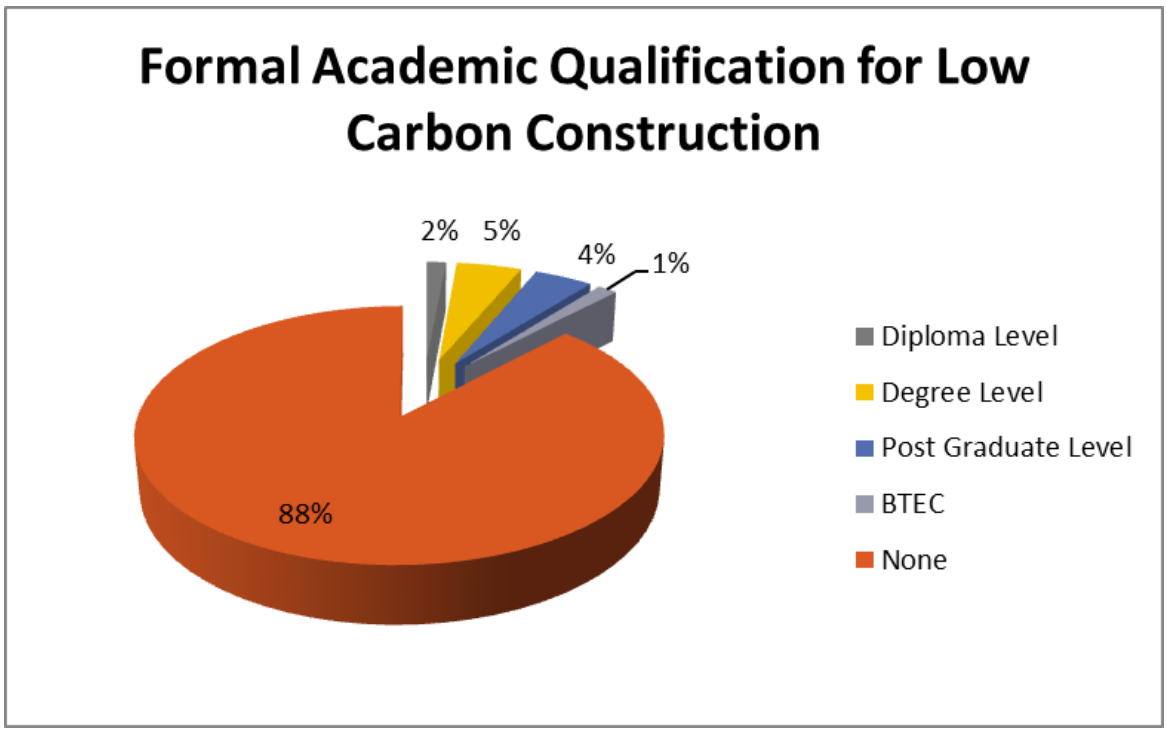


Figure 4.8 Respondent Attendances for Formal Academic Qualifications for Low Carbon Construction

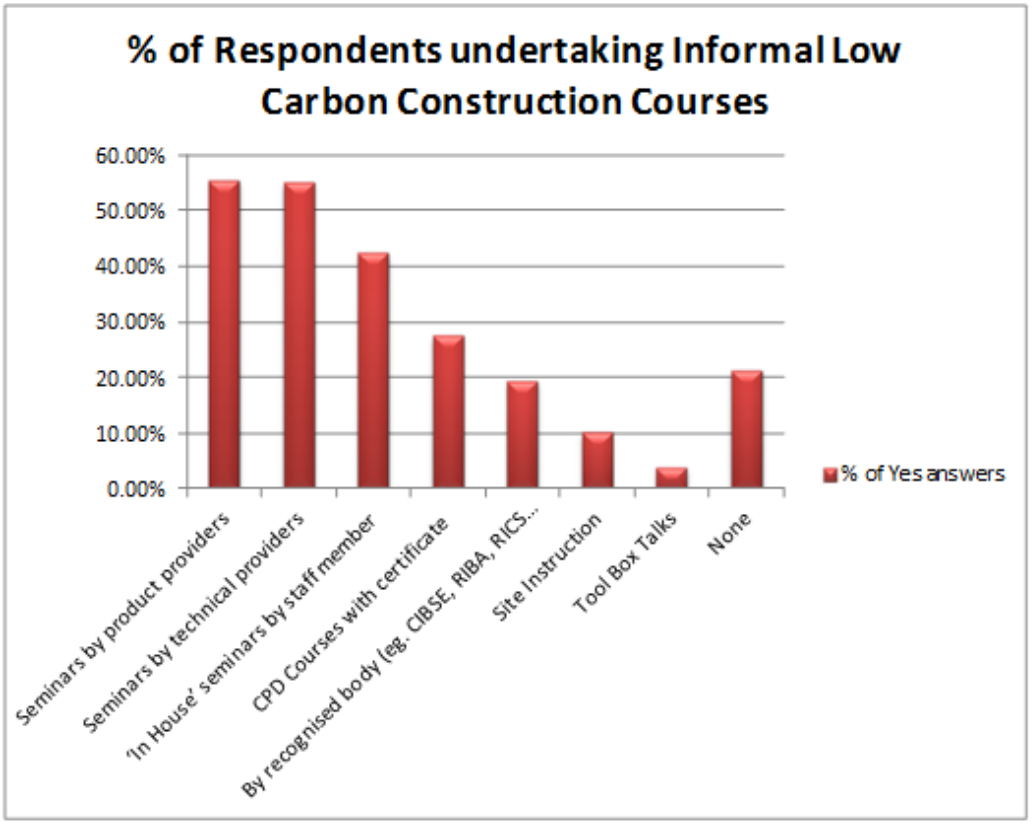
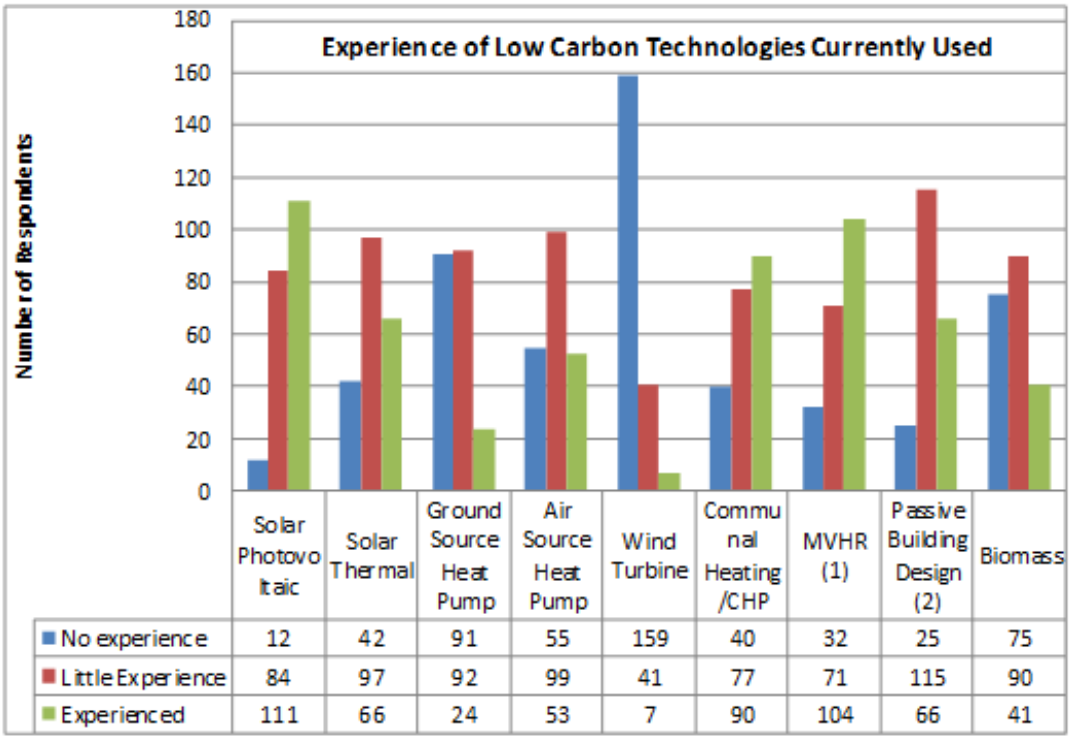


Figure 4.9 Respondent Attendance for Informal Courses for Low Carbon Construction

Figure 4.8 would appear to indicate that there is little formal academic education undertaken for low carbon construction by the respondents, all of who are operating within the housing market. This may be due to the senior level of the staff however, as low carbon construction has been part of the industry for upwards of 10 years it was expected that more academic education would have been seen in the survey. Figure 4.9 demonstrates that there is attendance at short courses and technical seminars across the respondent categories. Many of these are manufacture and sales led, lasting for very short durations, often 'lunchtime seminars', and product orientated. Whilst these may be relevant for initial information on specific products, the level of transfer of unbiased information may be low and therefore, feed into, and not close, the knowledge and skills gap (Heffernan et al, 2012). This can also be seen with the much lower level of attendance at courses undertaken by professional

bodies where an unbiased view may be more expected. This shorter term product led learning process, which is suggested by the survey, also supports what Bakker et al have referred to as 'the paradoxical nature of learning' (Bakker et al, 2011:p494-503) within construction whereby the short term nature of the project hinders knowledge construction and transfer.

Figure 4.10 indicates the extent of experience of the respondents for the range of low carbon technologies currently used within domestic construction. The respondents were ask to give their level of experience to understand how familiar they were with the technologies.



	Solar Photovoltaic	Solar Thermal	Ground Source Heat Pump	Air Source Heat Pump	Wind Turbine	Communal Heating /CHP	MVHR (1)	Passive Building Design (2)	Biomass
No experience	12	42	91	55	159	40	32	25	75
Little Experience	84	97	92	99	41	77	71	115	90
Experienced	111	66	24	53	7	90	104	66	41

Figure 4.10 Respondent Level of Experience with Low Carbon Technologies

From the bar chart above wind, ground source heat pumps and biomass technologies were the least familiar, with PV, MVHR and communal heating being the most familiar. This spread of experience reflects the current technologies employed on projects within London

and the Southeast of England, which covers the area and spread of the questionnaires as part of the survey. The increase in experience for communal heat and CHP come predominately from London based projects where the London Plan (GLA, 2014) currently requires review on all new projects. The spread of technologies also compares with studies undertaken by NHBC (NHBC, 2008), which indicate solar technology as the most prominent and most familiar to the domestic market. There could also be a further reason for the prominence of the PV technology as identified by Abdulkadir et al (2015), namely the industries 'conservative' preference for 'tried and trusted technologies and a drive for the path of least resistance.

Having established the roles and responsibilities of the respondents the next stage of the questionnaire was to review the opinions and experiences of installation, commissioning and defects. The responses were important to the research in giving the structure to the plan for action, and were used along with the historic data and interviews to identify the areas of observation during the action stages.

4.5.3 Respondents Opinion on Information and Guidance

Section 2 of the questionnaire was designed to gather data on the respondent's opinions on the start of the construction process, and in particular the method of collection and use of information and guidance for low carbon technologies. Within this section of the survey the first key area of understanding was the respondent's experience of information and guidance and what impact this has on the construction process.

One of the main instigators of change for the low carbon domestic market has been the Code for Sustainable homes (Heffernan, 2013). Its introduction and use was intended by

government to create a ‘step change’ in low carbon housing construction both in the private and public sectors (GLC, 2008). Whilst this was the intention both Heffernan et al (2015) and Abdulkadir et al (2015) have observed that there is a continuing gap in skills and knowledge as the main barriers to change across the stakeholder groups. Figure 4.11 indicates the responses on opinions to change in the construction processes as a direct result of the code. Figure 4.11 suggests that there has been noticeable change in a number of construction areas.

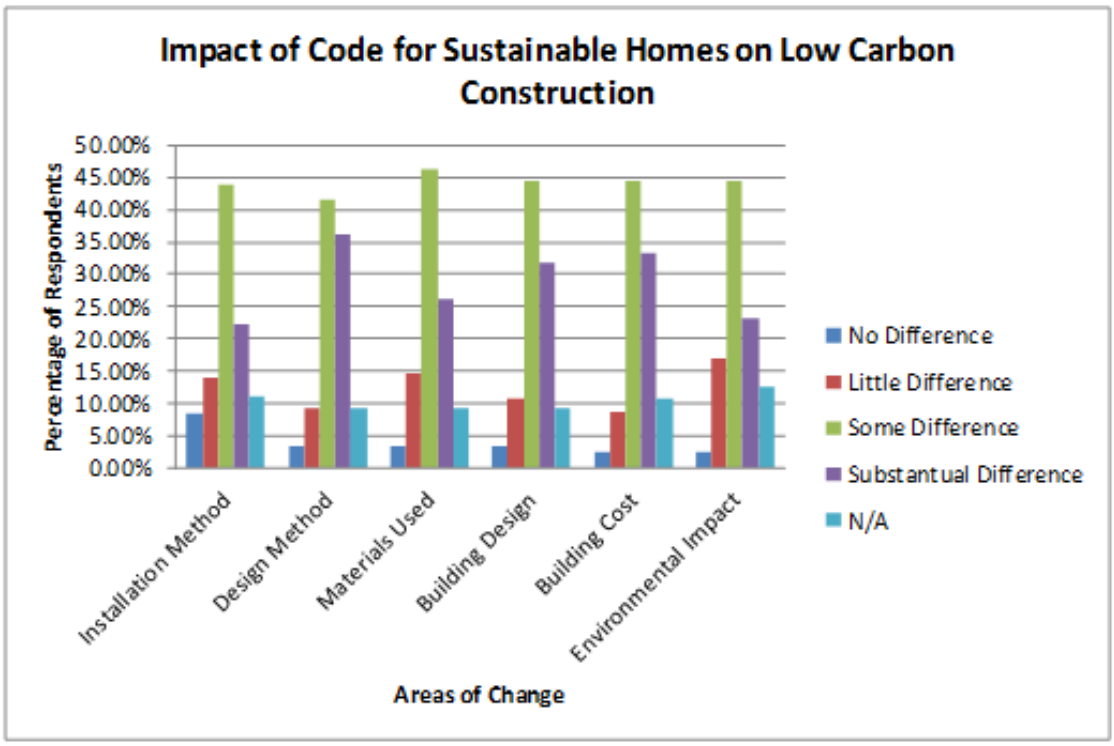


Figure 4.11 Impact of Code for Sustainable Homes on Low Carbon Construction

It can be observed that the respondents have seen ‘some difference’ to all areas of the construction process with design method, building design and building costs indicated as the most ‘substantial differences’. This is also seen when comparing the three construction stakeholder groups (Design, Developer/HA and Construction), within the survey, with each group being comparable with the statement ‘some difference’ experience as a direct result of the code. In itself this is not a surprising result, from the data, as the code has been required

for funding and planning since 2007, and is based on a ‘per dwelling’ compliance method. However, what is of interest to the research is how that ‘difference’ has been managed and developed within the construction process. This question was explored further in both the semi-structured interviews and the action phase of the research cycle to understand the effects of observable change.

Regulation has also been a key instigator to change for low carbon construction. The Building Regulations Part L (Conservation of Fuel and Power) has been linked to the Code for Sustainable Homes since 2010 (DECC, 2015), with 2010 linked to the energy requirement of Code 3 for building regulations compliance. However, the continuation of the link was separated in 2013 with a reduction in the target required to a further 6% as opposed to the Code 4 requirement of 25% further reduction over 2010 regulations (DECC, 2015). Further changes have been instigated by the current Government with the removal of the Code for Sustainable Homes in 2015 and a change to the zero carbon targets for 2016 (ibid). A key question in the survey was directed at the stakeholder understanding of the changes, which at the time of the survey 2014/15, was in the midst of amendment. Figure 4.12 indicates the stakeholder’s response to their opinions of regulation and guidance for new low carbon projects:

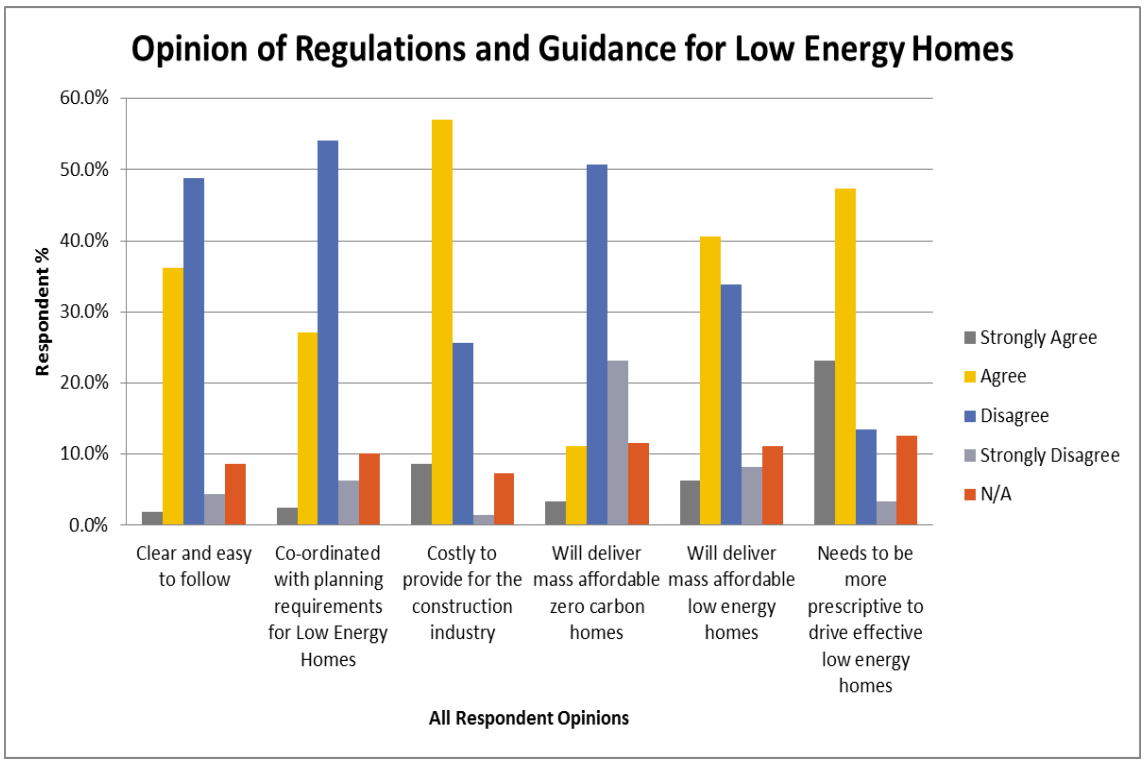


Figure 4.12 Stakeholder Opinions of Regulation and Guidance for Low Energy Homes

The bar chart indicates four areas of strong opinion, namely co-ordination, cost of provision, delivery of zero carbon homes and level of guidance. To further understand the opinions of the stakeholders the responses were broken down into the key groups of design, developer/HA and construction. Figure 4.13 illustrates the percentage responses from the key groups, which indicate higher costs, co-ordination with planning and zero carbon delivery as the three main areas of concern consistent across the groups. This corresponds with research by (Goodchild and Walshaw 2011), which indicates that clarity and consistency of approach is important to enable effective implementation for construction. This perceived lack co-ordination within the low carbon development could therefore, be feeding into the higher construction costs and reduced confidence in zero carbon delivery indicated in the survey data.

Table 4.4 Key Stakeholder Group Opinions of Regulation and Guidance for Low Energy Homes

Construction	Strongly Agree	Agree	Disagree	Strongly Disagree	N/A
Clear and easy to follow	1.9%	46.3%	42.6%	5.6%	3.7%
Co-ordinated with planning requirements for Low Energy Homes	0.0%	31.5%	57.4%	3.7%	7.4%
Costly to provide for the construction industry	16.7%	66.7%	14.8%	0.0%	1.9%
Will deliver mass affordable zero carbon homes	3.7%	5.6%	61.1%	22.2%	7.4%
Will deliver mass affordable low energy homes	11.1%	38.9%	33.3%	13.0%	3.7%
Needs to be more prescriptive to drive effective low energy homes	24.1%	48.1%	14.8%	14.8%	11.1%
Developer/HA/PM	Strongly Agree	Agree	Disagree	Strongly Disagree	N/A
Clear and easy to follow	2.2%	34.4%	47.8%	4.4%	11.1%
Co-ordinated with planning requirements for Low Energy Homes	3.3%	27.8%	47.8%	6.7%	14.4%
Costly to provide for the construction industry	10.0%	56.7%	20.0%	1.1%	12.2%
Will deliver mass affordable zero carbon homes	3.3%	12.2%	45.6%	24.4%	14.4%
Will deliver mass affordable low energy homes	3.3%	40.0%	34.4%	5.6%	16.7%
Needs to be more prescriptive to drive effective low energy homes	24.4%	47.8%	11.1%	3.3%	13.3%
Design	Strongly Agree	Agree	Disagree	Strongly Disagree	N/A
Clear and easy to follow	1.6%	30.2%	55.6%	3.2%	9.5%
Co-ordinated with planning requirements for Low Energy Homes	3.2%	22.2%	60.3%	7.9%	6.3%
Costly to provide for the construction industry	0.0%	49.2%	42.9%	3.2%	4.8%
Will deliver mass affordable zero carbon homes	3.2%	14.3%	49.2%	22.2%	11.1%
Will deliver mass affordable low energy homes	6.3%	42.9%	33.3%	7.9%	9.5%
Needs to be more prescriptive to drive effective low energy homes	20.6%	46.0%	15.9%	4.8%	12.7%

Table 4.4 also indicates that cost is the highest concern from a construction/ developer perspective with co-ordination with planning requirements and zero carbon delivery being the next areas of concern. Whilst cost pressures and the construction process are nothing new, the survey indicates that within low carbon development it is adding additional pressure, along with the uncertainty of delivery, which maybe affecting the installation and ommissioning process. With this level of unfamiliarity with the process and uncertainty over implementation, the ability to effectively communicate and have confidence in the end product becomes more focused with increased complexity (NHBC, 2012). How that complexity is managed and developed, during the construction process, will inevitability link to the installation and commissioning processes, as these will be key to the end performance of the development. Therefore, a question raised in the survey looked particularly at the level of information that was used by the stakeholders in the development of low carbon homes, and where that information was derived. Figure 4.13 indicates where the stakeholders identified the main areas of information sources and how often they were used.

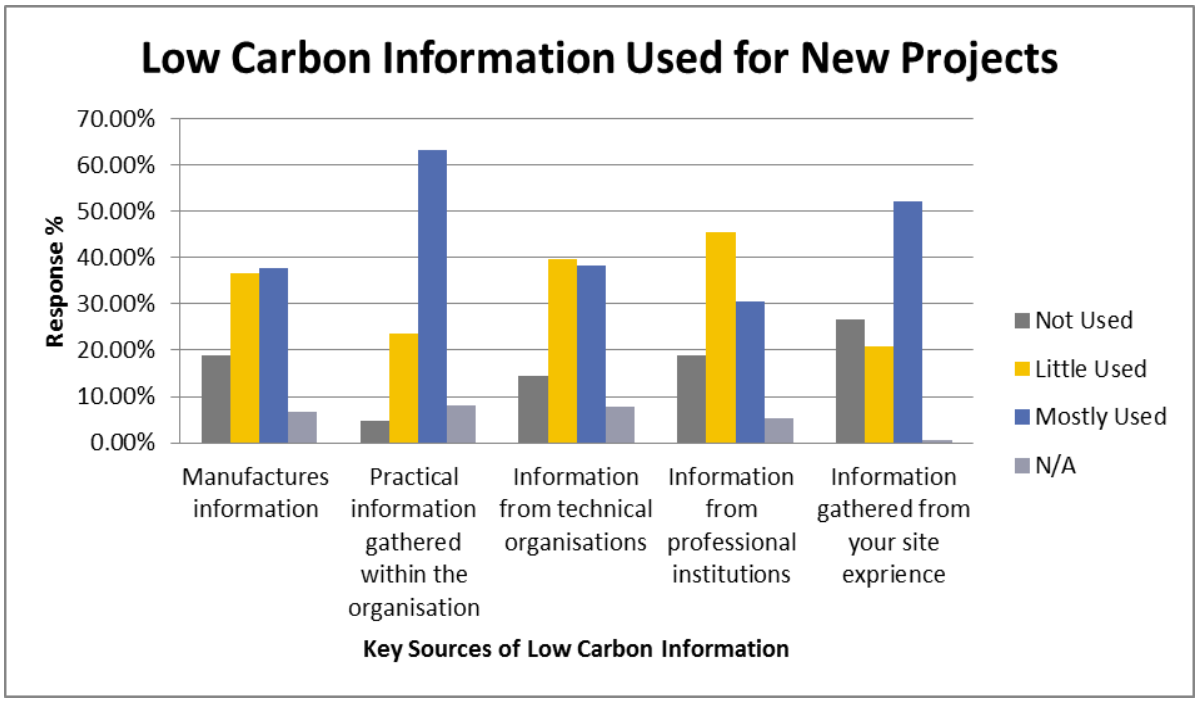


Figure 4.13 Low Carbon Information Sources Used by Stakeholders on New Projects

The chart illustrates that practical information from the stakeholder organisation and site experience are the two main areas identified in the survey. Whilst professional and technical organisations are used within the sample group, they are to a lesser extent. The key stakeholder groups were further explored to see what difference was displayed between the groups. Table 4.5 illustrates the key stakeholder groups and highlights the highest scores

Table 4.5 Low Carbon Information Sources Used by Stakeholder Key Groups on New Projects

Construction	Not Used	Little Used	Mostly Used
Manufactures information	11.11%	31.48%	51.85%
Practical information gathered within the organisation	3.70%	20.37%	72.22%
Information from technical organisations	11.11%	33.33%	38.89%
Information from professional institutions	25.93%	44.44%	25.93%
Information gathered from your site exprience	14.81%	16.67%	66.67%
Deveolper/HA/PM	**Not Used**	**Little Used**	**Mostly Used**
Manufactures information	25.56%	37.78%	25.56%
Practical information gathered within the organisation	6.67%	27.78%	56.67%
Information from technical organisations	18.89%	44.44%	28.89%
Information from professional institutions	22.22%	43.33%	30.00%
Information gathered from your site exprience	21.11%	23.33%	53.33%
Designers	**Not Used**	**Little Used**	**Mostly Used**
Manufactures information	15.87%	39.68%	42.86%
Practical information gathered within the organisation	3.17%	20.63%	65.08%
Information from technical organisations	7.94%	38.10%	50.79%
Information from professional institutions	4.76%	41.27%	47.62%
Information gathered from your site exprience	17.46%	33.33%	49.21%

Practical information from within the stakeholder organisation and site experience were the two sources most used by construction and developer groups whilst designers had a more even spread across technical and practical information. This use of mainly tacit type information by the sample groups is one of the predominate means of information transfer within construction as identified by Hartmann and Doree (2013). They suggest that the potential hurdles, endemic to construction, of time constraints and insufficient data feeds into the potential failure of the knowledge transfer. The process is often seen as 'additional work' to be carried out in the same time frame; therefore, unpopular and unlikely to be completed successfully or in a form useful to the company in future (ibid). It may be the case that whilst practical company and site information is identified as the main source of information within the sample group; this information is potentially incomplete or fragmented. This therefore, is creating on-going issue, observed in sample projects as part of this research, during the construction process. The skills, education and information gap, identified by NHBC (2012) as needing much further research is apparent in this reconnaissance stage. This area was therefore, further identified as a potential contributing factor for the low carbon construction process, investigated during the action cycle to understand the impact during installation and commissioning phases.

4.5.4 Respondents Opinion on Installation and Commissioning

Sections 2, 3 and 4 of the questionnaire were designed to gather data on the respondent's opinions on the construction process, and in particular installation, commissioning and the defects process. Therefore, emphasis was placed on the construction processes to target the areas for later observations, as part of the research conducted on the sample construction sites. This section of the survey asked questions related to the installation approach, commissioning activities and the impacts of defects on the completed projects.

Respondent were questioned in this area to understand, from the sample groups, what the stakeholder perception was of these key 'on site' construction processes. Heffernan et al (2012) argue that skills gaps and lack of knowledge are the primary barriers to moving forward with low carbon homes. Therefore, gaining an understanding from the stakeholder groups has given direction to the action phases of the research to further expose, and address, these gaps at the installation and commissioning phases of the projects. Figure 4.14 indicates the respondent perception of the initial approach to low carbon homes during construction.

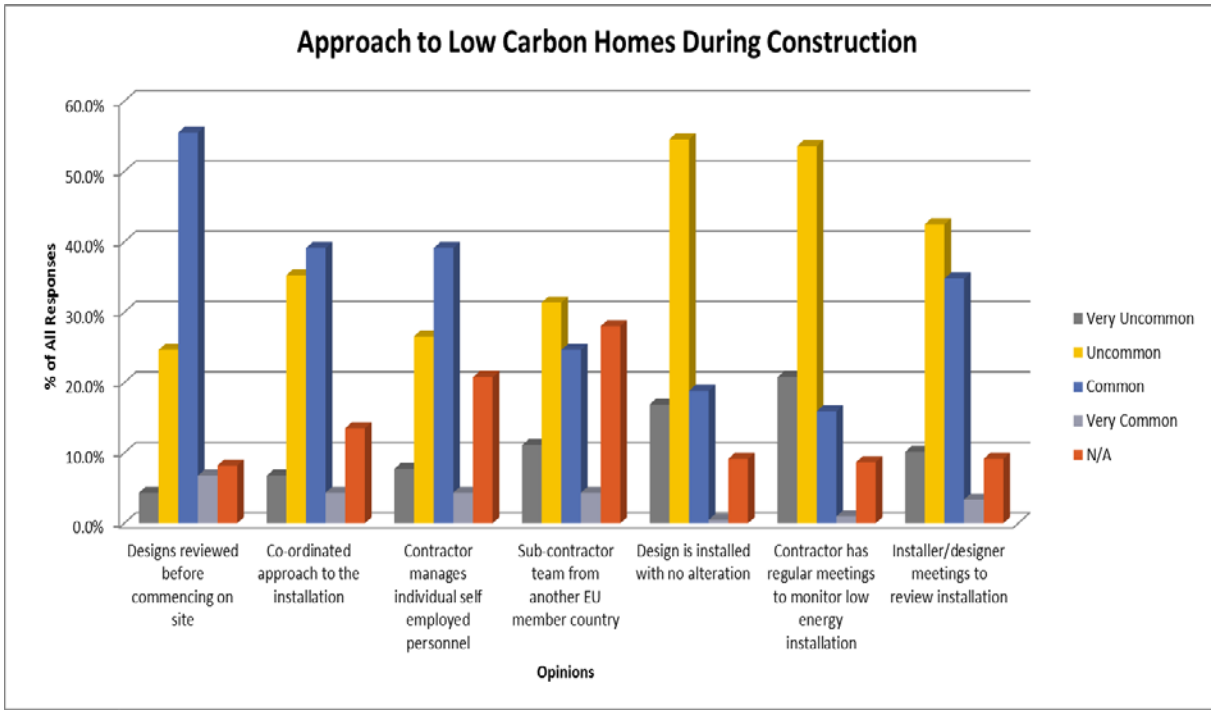


Figure 4.14 Respondent Opinion of the Approach to Low Energy Homes during Construction

The chart indicates that the view taken across all the stakeholder groups is that most designs are reviewed with the construction team before commencement on site. However, what is interesting is that once construction has started, it would appear, that the perception of the sample group is that the design is then subject to alteration with an apparent lack of subsequent monitoring of the technology installation. In many cases the design alterations

are due to value engineering (VE) in one form or another. As seen in figure 4:15 below, the stakeholder groups indicated 80.7% response rate to the question of VE activity as 'always' or 'sometimes' carried out as part of the project process. What is evident from the responses is the perception that monitoring of low carbon technologies is uncommon within the installation process (74.4% of respondents). This was further analyses by looking at each of the key stakeholder groups as shown in Table 4.6.

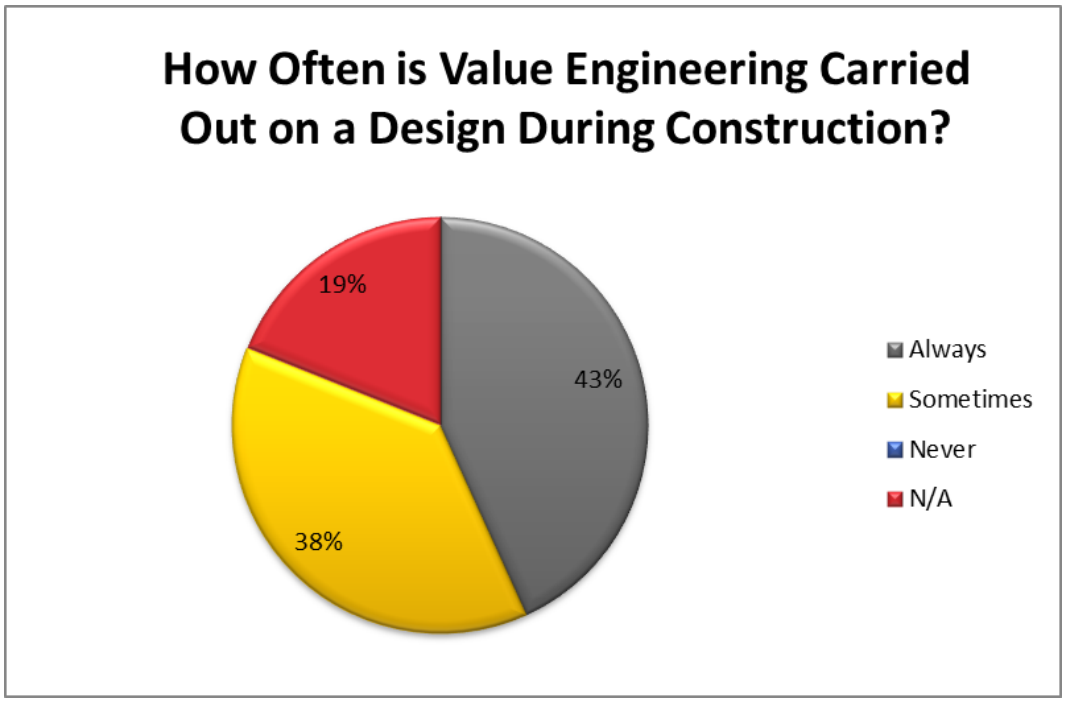


Figure 4:15 Value Engineering Carried out on a Design During Construction

Table 4.6 Key Stakeholder responses to the Approach to Low Carbon Installation During Construction

Construction	Very Uncommon	Uncommon	Common	Very Common
Designs reviewed before commencing on site	5.6%	22.2%	50.0%	14.8%
Co-ordinated approach to the installation	3.7%	33.3%	46.3%	5.6%
Contractor manages individual self employed personnel	11.1%	24.1%	46.3%	9.3%
Sub-contractor team from another EU member country	9.3%	35.2%	24.1%	3.7%
Design is installed with no alteration	20.4%	46.3%	25.9%	0.0%
Contractor has regular meetings to monitor low energy installation	14.8%	53.7%	24.1%	1.9%
Installer/designer meetings to review installation	9.3%	29.6%	46.3%	5.6%
PM/HA	Very Uncommon	Uncommon	Common	Very Common
Designs reviewed before commencing on site	2.2%	21.1%	63.3%	2.2%
Co-ordinated approach to the installation	4.4%	34.4%	45.6%	2.2%
Contractor manages individual self employed personnel	7.8%	34.4%	31.1%	0.0%
Sub-contractor team from another EU member country	14.4%	31.1%	21.1%	2.2%
Design is installed with no alteration	12.2%	60.0%	20.0%	1.1%
Contractor has regular meetings to monitor low energy installation	22.2%	48.9%	16.7%	1.1%
Installer/designer meetings to review installation	7.8%	42.2%	41.1%	2.2%
Design	Very Uncommon	Uncommon	Common	Very Common
Designs reviewed before commencing on site	6.3%	31.7%	49.2%	6.3%
Co-ordinated approach to the installation	12.7%	38.1%	23.8%	6.3%
Contractor manages individual self employed personnel	4.8%	17.5%	44.4%	6.3%
Sub-contractor team from another EU member country	7.9%	28.6%	30.2%	7.9%
Design is installed with no alteration	20.6%	54.0%	11.1%	0.0%
Contractor has regular meetings to monitor low energy installation	23.8%	60.3%	7.9%	0.0%
Installer/designer meetings to review installation	14.3%	54.0%	15.9%	3.2%

Similar levels can be seen across the key stakeholder groups indicating that these issues are observed by all parts of the construction teams referred to in the survey. What appears to be happening, taken from the sample results, is that change is occurring during the early stages of the project to alter the design as part of the VE exercise. However, the follow up to monitor the actual change and its impact on the installation is absent. If, as indicated by Arditi and Chotibhongs, (2005), the relationship between the main contractor and services subcontractor is a fraught and confrontational affair influenced by cost, quality and workmanship; this gap in monitoring is acting as a persistent 'feedback loop' into this relationship dynamic. Therefore, accepting the diverse nature of low carbon construction as observed by NHBC, (2012), the lack of monitoring is presenting a gap in knowledge which, if understood, has potential academic and practical value, especially when looking at the complexity of the delivery of low carbon homes (Wong et al, 2005).

This area of monitoring leads to the concerns about commissioning for the low carbon technologies at the completion of the project. If monitoring is uncommon, as suggested by the stakeholder responses, commissioning becomes the last checking process before the development is handed over for occupation. Potential errors in installation, especially when inaccessible in location, such as pipework / ductwork routes and sizes become obstacle's which lead to compromise in performance and potential future carbon saving. Noyne et al (2013) identify these issues when observing the commissioning process in their '5 levels to commissioning' process, albeit that this is concerned mainly with commercial projects. They argue that in many cases the last two levels of 'can it deliver' and 'is it optimised' are often not tested or considered in the holistic as well as detailed review at the time of commissioning (ibid). Figure 4.16 indicates the perception of the approach to the commissioning for low carbon homes taken across all the stakeholder groups on known schemes. The chart suggests four areas that stand out namely updates to commissioning,

disruption to the commissioning process, co-ordination, and designer at commissioning. There would appear to be an equal opinion of no monitoring of commissioning, and therefore, Table 4.7 shows the further breakdown of the key stakeholder groups to observe if there is any difference between the groups on the opinions raised.

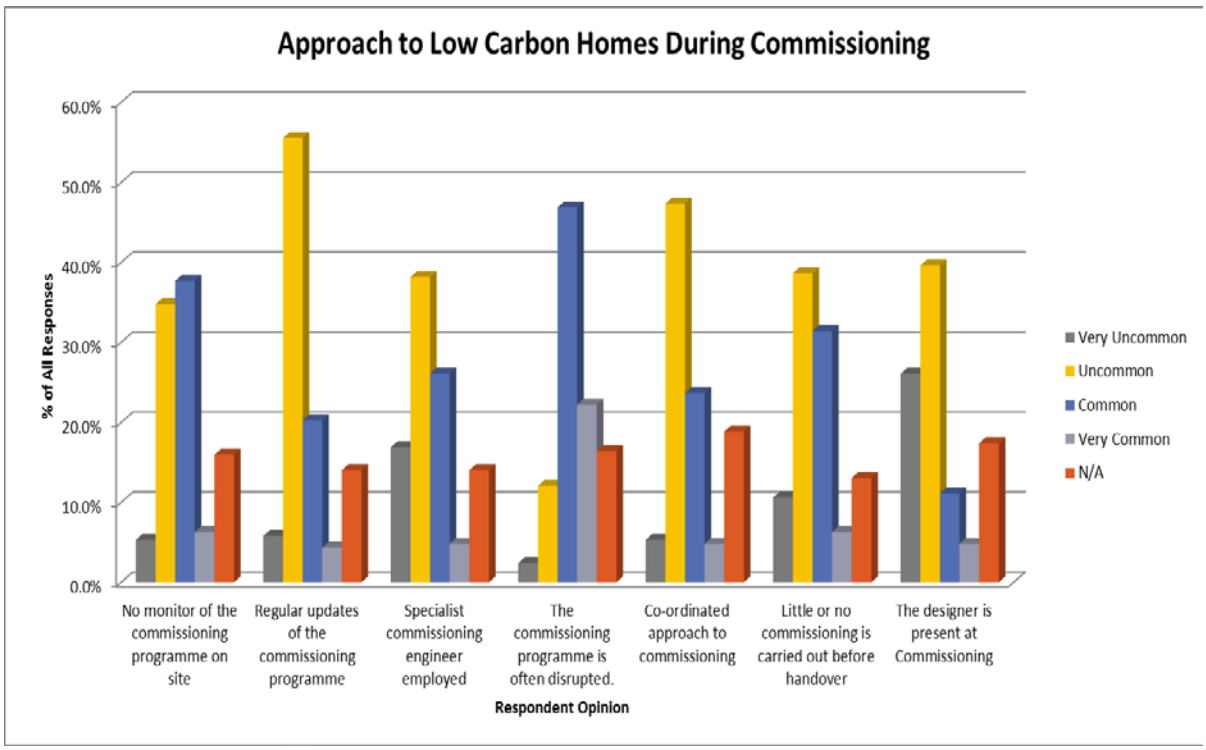


Figure 4.16 Respondent Opinion of the Approach to Low Energy Homes During Commissioning

Table 4.7 demonstrates a difference in opinion between design / developers and the construction respondents, with construction respondents suggesting that commissioning is more commonly monitored and carried out. This difference in interpretation is an interesting point raised from the question; therefore, this was identified as a key area to review during the observation and action phases on the selected construction development.

The question does not ask to what degree the commissioning is completed or monitored, and this is a potential weakness to the interpretation of this chart. The presence of the required commissioning certification could be the driving point to the difference in responses between contractor, developer and designer. With the presence of the certificate alone being the test of evidence that commissioning has been accurately achieved. It is therefore, considered that the question of the levels of commissioning detail, along with the clearly defined areas of common concern on programme, disruption, co-ordination and design validation, expressed by the stakeholders, warranted further review.

The stakeholders were then asked to consider the commissioning that was being carried out and if it was viewed as effective in low carbon homes. Figures 4.17 and Table 4.8 indicate the stakeholder view of the effectiveness of the commissioning being carried out on low carbon homes. What is apparent from these responses is that all three stakeholder groups indicate an opinion that the commissioning process in low carbon homes they are associated with, is not as effective as they should be. Therefore, regardless of the differences expressed to whether monitoring and commissioning is being carried out; there is a noticeable degree of opinion that suggests its level of effectiveness is lower than should be expected for low carbon performance.

Table 4.7 Key Stakeholder Responses to the Approach to Low Carbon Homes during Commissioning

Construction	Very Uncommon	Uncommon	Common	Very Common
No monitor of the commissioning programme on site	5.6%	48.1%	29.6%	9.3%
Regular updates of the commissioning programme	7.4%	53.7%	25.9%	3.7%
Specialist commissioning engineer employed	11.1%	38.9%	31.5%	9.3%
The commissioning programme is often disrupted.	1.9%	14.8%	46.3%	25.9%
Co-ordinated approach to commissioning	5.6%	37.0%	31.5%	9.3%
Little or no commissioning is carried out before handover	18.5%	37.0%	29.6%	3.7%
The designer is present at Commissioning	31.5%	38.9%	11.1%	0.0%
Developer/HA	Very Uncommon	Uncommon	Common	Very Common
No monitor of the commissioning programme on site	3.3%	23.3%	21.1%	1.1%
Regular updates of the commissioning programme	2.2%	30.0%	13.3%	2.2%
Specialist commissioning engineer employed	5.6%	20.0%	18.9%	2.2%
The commissioning programme is often disrupted.	1.1%	7.8%	31.1%	5.6%
Co-ordinated approach to commissioning	3.3%	25.6%	15.6%	2.2%
Little or no commissioning is carried out before handover	4.4%	24.4%	20.0%	3.3%
The designer is present at Commissioning	5.6%	30.0%	10.0%	2.2%
Design	Very Uncommon	Uncommon	Common	Very Common
No monitor of the commissioning programme on site	6.3%	19.0%	46.0%	6.3%
Regular updates of the commissioning programme	9.5%	61.9%	9.5%	6.3%
Specialist commissioning engineer employed	31.7%	38.1%	14.3%	3.2%
The commissioning programme is often disrupted.	3.2%	7.9%	42.9%	34.9%
Co-ordinated approach to commissioning	6.3%	55.6%	12.7%	4.8%
Little or no commissioning is carried out before handover	7.9%	30.2%	34.9%	7.9%
The designer is present at Commissioning	34.9%	33.3%	6.3%	6.3%

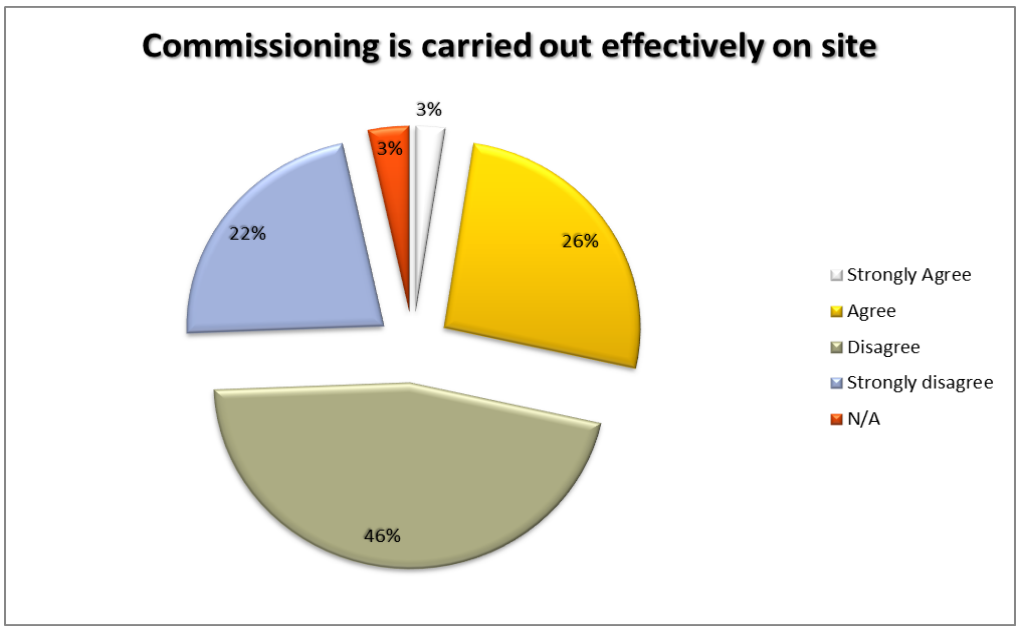


Figure 4.17 All Stakeholder Views on the Effectiveness of Commissioning

Table 4.8 Stakeholder Key Group Views on the Effectiveness of Commissioning

Construction	
Strongly Agree	1.9%
Agree	29.6%
Disagree	46.3%
Strongly disagree	16.7%
N/A	5.6%
Developer/HA/PM	
Strongly Agree	2.2%
Agree	31.1%
Disagree	48.9%
Strongly disagree	16.7%
N/A	1.1%
Design	
Strongly Agree	3.2%
Agree	15.9%
Disagree	41.3%
Strongly disagree	34.9%
N/A	4.8%

Figures 4.17 and Table 4.8 demonstrate that the three stakeholder groups see commissioning as affecting the effectiveness for low carbon homes.

The importance of commissioning within Low and Zero Carbon (LZC) housing, as with all other buildings, is paramount in achieving the required building performance (Noyne et al, 2013). This level of commonality in percentage responses across the stakeholder groups suggests a real area of concern when taken with the contributing factors already illustrated throughout the survey.

For the final section of the survey the stakeholders were asked their opinion on the defects process during the first year of occupation of the dwelling. Figure 4.18 shows the perception of the level of defects within low carbon homes across all the stakeholder groups.

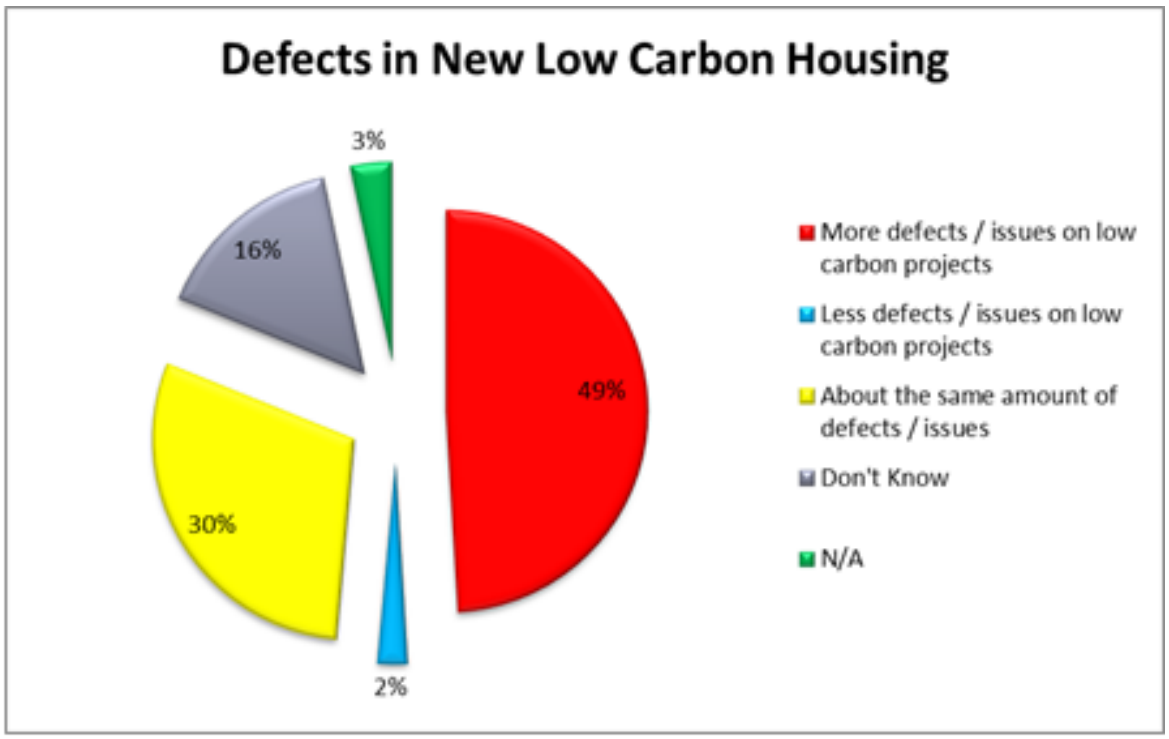


Figure 4.18 All stakeholder Views on Defects in New Low Carbon Housing

What is noticeable from the responses, along with the higher levels of defects observed, is the fact that only a very small percentage of the stakeholder group saw a reduction in defects. This was further reviewed within the key stakeholder groups to see if there were

any differences. Table 4.9 indicates the views between the key groups, and what can be seen is that there is a general consensus across the groups on the higher levels of defects

Table 4.9 Key Stakeholder Groups Views on Defects in Low Carbon Housing

Construction	Number of Yes Answers
More defects / issues on low energy projects	53.7%
Less defects / issues on low energy projects	1.9%
About the same amount of defects / issues	29.6%
Don't Know	11.1%
N/A	5.6%
Developer/PM/HA	Number of Yes Answers
More defects / issues on low energy projects	48.9%
Less defects / issues on low energy projects	4.4%
About the same amount of defects / issues	41.1%
Don't Know	7.8%
N/A	1.1%
Design	Number of Yes Answers
More defects / issues on low energy projects	49.2%
Less defects / issues on low energy projects	3.2%
About the same amount of defects / issues	15.9%
Don't Know	28.6%
N/A	4.8%

observed. It is also noticeable that a reduction in defects was not seen by any of the groups. However, amongst the developer/PM/HA group, whilst an increase in defects was noted, the percentage for 'about the same' level of general defects was much closer than that of the other two groups. This may be due to a higher level of defects experience on HA schemes (these being the largest contributors within the group) therefore; this was further investigated as part of the action cycle to observe if this had any impact in the research.

In gaining an understanding of the stakeholder's opinions on defects the questionnaire also asked which of the low carbon technologies contributed most to the defects issues. The intention was to assess whether more complex technologies gave higher instances of defects, and also how this may be linked with the contractor's familiarity with installation and

commissioning. Figure 4.19 gives the responses to the question of the stakeholder's opinion of residents responses to the low carbon technologies installed in the dwelling during the defects period.

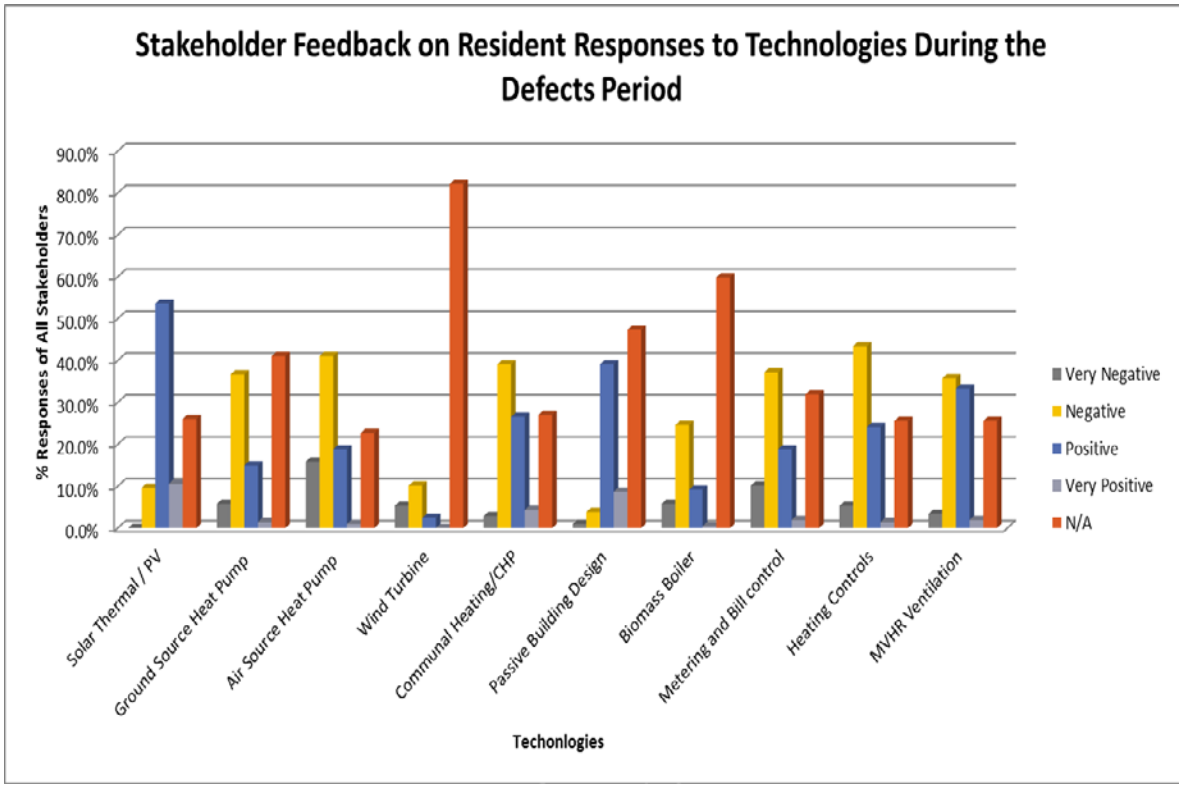


Figure 4.19 Stakeholder Feedback on Resident Responses to Technologies During the Defects Period

The most accepted technology, is the solar thermal and photovoltaic installations. Passive building design including air tightness, low U values and window design are the next most popular by response percentage. The other technologies, which require interaction as part of the low carbon performance, all have higher negative opinions with air source heat pumps, communal heating and heating controls having the highest negative scores. It is observed that some of the technologies have high levels of N/A responses. It is assumed that as these are the least used technologies, many of the respondents have not had experience or subsequent resident contact to allow for an opinion to be registered in the survey. This can also be seen by the response rates to technologies in Figure 4.10, which show Wind,

Biomass and Ground Source Heat Pumps as the least often used technologies amongst the stakeholder groups. Table 4:10 shows the divide between the key stakeholder groups which reflects the general group.

Table 4.10 Key Stakeholder Groups Feedback on Resident Responses to Technologies during the Defects Period

Construction	Very Negative	Negative	Positive	Very Positive	N/A
Solar Thermal /PV	0.0%	13.0%	51.9%	13.0%	22.2%
Ground Source Heat Pump	5.6%	37.0%	24.1%	1.9%	31.5%
Air Source Heat Pump	14.8%	42.6%	27.8%	0.0%	14.8%
Wind Turbine	5.6%	13.0%	1.9%	0.0%	79.6%
Communal Heating/CHP	1.9%	48.1%	25.9%	3.7%	20.4%
Passive Building Design	3.7%	3.7%	40.7%	13.0%	38.9%
Biomass Boiler	5.6%	24.1%	18.5%	0.0%	51.9%
Metering and Bill control	11.1%	35.2%	22.2%	3.7%	27.8%
Heating Controls	3.7%	33.3%	29.6%	0.0%	33.3%
MVHR Ventilation	1.9%	29.6%	40.7%	1.9%	25.9%
Developer/PM/HA	Very Negative	Negative	Positive	Very Positive	N/A
Solar Thermal / PV	0.0%	10.0%	54.4%	5.6%	30.0%
Ground Source Heat Pump	4.4%	34.4%	10.0%	1.1%	50.0%
Air Source Heat Pump	13.3%	44.4%	15.6%	1.1%	24.4%
Wind Turbine	4.4%	8.9%	1.1%	0.0%	85.6%
Communal Heating/CHP	2.2%	44.4%	22.2%	1.1%	30.0%
Passive Building Design	0.0%	4.4%	34.4%	7.8%	53.3%
Biomass Boiler	6.7%	18.9%	6.7%	0.0%	67.8%
Metering and Bill control	12.2%	45.6%	20.0%	2.2%	20.0%
Heating Controls	6.7%	54.4%	23.3%	2.2%	13.3%
MVHR Ventilation	5.6%	37.8%	35.6%	3.3%	17.8%
Design	Very Negative	Negative	Positive	Very Positive	N/A
Solar Thermal / PV	0.0%	6.3%	60.3%	17.5%	15.9%
Ground Source Heat Pump	7.9%	47.6%	14.3%	1.6%	28.6%
Air Source Heat Pump	20.6%	39.7%	17.5%	1.6%	20.6%
Wind Turbine	6.3%	11.1%	4.8%	0.0%	77.8%
Communal Heating/CHP	4.8%	41.3%	20.6%	9.5%	23.8%
Passive Building Design	0.0%	3.2%	54.0%	6.3%	36.5%
Biomass Boiler	4.8%	33.3%	4.8%	1.6%	55.6%
Metering and Bill control	6.3%	33.3%	12.7%	0.0%	47.6%
Heating Controls	4.8%	36.5%	20.6%	1.6%	36.5%
MVHR Ventilation	1.6%	36.5%	20.6%	1.6%	36.5%

Where the complex technologies are being used for low carbon housing, the higher rate of defects could be related to the extended ‘post-handover’ commissioning of the installed system. Lohne et al (2015) refer to this as the ‘fuzzy commissioning’ process when commissioning is continuing, rightly or wrongly, long after the building is handed over by way

of defect rectification. This is commonly seen in the commercial sector where complex building services systems are ‘fine-tuned’ during the early occupation period. However, the difference between the two sectors, commercial and residential, is that this ‘fine-tuning’ is taking place whilst the residents are living in the dwelling. In this way, dependent on the level and duration of the intervention, the resident perceives the technology to be faulty and subsequent trust in operation is lost at the important early stage of occupation.

Lofthouse and Lilley, (2006) looking at user centered research methods for design of low carbon technologies observed that people find a way around failing or flawed technology to achieve a comfort level in the home. This often involves using the technology in ways not intended for the original use or the intended operation to allow them to be energy efficient. Therefore, the ‘evolving technology use’ (individually evolved unintended operation of the technology), due to poor installation or unfinished commissioning, is potentially compounding the issues at the construction stage. This could also be affecting the long term use of the technology due to installation and commissioning errors. However, as observed by Hopkins et al, (2015) the process of learning from commissioning and defects, and the approach the construction industry takes to analysing and monitoring, largely absent from the literature.

4.5.5 Reflection on Responses

The responses from the stakeholders have revealed a number of areas that warrant further investigation within the researcher’s project professional practice, to establish the basis for the action research cycle. The survey coverage has given a representative cross section of the main construction stakeholders including views from design, development, project management and construction, with representation from both contractors and

subcontractors. It is observed that there could have been more representation from subcontractors, which would have given a greater level of detail to the ‘on site’ activities. However, this is further addressed during the action phase when access was gained to a number of contractors and subcontractors on the sample construction sites, therefore adding to the research narrative.

Several themes emerge from the survey data that have a common thread through the construction process and stakeholder groups observed for the research. Firstly, responses from the information and guidance suggest that the influence of the Building Regulations and the Code for Sustainable Homes have been seen as having a distinct impact on low carbon construction. Cost, co-ordination of regulation and construction, and the change to design and materials used, have all been viewed to have the greatest significance for the management of formation and guidance for construction. The responses illustrate that in a majority of cases the industry is using ‘in house’ knowledge and construction experience to build a practical response to legislation and regulation, with technical and professional bodies used to a lesser extent. This is, at first view, surprising as there has been substantial change to low carbon construction guidance over the past 10 years. One would have assumed that professional bodies would have had a larger part to play within the industry structure. However, this may be hidden within the survey results with individual access to professional bodies being disseminated within the work place as company based information. The validity of this assumption is examined further in the follow up interviews and the action cycle observations, to understand the tacit and explicit nature of the information used, and how that feeds into the construction process and the observed stakeholder narrative.

Secondly, the responses illustrated a key issue surrounding the monitoring of low carbon technology installations in new developments. Whilst the perception across all the key stakeholder groups was that review of designs were undertaken before construction commenced; once started the process was less clear-cut. As found in the information and guidance section, cost was seen as a driving factor, apparently encouraging value engineering (VE) and design change.

However, what was thought provoking was that once value engineering had been achieved, there was the perception that very little monitoring was carried out during the installation stages. This therefore, raises the question that if there is little monitoring to the VE design, and the designers are not often present at the commissioning stages, what is the validation process for the commissioning? And what constitutes a completed scheme? This is especially relevant when responses indicated that commissioning was often disrupted, or not completed in a methodical process. There is also a further concern centred on the responses to the 'effectiveness of the commissioning processes' for low carbon homes. This suggests that there are real construction industry concerns, expressed amongst the stakeholders, with the level and ability of the construction workforce to commission especially on more complex low carbon technologies. This concern is seen within the literature with Zero Carbon Hub identifying that 'the development of appropriate testing, measuring and assessment techniques is urgently required to enable the '2020 Ambition' to be demonstrated' (Zero Carbon Hub, 2014:p2).

This same theme also followed through to the defects responses, with stakeholders suggesting that defects were more prevalent on low carbon schemes reviewed in the research. This was also seen with the more complex technologies, signifying that the lack of

co-ordination, monitoring and effective commissioning is directly affecting new low carbon home and possibly the longer term potential carbon reductions.

To investigate this further and to gain a better understanding of the responses, a number of stakeholder who responded to the questionnaire, and gave agreement to a follow up interview, were approach to explore some of the survey responses in more detail.

4.6 Exploring Meaning behind the Responses to the Questionnaire

The interview process followed on from the completion of the survey, with the selection of a group of stakeholders from the list of respondent who had agreed to the follow up interview. The interview process has been selected to further explore some of the areas that emerged from the survey, and to gain understanding for the action phase of the research. Arksey and Knight suggest that interviewing is a powerful way of exploring more detail within responses from stakeholders. They go on to state that interviewing ‘helps people to make explicit things which have hitherto been implicit’ (Arksey and Knight, 1999:p32). Gray also suggests that interviews are useful where people ‘like talking about their work more than filling in questionnaires’ (Gray, 2011:p370). This is very often the case in professional practice and especially when concerned with the construction process where response rates are not very high to surveys.

Of the 255 respondents 28 respondents agreed to a follow on interview, which represented 14% responses rate. The 28 respondent represented the following stakeholder groups:

Design – *10 responses*

Development/HA/PM – *11 Responses*

Construction – *7 Responses*

Each of the respondents were contacted and thanked for agreeing to take part in the interview process and the criteria for attending the interview was discussed. Some of the selection criterion was as follows:

1. Representative from the stakeholder groups
2. Well informed of the construction process
3. Availability of attendance for the interview
4. Agreement to have the interview audio recorded for transcribing
5. Third party agreements, where required, from employer to take part

Of the 28 respondents a further 9 declined due to availability and agreement with their employer to take part for taped interviews. From the remaining potential 19 participants 6 were from Architecture and Building Services groups within the research professional practice; therefore, 2 were selected from this group as representative of these respondents. This further assisted in reducing the number of interviews to 11, having at least two respondents from each of the three key groups. This was more manageable within the time frame to interview and transcribe. Audio transcription was undertaking within the research professional practice using an audio typist to ensure accuracy of the information.

The final list for the interviews was as follows:

- **Design** – 2 Interview Code – BS-01 and A-01
- **Housing Association** – 3 Interview Code – HA-01 to HA-03
- **Project Management** – 2 Interview Code – PM-01 to PM-02
- **Developer** – 1 Interview Code – D-01
- **Construction** – 3 Interview Code – C-01 to C-03

Interviews were undertaken over a one month period, after completion of the questionnaires, and were conducted within each of the respondent's place of employment for ease of access, and to comply with time constraints of the respondents and the research.

4.6.1 Interview Design and Process

Gray identifies that there are several different types of interview with the choice of technique based on 'the aims and objects of the research' (Gray, 2011:p371). A semi-structured interview technique was selected for the research as this offered the most productive method to gather information from the respondents. This method gives the opportunity to compared data against a set range of questions, posed to all stakeholders, and the freedom to probe more deeply in areas of significance as they emerge from the interview. The semi structure interview was based on the questionnaire information so that further triangulation could be carried out to test the validity of the data gathered and to identify emergent themes for the action phases (Creswell and Plano Clark, 2011). Arksey and Knight (1999) also suggest methods to strengthen the validity of the interview process, these include building rapport and trust with the respondent to allow freedom of expression, encouragement to expand on the respondents initial responses and ensuring the interview is of a suitable length to gain the required detail (Gray, 2011). External validity, creating the plausible case

for generalising from the research data (Gray, 2011), is also important and Arksey and Knight (1999) suggest two main courses of action for validity. Firstly, to select a sample that allows the subject to be viewed from the relevant perspectives, and to choose a sample size to explore emergent data. This has been achieved within the extent of the research by combining the interviews and questionnaires to explore the emerging data from all the key stakeholder viewpoints, before moving to the next stage of the action research cycle.

The semi-structured interview data was explored using thematic analysis. As seen from chapter 3, Braun and Clarke suggest that thematic analysis lends a flexible approach to the analysing of interviews and observations however, they point out that the method should be undertaken to ensure the analysis is 'theoretically and methodologically sound' (Braun& Clarke, 2006;p2). The research uses their 6 point guide (see table 4.11) to the analyse the data to ensure that it is carried out in a 'deliberate and rigorous way' (ibid: p2)

Table 4.11 6 Point Guide to Thematic Analysis (adapted Braun and Clarke, 2006:p35)

Phase of Analysis for Interviews	Description of Analysis for each Phase
1. Familiarisation with the data	Transcribing data, reading and rereading the data, noting down initial ideas. Information from interviews forming part of the research
2. Generate initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes	Checking in the themes work in relation to the coded extracts; generating a thematic map of the analysis.
5. Defining and naming themes	On-going analysis to refine the specifics of each theme, and the overall story the analysis tells; generating clear definitions and names for each theme.
6. Producing findings	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back to the analysis to the research question and literature.

This data analysis method gives validity as argued by Braun and Clarke as it offers an 'accessible and theoretically-flexible approach to analysing qualitative data' (Braun and Clarke, 2006:p2). They go on to state that as the method has theoretical freedom, thematic analysis provides a 'flexible and useful research tool, which can potentially provide a rich and detailed, yet complex account of data'. (Braun and Clarke, 2006:p5). This is further supported by Holloway & Todres who identify that Qualitative approaches are diverse and complex in their form and structure therefore, thematic analysis should be seen as a 'foundational method for qualitative analysis' (Holloway & Todres, 2003:p347).

Reliability and bias have also been considered as part of the research process, especially where the interviews are concerned. Gray advocates that to be reliable the 'research instrument' must also be 'consistently measured' Gray (2011). Within the semi structured

interview this has been achieved by maintaining the same set of interview questions for each respondent. In addition to the set questions, the interview structure was constructed to encourage rapport and trust at the early stage. However, it must be said that in probing for further information the script was not always maintained, and this is a potential weakness of the interview process. Therefore, to increase validity the interview data has been compared against all of the interviewee's information, and triangulated with the survey and focus group data.

The protocols that were set up for the semi-structured interviews adopted the following criteria:

1. Participants selected through the survey process, with further contact to establish wiliness to engage, understanding of the interview to be undertaken and confirmation that the correct procedures have been followed to allow the information to be used.
2. Interview questions sent to all participants 2 weeks before the interview to allow the review and reflection before the interview.
3. Access arrangements and location of the interview arranged 1 month before the interview to ensure confidence and comfort for the respondent.
4. Equipment checked and additional batteries obtained to ensure the interview was fully recorded and no issues would be experienced, therefore detracting from the interview experience.
5. Anglia Ruskin Ethics committee approval obtained before the interviews were carried out. Approval obtained from all participants to ensure 'informed consent' and a full understanding of the process, and commitment to 'Non-disclosure of information' and the privacy and protection of the participant.
6. Interviews were recorded with a transcript sent to the participant to confirm content and ensure the information was representative of the interview undertaken

7. Note of thanks sent at the completion of the process, with a request for future follow up if required.

With these protocols in place the interviews gave a rich source of complementary information to the survey, focus group and historic data. This information was used as part of the diagnosis and reconnaissance to inform the action phase of the research.

4.6.2 Interview Setup

The semi-structured interviews were undertaken over a one month period during the course of September 2014. A single pilot interview was conducted, within the professional practice, to test the construction of the questions and to assess the potential length of the interview. The pilot study proved informative in suggesting procedural requirements for the interviews that were then adopted in the actual process. These key procedural structures included the following:

1. Interview area to be in a quiet location so that the recording could pick up responses without background interference.
2. Seating arrangements to be as flexible as possible to allow the respondent to feel relaxed.
3. Location of the tape recorder to be tested before the interview commenced.
4. Interview to start with ‘about you’ questions to build up rapport and trust and to create a comfortable environment for the interview process.
5. Instructions for the process of the interview to be read out and made clear before the start to ensure all interviews have the same level of information and structure for the interview session.

6. The respondent is made aware that the interview is confidential and may be stopped by them at any point, and that a script will be sent for a review before being used in the research.
7. All transcript information coded for analysis and so that all information used is anonymous
8. No information used without full permission of the respondent

The pilot interview was important in allowing these areas to be tested before the actual interviews took place. This is supported by Arksey and Knight (1999), who propose that validity is strengthened by investigating and building on interview techniques that build trust and rapport with the respondents, therefore giving the respondent sufficient scope to express themselves.

Each of the interviews was conducted within the respondent's work place with 1 hour and 30 minutes assigned to each session. This was pre-arranged with the respondent with the first 30minutes used to set up the tape recorder and prepare the room for the interview session as suggested by Wengraf (2001). The pilot interview suggested 40 minutes for the main session, however, an hour was allowed for familiarisation at the start and to have a 'post interview' period at the end, ensuring the respondent was comfortable with the interview process. Wengraf (2001) points out that a typical 45 minute interview can take upwards of 2 to 3 hours to prepare and complete to permit a stress free environment. This creation of a stress free environment is also key as part of the active listening skills required for a productive interview session (Gray, 2011). It is also important to point out that the reduction in stress during the interviews also permits a more open level of communication, one in which much more information is gained than in an otherwise closed environment. There was no set order to the interviews, and

interview dates were set around the work schedule of the respondents. The interview names were coded so that names and scripts could not be readily identified.

A Dictaphone with a microphone attached was used throughout the sessions as suggested by Patton (2002) to ensure that the interview was captured accurately, and without the distraction of needing to note the interview responses. General notes were taken of the interview location and impression of the session, however during the session no notes were taken. Each audio tape had a 4 hour runtime to ensure that the sessions did not need to be stopped to change tapes or adjust the audio equipment. A sample of the interview questions and the structure are included in Appendix 4.

4.6.3 Interview Responses

This section will examine the responses from the interview groups to explore the themes as seen within their areas of experience (see appendix 4 and 5 for sample structure and transcripts). The responses have been evaluated together across all of the stakeholder groups to observe emergent and key themes common to all the stakeholders interviewed, and to inform the action cycle of the research. Coding labels have been used to identify the stakeholder job title and for ease of reference they are noted again. However, this time to further assist the reader, a brief introduction is given to the interviews with an outline of each of the participants (See Table 4.12 below).

Table 4.12 List of Interview Participants

Discipline	Interview Code	Brief Description
Design	BS-01	Building Services Engineer Senior Engineer
Design	A-01	Architect - Partner
Housing Association	HA-01	Housing Association Sustainability Manager
Housing Association	HA-02	Housing Association Development Director
Housing Association	HA-03	Housing Association Project Co-ordinator and Sustainability Manager
Project Manager	PM-01	Project Manager Senior Consultant
Project Manager	PM-02	Project Manager Senior Consultant
Developer	D-01	Developer –SME Company Housing Development Only
Contractor	C-01	Mechanical and Electrical Sub Contractor Site Manager
Contractor	C-02	Construction Manager – Site Based Lead Construction Manager
Contractor	C-03	Construction Development Director – Office Based

The interviews represent the three key stakeholder groups that were identified and explored as part of the questionnaire data. The information has added to the strengthening of validity through the process of triangulation of the data (Gray, 2011). The interviews have revealed a rich and informative picture of the opinions and experiences of the stakeholders involved. They have added to the data gained from the questionnaires, giving a further insight into attitudes and opinions already evaluated. The exploration of the data has fed into the emerging picture from the survey, and has displayed common threads evolving from the text. This has uncovered key areas of concern across the stakeholder groups, notwithstanding their participation level, within the construction process. What was noticeable from the texts, and therefore, strengthens the validity of the interviews, is that all participants were familiar with low carbon technologies and the current assessments and construction processes. This has assisted when comparing the information as it can be fairly

assumed that the opinions expressed are based on involvement with the process, regardless of the level of participation. This would therefore, suggest that these are worthy of comment and for further investigation in the action research cycle.

Technology

An early emergent theme from the interviews was the types of technologies that were considered the most effective within low carbon homes, and how that level of effectiveness was measured against ease and simplicity. Throughout the responses effectiveness was defined in a number of ways, from ‘ease of operation’, ‘operational systems with no issues’ to ‘they’re not going to cause you any problems they’ll just sit there’ (Respondent HA-01). It was important to identify these levels of interpretation of effectiveness to understand and contextualise the responses when comparing the themes from the stakeholder groups. Figure 4.20 indicates the classification tree developed from the coded responses for the technology themes (Schulz, 2014)

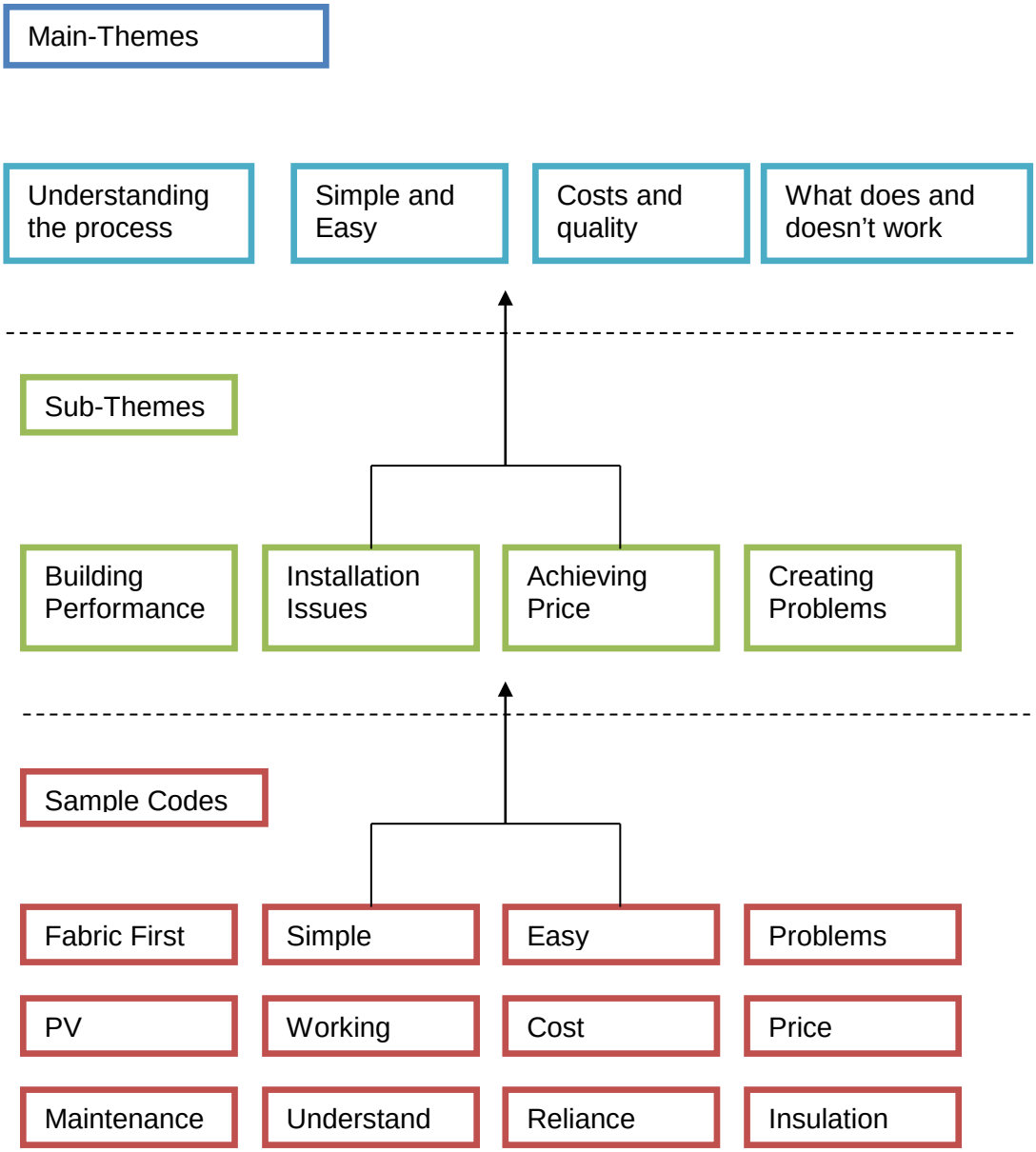


Figure 4.20 Classification Tree for Technology Themes

Respondent A-01 typified the comments on effective technologies by stating:

> **A-01 -** Well as I said at first I think if its fabric first it seems to make a lot of sense because you have the insulation levels and the building performing to its highest level without the reliance on things that can go wrong

Simplicity and practical operation, as a key consideration, was also expressed by respondent HA-03 who also linked the working approach of Photovoltaic panels (PV) to the wider implications of sales benefit and resident use:

> **HA-03** - It just works and the stuff that we've got works and our contractors that put it in are putting stuff in that works. It's almost that simple, it's an easy sell internally, it's an easy sell to a buyer, to a tenant, to someone who has been decanted somewhere, they understand what it is.

The link to both financial issues and problems with other technologies was echoed by respondent HA-01 the sustainability manager. Interestingly, even when the Photovoltaic Panels (PV) panels were perceived as not operating, they were still considered 'passive', and not affecting the on-going operation of the building or financial considerations of the Landlord:

> **HA-01 -** you put them up there if you don't do anything with them they're not going to cause you any problems they'll just sit there, they may not give you many gains but the problem that we have with some of the other technologies is that they actually create problems for you and create financial losses also

PM-01 continued the theme of simplicity with regards PV technologies:

> **PM-01 -** I think there's no doubt that most energy comes from the sun and onto the roofs, PV it's a simple concept and that seems to work

The Construction Manager C-02 also picked up on the simplicity issues and expanded further on his response with his concerns on 'errors', for what he considered, with more complex system:

> **C-02** - I would say LED lighting, solar panels and intelligent lighting. I think the others are affected by user error, installation error, commissioning errors or district heating overheating. When you go to something like a solar panel it's installed by a specialist.

This early theme of the simple approach and technologies considered passive in functioning and non-functioning operation, gave an indication across the stakeholder groups of the common attitude to low carbon technologies. It was observed that of the 11 interviews completed only one respondent suggested technology other than PV as the most effective. References were made to technologies such as biomass, Air Source and Ground Source Heat Pumps and Communal Heating systems utilising Combined Heating and Pump (CHP) units. However, these technologies were viewed, in the main, as more problematic. This could be seen from respondent C -01 when referring to biomass boilers:

> **C-01 -** It's not an ideal technology to use, especially where nobody is maintaining it. If you've got a full time maintenance guy it's fine, but if you're just pouring it in and expecting it to work it doesn't work that way, somebody has to clear the ash pans out and everything else, it's not ideal.

The construction manager also referred to other technologies used, with a general opinion that the systems had not 'worked for us'. C-02 went on the comment:

> **C-02 -** Ground source heat pumps just don't work for us, well we've had it where it hasn't worked and I don't know if that's to do with the technology or, same again, the interface between the packages, and whatever's its fallen down and it's not really worked for us, the NIBE units [Exhaust Air Source Heat Pumps], are the same again.

There was a different perspective from respondent HA-03; here the issues were not necessarily seen as technology but the cost implications of the installation and operation:

> I don't see that there should be any problems with doing it where it's viable [communal heating systems with CHP]. So I think it's a perfectly reasonable way of achieving kind of low carbon objectives. Whether or not you can achieve low price is another matter. I'm not always sure that you can.

If these themes are compared with Table 4.19, on the technologies considered effective during the defect period, this would support the data showing PV as the most accepted technology amongst the stakeholder groups. This is also supported in research by NHBC where solar PV and solar thermal ranked the most popular technology used on new green field and brownfield sites (NHBC, 2012). However, it is interesting to note that this does not necessarily indicate the most carbon effective or even operationally effective; it could be due to its 'benign effect' regardless of operation as noted by respondent HA-01. This may, to an extent, be the case in new blocks of flats as the PV will not be directly connected to the

dwelling. In most, if not all, cases the system is connected to the communal electrical supply to reduce installation cost whilst meeting the carbon performance standards. Therefore, whilst a low carbon technology is installed, in these low carbon developments, it is not directly related to the resident's day to day operation of their home, unlike the other low carbon technologies. Also, from the Landlords perspective, if the PV technology fails there is no direct complaint from the residents or subsequent failure in the other main domestic building services systems to contend with. We could therefore be observing PV technology as the most effective purely as it has the least interaction or concern for the stakeholders.

This can be seen further in the responses referring to other low carbon technologies; references are made towards interaction and third party involvement, with the terms ease and simplicity being replaced with some of the following remarks:

> 'nobody is maintaining it' (C-01),
> 'interface between the packages' (C-02)
> 'everything else we have problems with'(HA-01)
> 'wherever we've been is, I think, a lack of understanding of what these technologies are supposed to do' (A-01)

However, to what extent are these opinions based on actually failing technologies, as opposed to technologies that were not installed or commissioned optimally from the start of the development? Therefore, we could be witnessing a loss of confidence in a range of technologies, which if installed, commissioned and handed over effectively could contribute further to future low carbon dwellings. It is also noticeable, from the literature, that this comparison with the possible reasons for the adoption and use of technologies is almost silent.

Whilst PV plays an important part in the low carbon approach, technologies in large-scale and high-rise developments, where roof space is not sufficient for the required carbon reductions, need a complementary approach from other low carbon sources. These additional technologies, which invariably include more interactive variable control systems, have implications both in construction and in eventual use. Therefore, understanding and controlling this more 'interactive' technology needs increased research (Zero Carbon Hub, 2015). This was further investigated during the site observation to explore how the perceptions of the different technologies were manifested on the construction site as part of the action research cycle.

Regulation and Guidance

In gaining an impression of the technologies used, the interviews also explored the stakeholder's views of regulation and guidance, and to what extent they had influence in the construction process. The survey questionnaires indicated change within the industry, but also identified issues of co-ordination, costs and technology delivery. The interviews were used to probe what was driving the survey responses, to what extent this has influenced their opinions on low carbon dwellings, and how they see the on-going contribution to future developments. Respondent C-03 when giving an opinion on the code for sustainable homes observed that:

> **C-03 -** But it did force some of the market to actually do something to force a focus on energy. So that was good. The issue for me is that it became a tick box exercise and there's not a joined-up approach

This theme of change occurring within construction but, also attracting the perceived negative approach of the 'tick box' procedure, was echoed across most of the respondents. This is represented by the response from respondent HA-01 when it was stated:

> **HA-01 -** I can really appreciate that it brought in a lot of important awareness and pushed innovation in the industry, but I also think it's a bit too checklist based, too point scoring.

The awareness of a 'formulaic approach' to achieving low carbon dwellings, growing out of the code for sustainable homes, indicates an emerging theme within the survey of stakeholder agendas in the process of compliance. These agendas of cost and quality have a grounding in the procurement process for domestic construction, and the potential issues that arise from the Design and Build (D&B) contract. What is initially tendered as a 'post planning' performance design is transferred to the D&B contractor to construct, with the responsibility of design and compliance attached to the contractor. Therefore, at this key point in the construction process change to the design are direct consequences of cost, through the value engineering exercise, and the skill base of the contractor. Respondent PM-02, the most positive in responses to the contribution of the Code, stated:

> **PM-02 -** The cost. I would say it's 80:20, the contractor doing it for cost, without a doubt, without a doubt. What the client's got to appreciate though is that the client cannot say to the contractor 'Mr D&B Contractor [Design and Build Contract] go out and achieve it how you like [Code for sustainable homes] and then when the proposals come forward say actually we don't like that, we would like it this way, if you want to be that prescriptive you must be prescriptive at the outset

This theme of the D&B process is also referred to by respondent HA-03:

> **HA-03 -** So I know D&B contracts can really restrict your freedom essentially, but still I don't think you should ever just hold your hands up and go oh it's a D&B contract we can't do anything about it. You've got to be a good client and you've got to be a good client from the start not halfway through when you suddenly get jittery about something.

Respondent C-01 speaking from the perspective of a mechanical and electrical subcontractor identified the further cost implications of the D&B process acknowledging the technical changes that are taking place to reduce costs:

> **C-01 -** The builder or the developer sits in on it half way through the process with his technical guys, and the first thing they're trying to do is remove all the concepts that have been started in the first place to reduce the cost of the build

These stakeholder perspectives of compliance indicate a conflict as a consequence of the procurement method therefore, illustrating the influence costs and quality play in the construction process. Of course, this tension between cost and quality is nothing new in construction. However, its effect on low carbon technology selection and the implications for installation and commissioning are an area of concern that needs to be fully understood, and is little researched. An interesting point raised by respondent C-02 alludes to this issue of tension of cost and quality and how this may be affecting the end results:

> **C-02 -** For a main contractor it's ticking the box, it's ticking the box. Depends on the client you're working with but most of it is all about commercial gain and what's it going to return to the business rather than what that looks like for the end user.

This theme of cost and process constraints have a direct influence on the building design and the methods adopted for the installation. This was amplified in a response from respondent C-01:

> **C-01 -** It's one of those things, we don't get that involved in early doors [early in the project process planning stage] and then when we all sit down and think how did we get to this position, who's ticked these boxes to make us put these technologies in. It's almost as if it's at the wrong stage that this happens. Our issues then come with trying to actually get a building to work with the constraints that the Code has put on the building, not just financially but on spatial requirements and that is probably the biggest issue.

What emerges here is a theme of recognition of the term 'actually get the building to work'. This would suggest that the assessment process coupled with the D&B contract, with its stakeholder driven agendas of cost and technology, potentially delivers a building that has both financial and spatial constraints already imposed. If this is compared with the potential lack of confidence issues with the more 'interactive' low carbon technologies, there is grounds for conflict and error. Therefore, this perspective of 'partisan compliance' is creating a technology conflict at the construction stage of the project, where value engineering undertaken for mainly financial compliance, can affect the original intended design and

concept. Respondent BS-01 identifies the issues of knowledge and competence across the construction process:

> **BS-01** – There is major knowledge lacking in all aspects including professional design consultants who are meant to be the ones who understand the systems, I would say there is knowledge lacking there, there's knowledge lacking in planners, contractors, their subcontractors, commissioning engineers and clients themselves who then go on to run the projects and their maintenance teams don't have any knowledge of how to run the system.

If, as is suggested by the survey, the design team is not, in most cases, following through the construction and installation process; dependent on the knowledge and expertise of the installation and commissioning teams, the revised design and subsequent installation may be flawed. Therefore, the need to understand this element of the process and how it is affecting the installation and commissioning process needs further research as part of the action phase.

Installation and Commissioning

The final sections of the interviews were constructed to explore the installation and commissioning phases of the construction, and how that influences the low carbon technologies. Respondent BS-01 reflected on the low carbon aspect and captured a common theme in the interviews:

> **BS-01 -** I don't think it's at the forefront of the build process it's just considered as another process they have to go through, so when constructing again it's based on cost and programme rather than what's the optimum solution. So therefore, it's treated as just another process the contractor has to go through that they have to provide certain information to demonstrate they've done certain processes that provides accreditation at the end, rather than actual proof and evidence that what they've done will achieve the desired outcome

This emerging theme confirmed an apparent lack of integration for the low carbon technologies. The low carbon approach is seen simply as an extension of the current construction process, and not one where a more co-operative approach could be adopted. This presents a situation where the requirements of many low carbon technologies to operate co-operatively is being missed by the elemental process nature of installation and commissioning. In not appreciating the often holistic nature of the combined technology operation, the individual process approach is delivering reduced efficiency. Therefore, the installation and commissioning process is directly influencing the early stage use of the technology and thereby has the potential to affect long term use and perception of low carbon effectiveness.

This is further illustrated by respondent C-01, where it is indicated that the attitude, which is often experienced within domestic construction, is one where the responsibility on the actual system to operate efficiently and effectively is not seen as part of the construction process:

> **C-01 -** It's easy to build a block of flats and it's easy to walk away from it, but does it really work? Well, who cares, that's what they say isn't it, it's just done they walk away and we're all left to pick the pieces up for the next 2 or 3 years trying to put it right. So, yes, I can't knock D&B it's how I earn my living.

There is a repeated theme emerging of 'making it work' and not necessarily engaging with the technology to ensure it is installed and commissioned effectively for the end user. At handover the system is 'working', however, whether that means effective or efficient operation is all too often not considered. This is then further impacted by the level of knowledge and experience during the construction period observed by respondent PM-01:

> **PM-01 -** Well it's like employing an electrician who hasn't got the relevant paperwork, because at first fix it not always needed therefore, he gets away with it. It's only when the qualified guy comes along to sign it off that you get your bit of paper, and because construction is a mixed bag of people you never really know who you're getting to do the work on the project

There is a clear indication of the perception of the mixed level of experience amongst the installation teams, and how this experience is distributed throughout the site. This theme of knowledge and experience was identified further by respondent C-02. As a site construction manager his insight into the process of learning with low carbon technology was enlightening in that it indicates the endemic construction problem of communication of ideas and knowledge:

> **C-02 -** Lessons learned always too late because always after the event. And we don't share the learning. We then don't pass on lessons learned to the next scheme because it's a different design, it's a different driver, it's a different output spec, it's a different set of requirements what the client believes they need, so you can't always transfer the lessons learned skills across. It creates exclusions in subcontractors orders, items missed is a grey area which we split the packages it's what affects us. Sometimes we end up splitting the packages too much and we end up with grey areas in the way we let the orders to get a gain and then you end up with a bigger problem trying to link them together.

This identifies a number of issues including the process of learning on the development, sharing of skills and subcontractor packages. The overarching theme is one of a fractured approach, where the contract process elicits an installation and commissioning procedure that is not co-ordinated, consistant or centred on the end user experience. There is a clear indication given by respondent C-01 of the perceived lack of monitoring and commissioning for low energy technologies:

> **C-01 -** Do they really monitor it? Does anybody monitor it? I don't think they do, I think they just, we get a concept the design is there it all gets thrown in and we'll bumble out the other end of the building with no time to spare. Does anybody actually check it's installed as it should be installed; does anybody check is it working as it should. On houses no.

Respondent C-02 went on to comment on his own experiences by stating:

> **C-02 -** I spend half my life arguing about handover process and having to go back and set things up. Every time we go back it's never as it was set up, if it was set up in the first place. I would say 90% of the dwellings that we leave have never been commissioned properly and that's us as a company.

This was not an isolated theme amongst the interviews; this un-coordinated and haphazard approach is seen from several of the respondents as well as the survey, focus group and historic construction data. Respondent HA-03 illustrates the longer term Landlord perspective for the commissioning issues:

> **HA-03 -** the system is not even two years old, there's no way that you would get that drop off in performance in 18 months, no way. So it hasn't been commissioned properly. And then the other side of it I just think goes back to the installation, it's not been installed properly.

This is also observed by PM-01:

> **PM-01 -** And still on there up to the 12 months defect because the subcontractor's not bothered to come back. There's an apathy there for that sort of quality

The emerging data illustrates a picture of fundamental issues at the stages of installation and commissioning which would suggest that, at best, domestic commissioning regardless of the size of the development is a 'hit and miss' process. This is consistent with

observations by Noyne et al (2013), who found that when reviewing their '5 primary steps to commissioning' (ibid) on commercial buildings that steps 1 – 3, is it there, is it connected and does it work are completed. However, steps 4 and 5, does it deliver and is it optimised, are not consistently applied. From the survey and interview data this would appear to be the same case on domestic developments. This is further illustrated by respondent C-01 in the statement:

> **C-01 -** Well I get a week to commission 60 dwellings and that's heat recovery units, HIUs [Heat Interface Units], all the blending valves everything. How do you do that? You can only do that if you had 60 blokes. But I've got 4. It doesn't work, so I get an hour a dwelling. How does that
> work? The guy runs round turns it on hot yep yep done out.

When questioned on defects C-01 went on to state:

> **C-01 -** In truth if every defect was reported I would probably need 100 engineers.

This is further supported by C-02 who states:

> **C-02 -** There's a big grey area between the middle where you get PC (Practical Completion) you commission it to a set of results which might not have been the most efficient but it works, and that's what your asked 'does it work'.

The evolving theme here is clearly one where domestic commissioning is based on a 'does it work' approach; any further investigation is not completed. Respondent C-03 illustrates the point of the ability and time on site during the commissioning and handover process to manage the subcontractors:

> **C-03 -** The boys on site will just sign off anything, because they've got a million things going on, I'm not having a pop at them it's just the way it is. So we need to help them by going on site and checking these things for them. And until that happens we're always in danger of just shoving bits of kit into a building, connecting it all up and hoping it will work.

Given these responses from the interviewees it is apparent that if this level of commissioning (or lack thereof) is being carried out across the domestic construction sector, it is not surprising the level of resident issues with low energy technologies. This further substantiates the findings in figures 4:17 and table 4.8, where there was a strong opinion on the effectiveness of commissioning and on the level of defects. Whilst there are many research papers on the issues of resident use of low carbon technologies, this additional element of the effects of installation and commissioning has its part to play in the overall short and long tern performance, and perception of the technology.

As an additional point of interest respondent C-01 made the observation:

> **C-01 -** on a commercial scheme you wouldn't dream of walking out of the building the day it's handed over, you would have a 3 months running, commissioning, we would have hours with you

> boys[Designers], we would spend so much money on commissioning, proving figures, writing it off, handing it over. You tell me that's going to happen there [housing projects], that will never happen in a million years

What is observed from respondent C-01 is the distinct difference between the approach of the commercial and domestic sectors, which was also observed by other respondents. On larger scale domestic schemes, where district heating system are commonly installed, to all intense and purpose, these buildings are serviced as commercial systems. However, the commissioning is still at the same level as the remainder of the domestic construction. What is of interest is that whilst it is expected that commercial commissioning will go on after occupation, to deal with the 'bedding in' of the system; within the domestic construction there is no on-going allowance. The issues of the already poor level of installation and commissioning observed in the interviews; is further compounded by the perception of early failure, which would otherwise be attributed to a 'bedding in' period for commercial developments. The theme of a lack of understanding of the complete process is evident within the interview text, and confirms the gap in knowledge centred on the effectiveness of the installation and commissioning processes. The interview data has given additional context to the survey opinions from the stakeholder groups, indicating an area for further exploration. Therefore, the action phase of the research cycle was designed to explore this area in more detail to understand the contributing structures and the possible opportunities to develop professional practice.

4.7 Reflecting on the Responses and Preparing for the Action Cycle

The reconnaissance phase of the action research cycle has allowed the exploration of the research subject in some detail. This systematic approach, as observed by Stringer (2014) allows for the production of knowledge that is credible and has potential 'to be replicated in other settings' (Ivankova, 2015:p44). O'Leary (2004) also points out that action research is more than just about implementation and relies on the production of knowledge and the enactment of change. The gathering of this varied data both from inductive and deductive sources has created a basis for the research and validity for the research subject. Bringing these strands of qualitative and quantitative data sets together will assist in informing and developing the next stage of the cycle. The interview and survey data is also used during the action and observations cycle to compare data and to find meaning to the emerging research themes.

4.7.1 Triangulation of the Data

Greene et al (1989) identify that triangulation of the information, by gathering data from multiple sources, increases the level of validity and reliability. This approach has been adopted throughout the reconnaissance and diagnoses phase to allow the deductive and inductive data to be reviewed together. Table 4.13 indicates the data gathering methods use and the identification of the linked themes across the data sets. The process of triangulation throughout the research has created a feedback loop to continually test, compare and reflect on the data produced.

Table 4.13 Triangulation of data gathering method used

Methods used	Gap	Intervention
Historic Projects Review Revealed	• Projects completed but with high levels of defects • Installation and commissioning issues	Past Projects
Focus Group Revealed	• Technology issues especially with heating and hot water generation • Management, planning and communication gaps	Focus group
Questionnaires and Stakeholder Engagement Revealed	• Lack of training in low carbon technologies • Little co-ordination between installation and commissioning • Few commissioning programmes in Low energy dwellings • Lack of co-ordination between design and construction professionals	Survey questionnaires carried out
Interviews Revealed	• Construction professionals highlighting lack of understanding of commissioning low carbon homes • Clients unhappy with performance of low carbon homes. • Inadequate link between design, installation and commissioning • No marked increase in resident satisfaction of low carbon homes	In-depth one – one interviews with sample respondents
Conclusions	• Develop link with installation and commissioning • Co-ordination for commissioning	Reflection

The triangulation of the data during the reconnaissance phase has demonstrated a clear theme of failure surrounding the installation and commissioning of low carbon technologies. A sustained thread of emergent data is the management and actual functioning process of installation and commissioning of low energy technologies. The semi-structured interviews have highlighted the perception amongst the stakeholder groups that there is a varied level of information and skills sets on the low energy projects observed. This is also conveyed against a tension of cost pressures, lack of management and programming and an inability or reluctance, on the part of the construction team, to engage in an effective commissioning process. The questionnaire supports these responses indicating that there are at least 65% of the respondents that consider that commissioning was not carried out effectively on site. It

was also seen that both in response to commissioning processes and the defects period, all three stakeholder groups were indicating an issue with the process. If this is compared with the historic project data and the initial focus group responses, this same theme can be seen throughout, with many of the past construction projects having on-going technical issues derived, to a greater or lesser degree, from installation and commissioning issues.

In analysing the responses from the construction site professionals, there was a clear link between the interview respondents and questionnaires on the theme of ‘making it work and walking away’. This tendency to indicate that there are activities lacking in the installation and commissioning process comes through the data strongly regardless of the stakeholder group information. This triangulation of the data therefore, gives a response to one of the early research questions rooted firmly in the reconnaissance phase of the research, namely:

> What are stakeholder perceptions of low carbon technologies in new construction developments?

The responses across all the data sets indicate a failing process, and one that is directly perceived as affecting the operation and performance of low carbon technologies, especially where these technologies have an ‘interactive’ element. There is also an indication that failing construction side performance is affecting the technology selected, and also the possible longer term ‘resident relationship’ with the technology. In comparing the emerging data gathered with the literature this has identified a gap in the understanding of the installation and commissioning process for low carbon technologies, which needs further exploration. Figure 4.21 demonstrates the four key areas identified from the data where interventions could be developed to improve professional practice and the performance of low carbon homes.

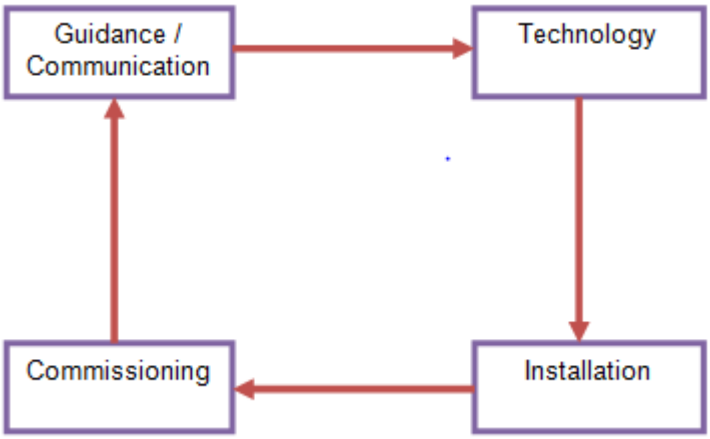


Figure 4.21 Key Areas for Intervention

For the planning of the action research cycle, installation and commissioning were the main research areas, however, the relationship with communication and technology was also part of the research to give further insight within the action phase. Limitations on the areas to be covered and the priorities for the limitations to the research, in the action phase, are discussed in Chapter 5.

4.6 Chapter Reflection

This chapter has defined the subject of the research through a systematic process of exploration by both inductive and deductive analysis. The multiple data sources have developed a 'rigorous and cohesive set of conclusions' (Ivankova, 2015:p46) about the research topic that are used to inform the action phases of the research cycle. The triangulation of the data, as suggested by Sagor (2005), has enhanced the credibility of the research findings to make a more 'feasible and reliable action plan' (Ivankova, 2015:p46).

From a critical perspective the structure and length of the questionnaire may have affected the level of responses from the stakeholders. Gillham (2000) refers to this and advises a

review during the pilot process, which was undertaken, but was not as successful as intended on the final question numbers selected. On analysing the questionnaire structure at the end of the process the whole survey could have been reduced to 10 questions, with the focus more targeted on the research questions. This is best illustrated by the fact that of the 28 questions set; only 10 were solely based on the research question (not including the initial identifier questions in section 1 of the questionnaire). The remainder were peripheral questions that could have been removed from the main questionnaire. This has not detracted from the level and quality of the responses and therefore the validity. However, more responses would have added to the richness of the data and increased perspective.

It is also to be recognised that in broadening the level of the questions and interviews the researcher has risked moving outside of the research boundaries. This was a constant concern within the research, and one which needed a ‘correction of course’ on a number of occasions. This has been dealt within the research by identifying the topic raised, assessing for direct value within the research context, and where outside the research parameter is left for a future research project. It must however, be observed that peripheral topics have had an influence on the research outcomes, and this will be investigated in the chapter on findings.

Another area of possible criticism is the limited number of semi-structured interviews undertaken. This could have been extended if additional research assistance had been used, or a greater time given to the interview process. There was a concern that additional assistance could affect the responses, as the trust element with each of the interviewees was a key point of securing the interview. However, with the time constraints of the professional doctorate, and the limited resources to conduct further interviews, the eventual

selection of 11 candidates across the stakeholder groups, did yield sufficient descriptive and rich data to be both valid and reliable in use within the research analysis.

Triangulation of the data has been the most effective process in illustrating the validity and reliability of the data. Having been gathered from several sources the comparisons have identified key themes to take forward to the next stage of the action cycle. The exploration has also opened emerging themes not considered at the start of the reconnaissance phase. The relationship between passive and interactive technologies may explain more about the way these technologies are installed and commissioned, and also how they are ultimately viewed as part of the construction processes.

Reflecting on these areas gives a developing perspective of the construction process and the role each of the stakeholders play in the eventual end product of the low carbon home, with its technology link. This will be further investigated as part of the next stages of the action cycle and will develop with the interventions to be explored.

Chapter 5

The Action Research Cycles – Plan for the Site Observations and Interventions

5.1 Introduction

In this chapter the planning and action cycles of the research established in the reconnaissance and diagnoses phase, investigated in the last chapter will be explored. It describes the planned strategy for the action cycle, and the development of interventions to effect the change process for professional practice in low carbon homes. The planning and action stages are critical to giving structure to the action cycle, and to chart the intervention strategies emerging from the observations of site installation and commissioning activities. Triangulation of the qualitative and quantitative data will be used to assess and reflect on the observations and applied interventions. These reflections will also draw on the data from the reconnaissance phase and discover new perspective from the emergent themes and data in the action cycle.

The chapter will detail the planning stage of the cycle and the engagement with the various stakeholder groups within the construction process. The planning and action phases will concentrate on the installation and commissioning activities with low carbon technologies, as this is the extent of the research parameters, However, where other influences are observed within the research, these will be commented upon, but will not form part of the direct research area. As indicated in chapter 4, reference will be made to the research being undertaken within the researchers professional practice, where this is recorded it will be referred to as ‘The professional practice’ or ‘the researcher’s professional practice’ for clarity.

5.2 Focusing on the Plan

McNiff et al (1996) and Gray (2011:p319) observed that an important step to identifying a suitable research focus is the sense of a ‘commitment to improvement’ (ibid). That commitment needs to be a core function of the activities within the action cycle, to ensure a focus is maintained and outcomes are achieved. It is suggested by Stringer (2014), that the action plan should consist of a number of tasks and activities that assist the practitioner researcher to achieve a resolution to the area they are investigating. In this way, the tasks can be treated as key steps to target both the activities and the interventions as they develop out of the research cycle (Ivankova, 2015).

The research plan has been constructed in stages based on the areas targeted for improvement by the practice, derived from the reconnaissance and diagnoses phases. The plan was focused on the research questions as key points throughout the observations and interventions. Emergent from the research and data gathered was a core theme for the improvement of installation and commissioning activities, to facilitate a more structured approach to low carbon construction processes. Direct observations and engagement with the stakeholder groups was seen as key to the targeted improvements; thereby generating the data, through close working involvement, for the analysis and refection at each research stage. The structure of tasks as key steps as advised by Stringer (2014) was adopted throughout the research cycle, and are further indicated in (Figure 5.1), detailed later in this chapter. Stringer (2007) also argues that it is important that all voices are heard in the process, and for this reason observation were made throughout the construction hierarchy to obtain perspective and understanding of the varying agendas of each group. These observations have also been compared with the interviews and questionnaires carried out and recorded in chapter 4, enabling comparison to the wider stakeholder viewpoints.

5.2.1 Defining the Plan

The preparation and planning work undertaken in the reconnaissance phase has formed the basis for further developing and defining the plan for action. The culmination of the data gathered from the early focus group meeting, survey and interviews has established the need for further research, which the action phase continued to uncover and illuminate as part of the interventions strategy. To give direction to the research Gray (2011) categorizes a set of key focus areas established as part of the plan, these are identified as:

- Why is the activity required
- What actions need to be taken
- How are the tasks to be completed
- Whom is responsible for each activity
- Where are the tasks to be performed
- When are the activities to commence and be completed

  (Gray, 2011:p319)

The first key area, and to an extent also including the second, has been identified and explored in chapter 4. This has focused the research on the installation and commissioning process for low carbon homes. From the output of the triangulation of the focus group, surveys and interviews there is an identification of the initial actions that need to be taken. These are concentrated on the site activities for installation and commissioning; both to establish the start of the process, the actual installation and commissioning period and the outcomes at the end of the procedure. To understand what is happening, during the process, a range of key steps and activities needed to be established (Stringer, 2014):

1. Identify the key stakeholders and location for the research
2. Engage with key stakeholders and establish trust and co-operation for the research study
3. Agree a procedure for observation and recording of data from the site activities
4. Observe and recording of the construction process for installation and commissioning
5. Observe the interactions between stakeholders during the site processes
6. Observe the communication of tacit and explicit knowledge transfer during the site process between the key stakeholders
7. Record commissioning outputs and stakeholder engagement during the process
8. Develop co-operation throughout the process and maintain ethical perspective on the processing of data from the research
9. Discuss interventions with the stakeholders and review outcomes of the intervention

A benefit of the professional doctorate process, in establishing these core activities, is the position of the researcher within the research area. The professional practice has enabled the 'insider research' perspective to be established quickly; with access to the stakeholder groups, already established through professional relationships and networks. Therefore, these established relationships have drawn on prolonged engagement in the research area, enabling a unique practitioner researcher perspective to the research problem.

There is however, a note of caution to these relationships and the potential for bias, which must be acknowledged and considered during the research process. Within the plan the research bias has be dealt with in four ways.

Firstly, the selection of sites and access has been arranged using both developer and constructor approval and selection. This avoids the possibilities of refused access to a site

where the outcomes may be considered unfavourable to a stakeholder or the researcher. (Appendix 6) indicates the permission form used for access to the projects.

Secondly, as a practitioner-researcher there has been prolonged time spent in the field, over many years, observing the process of construction, and in particular activities with low carbon technologies. This therefore, gives a wealth of knowledge within construction from which to draw and to gain further understanding.

Thirdly, all installation and commissioning observations have been shared with the stakeholders to seek a consensus on the information recorded. This has been undertaken by sharing observation notes and photographs, and arranging and attending installation and commissioning workshops to discuss observations and outcomes. It must be identified however, that consensus was not always achieved throughout the groups, and where this has occurred this is recorded, along with the effects within the research, as part of the analysis chapter.

Lastly, and in line with the action research structure, reflection has been used to critically analyse the research. Creswell (2013) observes, in his eight primary strategies to achieving validity, that reflection is an integral part of the qualitative process, and should contain the researcher's interpretation of the findings, and how they are coloured by the researcher's background, opinions, relationships to the research and experience. Herr and Anderson (2005) and Ivankova (2015) also recognise the role of reflection from the stand point of practitioner–researchers; suggesting that interpretations are recorded alongside observations as part of the reflective cycle. To identify and manage bias as well as strengthen the means of assessing legitimacy, the strategies for validation taken from Creswell's (2013) list, include triangulation, member checking, prolonged time in the field

and lastly reflection. Table 5.1 identifies each of these strategies for validation of the construction site activities, and the method undertaken as part of the planning and action stages of the research cycle.

Table 5.1 Planning – Activity and Validation Processes for Action Cycle

Activity and Validation Processes	Triangulation	Member checking	Prolonger time in the field	Reflection
1.Identify the key stakeholders and location for the research			Use current clients and contractor projects to enhance insider research role	
2.Engage with key stakeholders and establish trust and co-operation for the research study			All client and contractor contacts from 2007 – Also engaged in diagnoses stage of research	
3.Devise a procedure for observation and recording of data from the site activities	Qualitative / Quantitative data collection – Observation and data from commissioning	Reviewed with each stakeholder		Reflect on the procedure for recording site activities
4.Observe and recording of the construction process for installation and commissioning	Qualitative data from observation records	Reviewed with each stakeholder		Reflect on observations and interventions
5.Observe the interactions between stakeholders during the site processes	Qualitative data from observation records	Reviewed with each stakeholder		Reflect on the interactions processes
6.Observe the communication of tacit and explicit knowledge transfer during the site process between the key stakeholders	Qualitative data from observation records	Reviewed with each stakeholder		Reflect on communication during commissioning
7.Record commissioning outputs and stakeholder engagement during the process	Quantitative data from commissioning results	Reviewed with each stakeholder		Reflect on link to commissioning results
8.Develop co-operation throughout the process and maintain ethical perspective on the processing of data from the research		Reviewed with each stakeholder		Reflect on ethical process and data returned
9.Discuss interventions with the stakeholders and review outcomes of the intervention	Qualitative and Quantitative data review			Discussion with stakeholders during and after interventions

5.2.4 Engagement with the Key Stakeholders

Following the structure of stakeholder investigation and reconnaissance in chapter 4, the same key group structure has been adopted as part of the plan for engagement and observation throughout the action phase. From the perspective of the researchers practice, this has enabled the cycles of investigation and interventions from the stand point of the building services consultant (Designer), housing association, project manager and developer (Client) and main contractor and subcontractor (Construction). In this way the interventions have been developed and assessed for their effectiveness for the researcher's professional practice, and the possible longer term effect on the construction process.

Within the researcher's professional practice the engineering design team was engaged by the researcher to collectively review the process for recording installation and commissioning data This review had developed from the reconnaissance phase where it was identified in figures 4.16 and 4.18 that monitoring and site involvement on low carbon projects was low. The design team's involvement with the research project had been established within the survey and interview reconnaissance stages, and earlier participation in the focus group and review of historic projects. Therefore, using and combining the data already collected and detailed in chapter 4, opinions on the construction processes could be used as part of the development of the planning phase.

The review was undertaken in a single workshop, led by the researcher, to categorise the range of recording processes across the professional practice, and to understand how the primary information was communicated between their relevant stakeholder groups.

Table 5.2 Installation and commissioning Inspection recording processes and communication routes

Type of correspondence and method of transmission of Information	Email	Hard copy posted	Hard copy distributed at site meeting	Uploaded to document website	Part of BIM process
Verbal communication of inspection	**FU**	*	*	*	*
Inspection notes	**FU**	**NoU**	**NoU**	**NoU**	**NoU**
Informal Inspection Report	**FU**	**NU**	**NoU**	**NU**	**NU**
Formal Inspection Report	**FU**	**NoU**	**SU**	**SU**	**NU**
Pro-forma Report for use from Contractor	**NU**	**NU**	**NU**	**NU**	**NU**
Pro-forma Report for use from Client	**NU**	**NU**	**NU**	**NU**	**NU**
Pro-forma Report for use from the Professional Practice	**NU**	**NU**	**NU**	**NU**	**NU**
Photographs of Inspection Areas	**FU**	**NU**	**NU**	**NU**	**NU**
Pro-forma commissioning check list	**NU**	**NU**	**NU**	**NU**	**NU**
Commissioning Notes	**FU**	**NU**	**NU**	**NU**	**NU**
Post Commissioning Review	**NU**	**NU**	**NU**	**NU**	**NU**
Post Commissioning Completion Issue Sheet	**NU**	**NU**	**NU**	**NU**	**NU**

Note:

FU – Frequently Used
SU – Sometimes Used
NoU – Not often Used
NU – Not Used
* Not applicable

As seen from Table 5.2, the list of documentation actually used on the construction projects reviewed within the professional practice is minimal. Most, if not all, communication for installation and commissioning is via email and is of an informal nature. Predominantly informal note taking and sporadic formally issued reports (reports requested with agreed format and structure) are the main avenues of communication between the designer and the construction site teams. Document management platforms are used on projects for initial design information to the construction issue stage however, are seldom used for recording or monitoring installation and the commissioning processes. The primary routes of communication for reporting installation and commissioning issues were determined as

between the designer and client on client led projects, and between the designer and constructor on direct engagement to the constructor. In both cases the contracts were design and build; meaning design and construction responsibility remained with the constructor. However, in the former the engagement was mainly as checking consultant for the client, and in the latter designer for the contractor up to construction issue of information. It became apparent from the diagnostic stage that there is little control or management of communication for installation and commissioning stages. It was also apparent, that where engaged as designers by the contractor on low carbon schemes, there were few occasions where the professional practice had an installation and commissioning checking role. This can also be observed in Table 4.2, where the review of schemes completed over the last 5 years, indicated very few monitoring roles commissioned by contractor engagement. In these cases site reviews were instigated by a design or installation issue and were, as a consequence, purely reactive in response to a site issue.

The workshop feedback indicated that communication between site and design office was, for the most part, explicit written instructions; generally conveyed in a formal instruction for design queries, and informally for installation and commissioning issues. However, from the installation perspective they were conveyed at a site problem point and not as part of a proactive aid or process to the installation of the technology. This in itself is not a primary issue, as the site instruction process, Request for Instruction (RFI), is part of the contractual arrangement for communicating and instructing the change process. However, what is not conveyed in the instruction, which is then subsequently seen on site, is the instruction engages a process, which then uncovers the installation standard that therefore, instigates further investigation. A key area, which came out of the workshop feedback, was that it is often attending site for an unrelated instruction issue that first highlights installation issues, which would otherwise have been hidden by the process of the site construction. This

highlights hidden installation issues creating operational or efficiency problems, which do not become apparent until much later in the project, or during operation by the resident. Cole and Jones (2016) highlight this point in the post occupancy monitoring of communal heating systems, where operational inefficiencies and poor energy performance is as a direct result of the errors at the installation and commissioning stages. Cole and Jones suggest that the use of extensive data gathering on district heating systems, utilising combined heat and power, is emphasising the under performance stating ‘we hadn’t appreciated the extent of the problem and how bad the performance was on the majority of sites’ (Cole and Jones, 2016:p34). Therefore, pre-intervention, the issues emerging from the design perspective were focused on the level and timing of involvement on the installation and commissioning activities. This revealed a new perspective around the level of information, timing of involvement and method of exchange of communication, rather than a complete lack in any one of the three areas. The primary consideration for intervention therefore, from the designer perspective, was to observe the site reporting process and to evolve, through interaction, an early proactive stance for information sharing for installation and commissioning.

Reporting at the installation stage also revealed that the main instances of site installation issues were with low carbon heating and hot water technologies. These include heat pumps, heat recovery ventilation and district heating systems. As already identified these technologies require a greater degree of interaction on the part of the installation and commissioning teams to put into operation. Therefore, observations of these activities were planned as part of the intervention process to build and evolve an understanding of where, in the process, the problem of installation developed. This allowed for the intervention to be emergent from the process, as a consequence of cooperation with the stakeholders, as opposed to being imposed on the construction activity.

Combining the research process with the stakeholder groups, the professional practice (Designer), engaged with both the developer/HA and project management groups (Client), as well as the construction teams (Constructor). In bring the three groups together this permitted the research to gain insight into the processes from the construction stakeholder's different perspectives. Client and constructor engagement was initiated through a selection of the existing schemes with which the professional practice was invovled, and where observation of site installation and commissioning activities could be undertaken. The client and constructor stakeholder groups were approached on the bases of the initial plan of observing and recording the selected sites. The data was then used, along with the survey and interview results, to engage in an intervention strategy to improve the installation and commissioning processes for the low carbon technologies.

5.2.2 Selection of Construction Sites

Three prominent Housing Associations (HA's) were approached via an informal meeting for installations, which involved district heating utilising combined heat and power (CHP), mechanical ventilation with heat recovery (MVHR), air source heat pumps (ASHP), and photovoltaic (PV) panels. The housing associations were chosen from amongst the organisations that were contacted through the survey, and that predominantly work with the professional practice. This was considered as the most effective way of engagement with the stakeholder groups from the insider research perspective, taking the role of the practitioner researcher. Gray (2011:p402) identifies that this is an ideal position to understand the 'culture, strengths and weaknesses of the organisation, as well as its developing needs'. The approach was centred on project commissions that had already been secured by the professional practice with the Housing Association, and that were at an early and intermediate period in the installation and commissioning process. As identified in

the reconnaissance phase inspection and site monitoring of M&E installation and commissioning is not common in housing construction. These early commissions proved useful for access and collecting the research data, without the requirement for special arrangements at site with no connection to the professional practice.

All three HA organisations expressed a willingness to be involved in the review, and it was confirmed that all information used would be treated sensitively, and compliant with the ethics approval obtained through the university (See chapter 3). Therefore, no site, contractor or client is identified in the action research and all stakeholders referred to in the text are given either numeric or text based codes to ensure source and location cannot directly be identified. The main contractors of each of the selected sites were approach to gain consent to observe, record and initiate the action research process. It was made clear to the main contractors approached that, regardless of the HA approval to use the site, the information would not be used if not agreed with the main and subcontractor teams. It was also further identified that non-participation did not affect the relationship and contractual arrangements with the HA, as this was a research project based on voluntary and confidential involvement. Mechanical and electrical subcontractors were also approached under the same premise as the other stakeholders for voluntary involvement. The following guidance and commitment was given to all participants before any observations or interventions were undertaken:

1. All participant site to be given a code number with location given by region only
2. All observations to be coded with no information given on site specific location, name or company names of the construction and client teams.
3. Where commissioning data is used the location and site identifying information was removed from the photocopy or tabulated information

4. Confidentiality maintained throughout the process

Bailey (1996) contends that one of the best ways of gaining entry for the observation process is through building relationships with individuals that play a key role in the process, and who can also give access. To this end, positioned within the role of 'insider researcher' sites, constructors and clients used by the professional practice have been engaged for access and observation. However, it must be recognised that in taking this approach bias and reactivity (between researcher and those being researched) through observation does present a challenge to the research (Gray, 2011). This challenge is, to an extent, increased by the use of overt participant observations. In this case there is a danger that the observer and observed could become influenced, not by the activities, but by 'preconceived ideas and mental constructs of the researcher' (Gray, 2011:p397). The research plan has therefore, been constructed, as noted in (table 5.1), to use mixed methods to review and interpret the data. This is consistent with the research methodology and commensurate with the theoretical perspective adopted. In this way the triangulation of the data will increase the validity and reliability of the results and subsequent analyses. McNiff asserts that the role of action research is to recognise the problem and look for solutions 'not accepting the status quo' (McNiff, 1988:p50). In this way the strength as well as the potential weakness, of the insider researcher, is to be close to the problem. This closeness however, must remain objective to enact the process of change. Therefore, accepting that this potential for bias exists as a practitioner researcher, working on the inside of the problem, field notes for observations have recorded not only the observation, but the thoughts of the researcher at the time of the observation.

The sites were selected to include developments with phased completions, these being sites where several blocks of low carbon dwellings are constructed in staged completions. This

method was selected to enable comparisons to be drawn between the phased works, and to observe any changes from the interventions. This also permitted longer timescales for involvement with the stakeholders, enabling development of trust and working relationships to be gained to enable development to the interventions applied. Patton (2002) states a self-evident point in that the fieldwork should take as long as required to get the job done. However, there is a limit to the timescale within the professional doctorate, and whilst the development of further solutions will go on throughout the practitioner's professional life, 'getting out' of the research, as suggested by Gray (2011:p415), needed to be considered within the plan. Therefore, in selecting the sites the phase nature of the development allows for a single phase or multiple phases to be selected for the research period. This has been undertaken on each of the sites to enable reflection on the different intervention aspects of the action research and to observe the construction stages. The nature of the relationship with each of the stakeholders has also permitted the observation of the interventions from different stakeholder perspectives. Table 5.3 highlights the sites selected and the stakeholder engagement structure for the research.

Table 5.3 Sites Selected and Stakeholder Engagement Structure

Detail of Site Selected and Code Ref.	The Professional Practice Engagement	Stakeholder Role for Designer	Stakeholder Role for Client	Stakeholder Role for Constructor
S1 – 300 units, 2 phases. Exhaust Air Source Heat Pumps. London and Southeast. Code 4 scheme	Client HA engagement for inspection and commissioning review	Third party designer for contractor. No site inspection role	**The Professional practice review of installation of low carbon technologies**. Development for HA for rented and sales units	Main contractor Design and Build. Single joint M&E contractor for all building services
S2 – 750 units, 6 phases. District heating system with CHP, MVHR and PV. London and Southeast. Code 4 scheme	Contractor engagement under Design and Build contract as designer	**The professional practice as designer. Design of M&E services phases 2 – 6** with phase 1 by another design team	Joint development for HA and development contractor. Rented with HA and sales units shared by both	Main contractor Design and Build. Single joint M&E contractor for all building services
S3 – 550 units, 3 phases. District heating system with CHP, MVHR and PV. London and Southeast. Code 4 scheme	Client HA engagement for inspection and commissioning review	Third party designer for contractor. No site inspection role	**The professional practice review of M&E installation and low carbon technologies**. HA for rented and sales units	Main contractor Design and Build. Separate M&E contractors for building services Specialist contractor for communal PV installation

As a result of the plan for the observation of each of the three sites, it has been possible to compare the actions on each site to gain a further understanding of the issues. However, timescales have not allowed the interventions from all of the sites to be trialled on one complete site, this will therefore, be left to future research to develop further. This could be interpreted as a potential weakness to the research, and if taken outside of the context of continuing long-term involvement within the construction field, could have been an issue. However, the benefit of the professional doctorate and the role of the insider researcher is the on-going involvement in professional practice. Therefore, this allows for the research to continue and develop post professional doctorate completion.

5.2.4 Engagement with Construction Main and Sub-contractors

In planning the action research cycle with the majority of the activities taking place on the construction site, engagement with the main and subcontractors needed to be considered in detail. Arditi and Chotibhongs, (2005) identify, as seen in chapter 2, that the relationship between the main contractor and services subcontractor has always been, and continues to be at best, a fraught and confrontational affair influenced by cost, quality and workmanship. Establishing trust, as suggested by Wong et al (2005), is a critical success factor in construction partnering with 'performance' (competency and problem solving) and 'permeability' (openness to share information) being key to a successful project outcome. Early involvement within the research plan was critical in achieving active and positive engagement from the construction site stakeholders. To this end, each of the main contractors and mechanical and electrical subcontractors, were approached for their permission at the same time as client housing association support was requested. The structure of the research was discussed with each of the contractor groups, and the stipulation on confidentiality was made from the start of the process. The discussions took the form of a short meeting on site, where our presence was already established as either the M&E designer or in an inspection and checking role on behalf of the housing association. It was apparent from the discussions with the building services subcontractor groups that they were predominantly structured as small companies, or self-employed individuals operating under the banner of a company name. This concurred with data observed by the Office for National Statistics (2015) where such companies and sole traders make up at least 85% of the M&E subcontractor workforce. Therefore, agreement to observe activities, although agreed at the client and main contractor level, needed a constant process of approval if the subcontractor member changed, as was sometimes the case. It was made clear at each of the sites the difference between the contracted

inspection arrangements, to be undertaken by the professional practice, and additional research observations made during the inspections, or at separate observational visits. It was also confirmed to all stakeholders that all information used in the research would be confidential. The following protocol (see appendix 8 for sample observation notes) was used on each site to ensure confidence was maintained:

1. Installation or commissioning contractor's names not recorded
2. No location specific details recorded on the observation sheets
3. Where photographs were taken these were of the issues observed and did not include location specific information
4. Any notes taken during the observation shown to the stakeholder in full
5. No audio tape or video recording were undertaken on the construction site
6. Standard contractual site inspection reports, where undertaken had all identification information removed before using in the research
7. Any e-mail communication used in the research had all identification information removed before using in the research

There were no direct refusals for observations, however each time an observation visit took place it was re-asserted by the researcher, that all information used outside of the development was in confidence. It was further stipulated that any confidential statements made by the stakeholder during an observation would remain confidential, and would be used anonymously within the research.

The issue of the conflict of interest was discussed with all stakeholders as research was carried out within the actual 'real world' construction process. One of the observation sites instigated a confidentiality contract for all information used; the professional practice

adopted this process. The remaining sites required confidentially for the research reporting however, as it was an action research project, they welcomed the opportunities for intervention and change for the construction site. Therefore, whilst at the site level information was shared on intervention activities, within the research document confidentiality has been maintained to protect the companies and their employees.

Figure 5.1 indicates the structure for the plan of action at the start of the action phase, as discussed earlier in this chapter; the plan has been structured to develop emergent interventions from the action cycle. Ivankova supports this by pointing out that action research should be both ‘collaborative and participatory’ (Ivankova, 2015:p58), therefore, the nature of the construction project lends itself to participation through learning out of action.

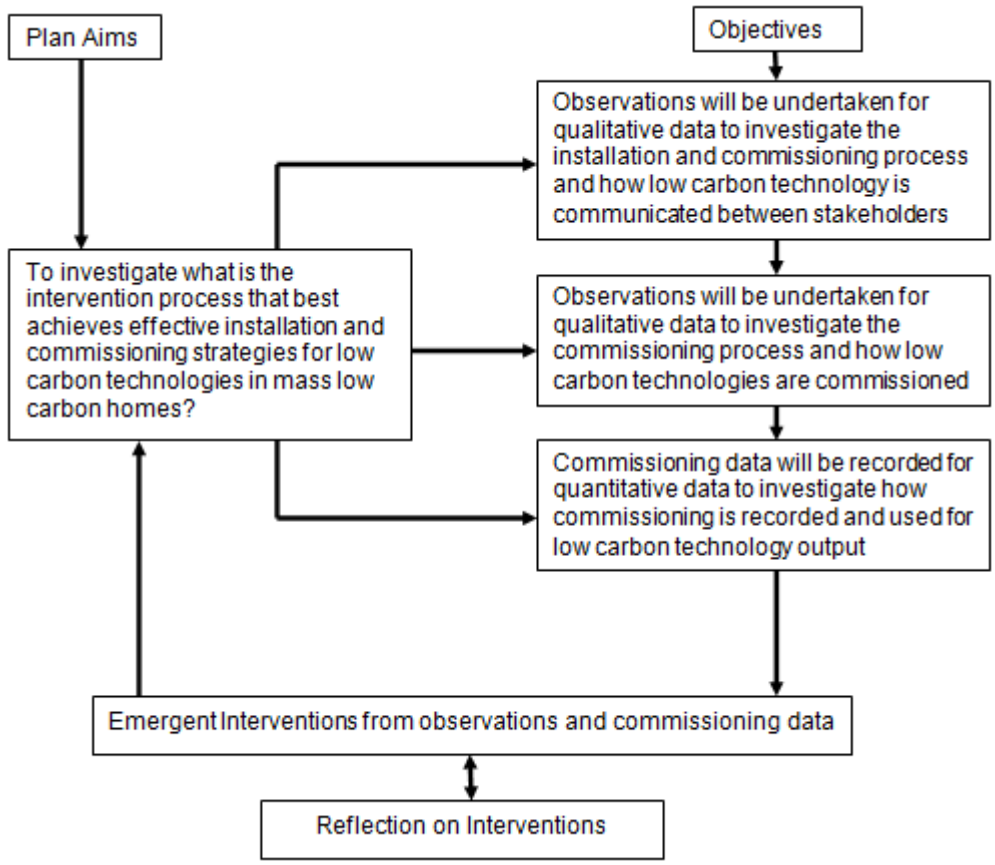


Figure 5.1 Plan for Action and Reflection Cycle

The research questions were used as the framework and boundary of the plan and action phases, keeping the actions and interventions focused on the aims and objectives of the research. Reflection on each of the intervention stages has been essential as part of the research cycle. As Herr and Anderson point out 'self-reflection is the hallmark of good practitioner research' (Herr and Anderson, 2005:p47). Therefore, the plan has included for both reflection of the actions as well as self-reflection and examination to enhance the validity of the research.

5.2.5 Reflection on the Plan

The Planning stage has evolved from the diagnoses and reconnaissance phases of the research cycle. The establishment of the 'who, what and where' questions, vital to the planning stage, has enabled the development of the stakeholder engagement, data collection methods and research location. Mills (2011) recommends that through the process of the critical examination of a professional practice the reflective stance is important to self-development and change. Therefore, every opportunity has been taken to critically reflect and identify the strengths and the weaknesses of the plan, to enable further development through the action cycle.

As observed by Dickens and Watkins the action cycle has a tendency not to be as neat and tidy as the cyclical structure suggests 'it can go forwards, backwards, and in all directions at once' (Dickens and Watkins, 1999:p135). This has been experienced throughout the research cycles as the construction process, by its very nature, is seldom set up to allow a completely orderly process of investigation and research. Cancelled meetings and commissioning reviews have been a regular occurrence, as have been changes in staff or the withdrawal of assistance when site conditions have become difficult or obstructive. Therefore, the field notes have recorded where this has occurred and made observations on the reflected outcomes.

Difficulties have been experienced in the setting up of the plan, not as expected from refusal to participate, but from disengagement and disinterest in the process and during data collection. An observation of the construction process from the insider perspective, as supported by Bishop et al (2008) and Smith (2001), is that M&E subcontractors are predominantly small companies where time constraints are imposed and information transfer

capability, where not directly project related, are not often seen within the working culture as important. This lack of cultural importance is therefore a key area for the disengagement observed on the projects, which to an extent, during the research was only partially overcome. The element of ‘catching the butterfly’ (Smith, 2001:p311-321), when alluding to the difficulty of subcontractor engagement, has been witnessed throughout the data collection process, and as a consequence, is noted in the observations.

During every stage of the research, trust between the main and subcontractors has been one of the largest hurdles to overcome. Establishing ground rules and the extent and scope of the research has been important for the engagement to be achieved and the evidence to be gathered effectively. Wong et al (2005) also identify, the need to understand the role that trust plays in the contractor partnering and management relationship which has both academic and practical value, especially when looking at the complexity of the delivery of low carbon homes. Whilst the struggle to maintain the focus of the research with the stakeholder groups has been a challenge, the structure and ‘voice’ of this action of disengagement formed an illuminating part of the research. It must however, be observed that this has not been to the detriment of the research. Instead, the sometimes disconnected nature of the contact, coupled with allowing the past and present data to interact, has elicited new meaning and direction to the research area. This is a professional doctorate undertaken within professional practice and thereby conducted in the real world. Therefore, this occasionally disjointed and often flexible approach has been expected, although from a data gathering activity, not always welcomed.

Action research, as with all forms of enquiry, are value laden (Ivankova, 2015), and as such the questions of who and how one benefits from the process need to be considered. From the practitioner researcher perspective the research has benefits from improving the

professional practice, and as such, the plan has been constructed to gain this insight. However, the plan must also accommodate the stakeholder perception of the same change process, thereby widening the benefit scope. As evidenced earlier in the chapter, from the questionnaire and interview data, formal processes for inspection and monitoring of commissions for M&E services are not common in housing construction. Therefore, the observations reflect access to a small selection of sites. However, this access, through the lens of the insider researcher, gives insight into the construction process, and to interventions that may have wider influence across this sector of the construction industry.

The plan for intervention, even when the intervention is for a positive change process, may not be viewed as such by all participants. The practitioner researcher needs to accept and record these conflicts during the action stage, and witness what effect they have on the results and interpretations given to the research. Bias has been highlighted earlier in this chapter however; observation of potential bias needs to be a continual part of the research.

An additional element of weakness in the plan could be considered as the number of sites that have and can be observed. On reflection more sites could have been brought into the observations section to enable a wider sample to be drawn on for the interventions stage. However, timescale has been the main issue with widening the site observation, and as Berg (2006) observes every hour spent in the field takes up to 4 hours to write up. Therefore, using sites that are of a phased nature, and further utilising the historic data in the sites from the diagnoses and reconnaissance phase has been selected to enrich the data collected. This is considered as a benefit for the professional doctorate, in that, the research area is already derived from an extended period spent in the field. Gray (2011) supports this by identifying that practitioner researcher's benefit from access and in-depth knowledge of the research area. Past experiences, where relevant to the research, are used in the action

refection cycle, to be gained further perspective to the observations. This continual reflection from the professional practice standpoint identifies the on-going nature of the research as part of the role of the practitioner. This will therefore, extend the involvement within the professional practice to continue to develop the interventions cycle as part of the on-going professional practice research in this area.

Chapter 6

The Action Research Cycles – The Site Observations

6.1 Taking Observations at the Sample Construction Sites

Having constructed the plan for the action cycle the next stage of the research has engaged with the stakeholders through observation and intervention. Having identified the three sample construction sites an initial meeting was conducted at each site to set out the observations process, detailing the objectives of the research. Ivankova (2015) points out that co-operation with the stakeholder groups is essential within the action cycle, and engaging in the research through participation permits valuable data to be gained from the process. The site observations were conducted as part of the normal site activities for the professional practice, not constructed to be stand alone or 'specially' arranged. In this way, it removed the impression that the research was for special or disconnected activities, but was to be immersed in the regular site processes. McNiff asserts that the role of action research is to recognise the problem and look for solutions 'not accepting the status quo' (McNiff, 1988:p50). Therefore, in engaging in what is considered as the 'normal activities' of the construction process, the emergent interventions are relevant to the stakeholder groups. This relevance was important to the research and the outcomes if longer-term solutions are to be enacted within the construction process.

6.1.1 Getting Started on the Observations

The research was conducted where there was already an engagement with the professional practice positioned on either the client/developer side or the construction side. This arrangement benefited from existing stakeholder relationships and availability of access to all stakeholder groups. Each of the schemes, when the research commenced, was at or before the ‘first fix’ services stage (this being the point in the project when building services installation commenced). In this way, each of the 3 developments could be seen from the same starting position and be followed through the construction process. At the first meeting, an outline of the research and method of observations was given to all stakeholders to enable an understanding of the process and the development of outcomes. Appendix 7 gives an example of the site meeting and the recorded outcomes at the start of the process.

The role of practitioner researcher had a positive effect within the sample sites from an early stage compliance perspective, as the research was seen as part of the day to day activities undertaken. However, this did only represent the viewpoint of senior members of the stakeholder groups, normally attending the site progress meetings, and not the individual installers engaged as part of the observations. Here the setup of the observation role was sometimes seen as an additional critique of their activities, and thereby detrimental to the individual ability to complete their programme.

The arrangement of the observations therefore, needed to be conducted with clear delineation between the requirements of the contract, and the objective of the research to improve professional practice. This was achieved by keeping the research observations and commissioning data gathering separate from the contractual activities of inspection. In

addition to this, the data gathered during the observations was shared with the installers and other stakeholders, maintaining anonymity, in an effort to gain trust and co-operation in the processes. Therefore, this enabled engagement at the key stakeholder level to discuss the results and develop interventions that could be incorporated within the site activities. In this way, the contractual obligations on the trial sites were not directly affected by the trial interventions.

6.1.2 Observations of installation and Commissioning Process

This section will look at each of the 3 trial sites indicating the results from the observations of the installation and commissioning processes. The section concludes by drawing together the results to enable reflection on the interventions for the next action cycle.

Field notes were taken at each of the sites as the method of gathering qualitative data. Figure 6.1 indicates the data gathering process. Bailey, states that field notes are the 'backbone of collecting and analysis field data' (Bailey, 1996:p80), they have been used to collect primary observations, reflections and analysis (Gray, 2011). In collecting the data, suggestions on structure by Berg (2006), have been used to ensure accuracy of the record. This has included:

- Recording key words and phrases
- Sequencing events
- Concentrating the observations to minimise unwanted data
- Writing up notes immediately after the observations

Observation notes were taken only when the subcontractor was present for the inspections, and these notes were kept separate to the inspection process. The observation notes were checked with the subcontractor after the observation to ensure comments were interpreted correctly. Reassurance was required at the start of the process on all the sample sites, to ensure information was confidential and would not form part of the inspection report. Once this was achieved, the observations were conducted in an open and cooperative manner. This said, there were several refusals for observations notes to be taken based on trust issues between the sub and main contractor, and therefore, the refusals were accepted and are recorded as part of the research.

Each set of observations were recorded using field notes, thematic analysis was used to gain an insight to the data. Braun and Clarke suggest that thematic analysis lends a flexible approach to the analysing of observations however, point out that the method should be undertaken to ensure the analysis is 'theoretically and methodologically sound' (Braun& Clarke, 2006;p2). The research has used the 6-point guide, as seen in Chapter 4 (see table 4.4), to the analyse the data to ensure that it is carried out in a 'deliberate and rigorous way' (ibid: p2). Emergent themes from the observations were identified as:

- Knowledge and Understanding
- Relationships and Trust
- Management of the Process
- Design and Design Responsibility
- Communication of Change

These shared a common set of threads across the trial sites and linked with the questionnaire and interview data gathered at the earlier stages. The themes share

theoretical perspectives from the literature, and further add a level of interpretation from the standpoint of domestic low energy construction. Each of the themes has several converging points, that when explored together form a more complete understanding to the theme as a whole. Evidence to support the themes are indicated throughout the excerpts from the field notes for each of the trial projects, and at the conclusion of the observations these are brought together to investigate further meaning.

Photographs have been used as part of the data gathering process, as these can more accurately indicate issues assisting the observation notes. The Photographs have also assisted in the participant analysis where a technology issues has been discussed, as the picture gives additional evidence to the written description to aid further understanding.

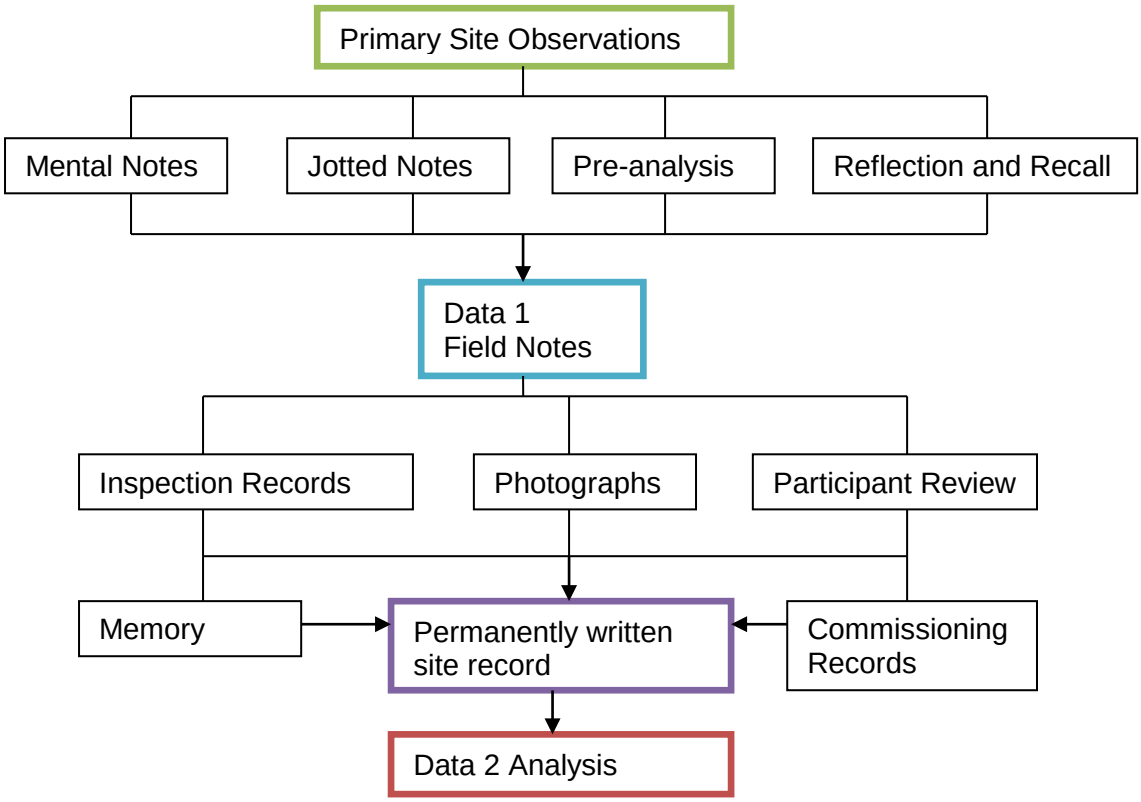


Figure 6.1 Observation data Gathering Process (adapted from Ellen, 1987)

Each set of observations for the three projects S1 – S3 have been recorded by the same process, regardless of the low carbon technology observed (as figure 6.1). Each project observation section also has specific site details, observations records and reflection on the procedure to identify the processes on each project. These records and reflections have been recorded to give an indication of the activities and interactions revealed during the 'first and second fix' stages. They are recorded in the order of the observations and give key elements taken from the field notes (for sample see Appendix 8). The codes and themes taken from the content analysis were used as 'signposts' for the text, this therefore, allowed for identification of the main themes and enables comparisons for similarities across the sample sites. These same themes are were also used for comparison with the questionnaire and interview data to explore further meaning across the stakeholder groups.

In addition to the observations, commissioning results and defects records, where available, have been tabulated for review and analysis for each sample site using, where appropriate, descriptive statistics. The data from the qualitative and quantitative methods of observations and the commissioning data records has also be triangulated to develop further meaning from the emerging action cycles.

6.2 Observations on Project - S1

Table 6.1 gives the site information for observation at project S1.

Table 6.1 Site Information for S1

Information	Comments
Site Location:	London - Southeast
No and type of dwellings:	300 – 3 to 7 storey blocks. Mixed use development with 40% Affordable Rent and 60% Private Sale
Phase of Development:	Each building completed as a phase
Low carbon technologies Used:	Exhaust Air Source Heat Pump installed in each dwelling as part of Code for Sustainable Homes Level 4 compliance
Building Regulations	Compliance with Part L1A 2010
Observation:	As part of periodic inspections for first, second fix installation and commissioning
Sub-contractor Arrangement:	Single sub-contractor for mechanical and electrical services
Observation Period:	30 minutes during each inspection with inspections every 4 - 6 weeks
Contract:	Design and Build
Engagement:	Client Engagement to inspect M&E services
Date: site period **Date: Observation/Intervention Period**	November 2013 – July 2015 October 2014 – January 2015

Background and Technology Description

Each dwelling has an Exhaust Air Source Heat Pump (EASHP) to provide heating and hot water. The heat pump is connected to under floor loops for heating, and an integral hot water storage vessel within the heat pump unit. The technology formed part of the planning application to achieve the Code, Building Regulations and London Plan requirements, and was adopted by the main contractor for the Design and Build contract.

Two EASHP unit types have been used on the development designed to accommodate the sizes of the dwellings. 1 and 2 bed units have a unit with a 550Watt internal compressor based on a Coefficient of Performance (CoP) of 3.0 (1.55KW of heat is produced from the compressor). In addition, there is an integral 3KW emission heater linked to the water cylinder for heat recovery and additional heat performance in winter. The 3 and 4 bed units with 2 bathrooms have the same 550Watt internal compressor based on a Coefficient of Performance (CoP) of 3.0. In addition, there is an integral 5KW emission heater with the same arrangement as the smaller unit. To provide air required for the compression cycle the smaller dwellings have 3 uncontrolled external 100mm ventilation inlets, and the larger dwellings have 4 ventilation inlets. Connection to the under floor heating system is via a heating manifold which distributes the heat flow and return to each of the dwelling loops. Heating control is via a thermostat in each room linked to control valves on each loop at the main manifold. The heat pump is controlled via two sensors, one in the living room to sense internal temperature and one externally to compensate for external conditions. The main heat pump compressor utilises air extracted from the bathroom/s and kitchen, and the subsequent extracted air is expelled from the unit via ducting to the external environment. Hot water is taken direct from the integral cylinder to taps with the temperature control by the heat pump. User settings/controls and maintenance/setup controls are integral to the heat pump unit for all heating and hot water requirements throughout the dwelling.

The exhaust air source heat pump unit has been used in housing association developments in the UK since the start of the Code for Sustainable Homes. This has mainly been as a consequence of the requirement for a ‘per dwelling’ compliance as opposed to a ‘per development’ compliance with the previous Ecohomes assessment method. Consequently, each individual dwelling has to achieve the carbon reduction, demonstrated through the SAP assessment, as opposed to a development wide compliance previously required.

Observation Method

The observations were integral to the general site inspections to gain access to the research area, whilst at the same time to remain part of the professional practice structure on the development. The professional practice commission was for monthly inspections with a follow up report, circulated to the client and main contractor, (for distribution to the subcontractor) for comment and action. The dwellings were inspected at ‘first fix’ (initial services installation before walls, ceilings and floors are closed and plastered), and at ‘second fix and commissioning’ (completion of all services in the dwelling and bring the services into operation) stages. Inspections were based on a review of 10% of dwellings selected at random during both stages. The installation sub-contractor was scheduled to be present at each of the inspections however, this was not always achieved and therefore, lone inspections were carried out. The main contractor attended randomly based on time allowance or the requirement to give instruction to the subcontractor on an inspection issue.

Observations S1

Observations are recorded using the themes from the content analysis of the field notes to act as a ‘signpost’ for the activities witnessed as ‘significant events’ (Gray, 2011:p418). Excerpts from the field notes represent the data indicating trends and activities associated with the installation and commissioning of the low energy EASHP technology. Where quotes are taken from the field notes they are assembled under the themes they represent. This has allowed for comparisons across the projects through the interventions and reflection stages, also using data already gathered as part of the action cycle.

Early stage meetings in the Main Site office

Theme – Knowledge and understanding

Site Manager (commenting when asked by the researcher about the EASHP system) – 'Renewables, it's a bit of a mystery to me'

Subcontractor Supervisor (manager not able to attend the meeting) - 'he's on another site so I'm standing in, I know a little bit about the units, but we can have a look when we get to the flats'

Site Manager (to supervisor) 'We really need to get this sorted, I want someone on site that knows more than just the basics. Make sure he gets a copy of the notes from today'

Observation Notes – confusion at the start of the meeting, those in attendance are not familiar with the technology to be inspected. Impression was this was seen as 'someone else's job'. There is a strained relationship between the two parties as the subcontractor manager is not in attendance. The inspection is to go ahead, but the site manager is to arrange another meeting.

It was evident from the field notes that the initial extent of knowledge possessed by these stakeholders was low, not only for the technology used, but for the system installed on the project. Both were in a relatively senior position on the site, however, an understanding of the technology did not appear to be seen as important, and as observed in the field notes, it appeared as a case of 'someone else's job'. The subsequent meeting with the M&E site manager identified a significant issue in the management structure, as the manager had two other projects and could not give a full time commitment to the project. The supervisor consequently controlled this project with weekly attendance from the manager. Therefore, a

key player in the installation process, with the day-to-day supervision of the installation, had limited knowledge of the EASHP system.

Early Stage Meetings in the site Office

> **Theme – design and design responsibility**
>
> **Subcontractor Supervisor** – Observation – (when asked by the researcher what role the subcontractor had in the technology selection) Explained that the units where selected as part of the planning and that they had 'put in a price' [tendered a price for the contract with the main contractor] for the installation. The designers employed by the main contractor had design responsibility and they were installing as indicated on the drawings. He was aware there had been a lot of 'bad press' around the EASHP, and made reference to a 'watch dog programme', but as they did not have design responsibility they were 'just installing the units, any issues it's with them' [designers].

The subcontractor made a clear point regarding the EASHP technology, which gave the impression that he was distancing himself from the selection process. The field notes recorded a strong indication that the main contractors, due to their links on previous schemes, had used the subcontractors, and that the knowledge of the technology was not the primary reason for using the subcontractor.

Early Stage Meetings in the site Office

Theme – Management of the process

M&E Site Manager – Observation – (asked by the researcher how the technology would be installed and commissioned) Explained that all his team could install the units 'just like boilers, and we've been doing that for years'. One of the installers had been on the manufactures heat pump 1 day installation course and was 'training the others on how to connect up'. (when asked about attendance on site for senior staff by the site manager) It was confirmed that the management structure was sufficient for the projects as the weekly attendance of the M&E site manager would cover the process.

The M&E site manager appeared to be more intent on 'convincing' the construction site manager than on answering the question posed by the researcher. Showing commitment to the project and giving reassurance to the site manager appeared to be the main goal of the comments. There was an indication of trust established between the two and the response from the main contractor confirmed this.

Early Stage Meetings in the site Office

Theme – Relationships and Trust

Site Manager – Observation – Noted that there are 300 to install 'so we should get it right by the end'. It was noted that knowledge of the EASHP was low with an attitude that 'this is what M&E are paid for'. The site manager identified that the construction company had worked with the M&E subcontractors on a number of previous schemes and

that there was rapport at the senior level. ‘We have achieved Code 4 on other schemes; this one shouldn’t be any different’.

An observation from the field notes recorded that the points made in the meeting was that this was ‘business as usual’ and that low energy schemes were all the same. This also appeared to be underlined by the trusted relationship between the two managers reaffirming each other’s view of the project goals. This emphasis on trust and the building of relationships over technical experience is borne out by Eriksson and Laan (2007); they propose that reliance on the perception of acceptable quality, as part of a selection criterion, can be a direct reflection of the main contractor’s relationships, and how they perceive the attainment of their reputational goals for the project.

Early Stage Meetings in the site Office

Theme – Knowledge and understanding

M&E Site Manager – Observation - (The researcher asked if EASHP had been used on the previous schemes). This had not been the case, EASHP were being used as this was detailed in the planning, included in the contract and tendered for project.

Site Manager - The site manager stated that this was an unfamiliar technology and would not have been used if not required by the contract.

Site Manger – Observation – (when asked by the researcher what level of involvement the designers had on the project).They had completed the Construction Issue drawings and would be called if there were issues on site. (Researcher asked if there was a monitoring role and witnessing of commissioning). The designers were not

engaged in this role and commissioning would be witnessed by the clients representative.

The conversation repeatedly focused on the EASHP technology not being directly selected by the construction team. This theme was used as a form of mitigation for the use of the technology.

Early Stage Meetings in the site Office

Theme – Design and Design Responsibility

M&E Site Supervisor – Observation – (responding to a question from the researcher on the integration of the EASHP installation). Stated that this was the remit of the designers and they were installing what was on the drawings and in the specification. If it was outside the tendered scope and tender cost, it was not their responsibility. Also commented on the units delivered at an early stage and any damage was not covered by the M&E installation.

Site Manager – Observation – stated that the units were protected and if protection was removed it would be replaced. (researcher asked if there was there a method statement for the protection). No method statement, but regular checks were being carried out.

The mitigation surrounding the technology became more evident as the meeting progressed. The field notes record an observation of ‘creating distance’ between the contractors previous trusted performance and their projected performance on this scheme.

Early Stage Meetings in the site Office

Theme – Management of the Process

Employers Agent – Observation – (responding to a question from the researcher on how the main contractor and subcontractor were selected for low energy performance). Cost and previous performance were main focuses in the selection process. The subcontractors were not identified at the bid and award stage, and low energy installation experience was 'not high on the list at interview'. The Contractor had achieved Code for sustainable Homes Level 3 and 4 on previous schemes and this was considered sufficient in the questions.

Client Project Manager – Observation – Was not very familiar with the technology, but had worked on several Code 3 and 4 schemes. They had worked with the contractor previously and felt that the management set up was sufficient for the installation of EASHP.

The early meetings were principally focused on management and design responsibility, with a key observation that limitation and protection of 'roles' was a predominant topic of the discussions. A clear defining line was evident for the design process, and where the limit of responsibility existed for the M&E subcontractor. The observations identified that cost was a factor for this delineation, with the subcontractor referring to the 'price' on numerous occasion to define responsibility. Familiarity with the M&E subcontractor was also identified by the site manager as part of the selection for the scheme. This process also observed by Hartmann and Caerteling (2010), showing that the main contractor is often willing to compromise on technical 'know-how' and co-operative skills, if the quality of the work is viewed as 'acceptable'. This compromise on technical 'know how' is evident in the observations and indicates the dynamic that familiarity and cost played as a guiding factor in

the selection process. From the observational evidence it can be seen that the low energy technology installation was not a governing focus at the early stages.

From a researcher perspective, the technology did not seem high on the list of priorities for any of the stakeholders. Regardless of the unfamiliarity with the technology, it appeared that this was regarded as a comparatively simple technology that the subcontractor could manage. An interesting observation was that the low carbon goal of the project was not mentioned by any of the stakeholders in the early meeting. This could be that it was ‘taken for granted’ by those present, however, the researcher considers, from the observations, that this was not a focus item for the project as a whole. Achievement of Code level 4 assessment process appeared the main goal from the contractors perspective, and the inclusion of the technology, regardless of its outcome performance, had already fulfilled this contractual criteria.

Moving on from the early stage meetings with the stakeholders the observations continued alongside the site inspections. The subcontractor supervisor and the subcontractor installers mainly attended these inspection and meeting with the main contractor and client/clients project manager attending infrequently. This inability to participate completely in the observations process was a recurrent theme throughout the project across the stakeholder groups. It was not, in the main, due to unwillingness to contribute, but to a continual change in the construction process linked to resources, and a constant impression of ‘fire fighting’ throughout the installation and commissioning processes. This is a key observation in the installation and commissioning process as the ‘fire fighting’ actions were repeatedly used as a reason for not following the desired installation and commissioning procedures (evident from the installation indicated in P5.1).

The installation and commissioning observations followed a pattern that emerged early in the process and continued throughout the project. This consisted of three elements. Firstly, an unstructured approach to the installation of the technology and a fragmented view of the overall installation of the building services. Secondly, the sharing of information remained at the tacit level and was not communicated explicitly for others to follow as a process. Thirdly, the structure of many of the self-employed companies did not allow them to look beyond the need to install to an agreed programme for payment. Therefore, each component of the installation was seen as a separate item, either with someone else responsible or otherwise completely ignored or not communicated by the M&E subcontractor. Observing the installations, this was witnessed in the following excerpts.

Dwelling Inspection

Theme - Progressing the installation

Subcontractor Supervisor – Observation - (responding to a question from the researcher on progress so far with the EASHP installation) – 'Units are too big to get through the dwelling front doors so they have had them in position from day one. Yep, before the walls have gone up, so every one of the units is covered in dust and plaster. We're not 'down' (contractually obliged) for covering them so the contractor has left them like this'.

Observation

It was observed that many of the units were not covered and this formed part of the inspection report. It was also observed that the installers were comfortable with the installation of the under-floor heating and manifold sections, however the connections between these elements and the heat pumps had been more problematic.

Further field note entries also record an example of the fragmented response to the installation from the subcontractors.

Dwelling Inspection

> **Theme – Knowledge and Understanding**
>
> **Mechanical subcontractor** – Observation – (when asked by the researcher about the technology and the subcontractors installation activities in the dwelling). The installer appear unsure of how the unit worked, but his 'job' was to connect the unit up to the under floor heating manifold. He did not know how the unit would be set up and was unclear how the ductwork was connected for supply and extract ventilation. (When asked by the researcher if he had worked on any other low carbon technologies). He had not worked on any and mainly installed boilers, but not 'electric heating system'. (asked about the external wall ventilation points), he stated that this wasn't part of his installation and someone was doing that element separately from the 'heating installation'.

Linked to this, the observations detected a gap in the process that illustrated how the installation at 'face value' seemed to be progressing well, but was creating a false impression of the actual installation of the technology.

Dwelling Inspection

Theme – Management of the Process

Mechanical Subcontractor – Observation – (when asked by the researcher how the installation of the units was progressing). He stated that [name removed] was the main person trained on the units and he was doing a review of the connection. However, because this was slowing the programme of units to complete, and was 'flat out on his own work load anyway' they were all connecting up as best they could. 'We've got to get them done on the programme or you don't get the payment; I'm self-employed so need to get them done. I've check the last few and they seem ok. We can always correct at commissioning if there's a problem'

The field notes identified an installation 'cultural issue', in that the EASHP unit was seen as a separate entity to the remaining heating and hot water installation. Its unfamiliarity was accentuated by its installation before any other 'first fix' item, therefore, immediately challenging the perception of the installation process. This was further compounded by the lack of understanding of the technology, which led to installers creating their own method of installation where unfamiliar connections were encountered. It was observed that the mechanical installers, a majority of which did not have experience or training, undertook the EASHP installation. Therefore, the dwelling inspection gave an insight into how the installation was affected by the lack of knowledge on the technology. It further illustrates how a fragmented process can form around the installation for the low energy technology. Therefore, creating an installation process, that whilst appearing to follow the design, can detract by poor installation from the required performance at the commissioning and

handover stages. The photographs in P6.1 illustrates a unit in position during the ‘first fix’ stage.

Exhaust Air Source Heat Pump Unit

Poor installation of duct work and insulation

External ventilation grille blocked with insulation

Figure 6.2 EASHP at First Fix Stage

The photographs indicate the typical location of a unit when the subcontractors first start on site, and an example of the ‘ad hoc’ attempts to complete the installation (poorly installed

high-level duct connections, insulation and incorrect expansion vessel position), without consideration to the requirements of the unit performance for low carbon operation. NHBC (2012) indicate a gap in the performance of the M&E subcontractor integration to achieve the demands of the installation of low carbon technology installation. It was evident from the observation field notes that this lack of co-ordination, understanding and collective responsibility was having a direct effect on the performance of the technology. It may also be said that any issues that arise from the installation would have a direct effect on the longer-term energy use by the resident, through loss of confidence in the technology operation.

This can be further illustrated from the observations during the commissioning (first block completed and commissioned as part of the phased handover of the development). Here the focus was on the commissioning of the units, and how the subcontractor interpreted the completion of commissioning. Observations showed that the process had followed the same fragmented approach as the installation. The field notes identified that the commissioning was conducted without the designer's involvement, as also noted in the results from the questionnaire Chapter 4, and without client participation in the process (which is often the case in design and build schemes). The observations reveal the completed commissioning as offered by the contractor ready for the client handover (ready for occupation) just over one week before first resident occupation. What was discovered in the field notes and commissioning test results is an indication of the wide variances in the performance achieved.

Dwelling Commissioning

Theme – Knowledge and Understanding

Subcontractor – Observation – (when asked by the researcher about their activities in the commissioning process). Manufactures installation manual was used for the setup of the units. Design figures for extract rates are given for the units and the fan was set up to achieve this. Problems setting up the rates in some dwellings and fan speeds are higher than expected. Flexible duct connections have been the main issue, but now that the ceilings are up and completed they can't be changed. Under floor heating temperatures have been changed several times to match the floor loops and finishes, which has meant the flow temperature has needed to increase in some areas to achieve the room temperature of 21^0C and 18^0C in the bedrooms. He suggested that there had been real problems getting the unit to work, especially as other trades were still working in the dwelling when commissioning was underway. [Name removed] was meant to come round and view all the units, but there just not been the time, so they have been set up like the manual and the 'heating and hot water works so this should be fine'.

M&E Supervisor – Observation – Stated that the specification did not 'say anything about energy efficiency' therefore, if it worked a bit harder, as long as it was 'covered by the unit' that was sufficient.

A key point was the fact that the system worked and energy efficiency was not contractually required, the central tenets therefore, being 'it works, its ok'. This was further picked up by the M&E supervisor in the description of the commissioning process completion.

Dwelling Commissioning

Theme – Management of the Process

M&E Supervisor - Observation – (When asked by the researcher how the commissioning process had been completed). Manufactures data was used for ventilation rates, water pressures, hot water flow rates and hot water temperature settings, and these were used for the set up. The heating and hot water flow rates had been set for each of the dwelling types (1bed and 2bed with single bathroom, 3bed and 4bed with two bathrooms). Bypasses for the heating loops were set in the same way as the flow rates with a setting for each dwelling type. Hot water temperature was set at 50^{o}C and heating circuit set 40^{o}C. Fresh air external ventilation point position and numbers recorded on the certificates. Commissioning certificates were completed based on this information for each dwelling and inserted in the Operation and Maintenance manual (O&M manual).

Spot tests after the inspection indicated the following:

- The ventilation rates for the extract in each room varied greatly due to the flexible ductwork lengths being either too long or damaged therefore, creating additional resistance, needing the fan speed to be increased directly affecting energy consumption.
- Heating loops differed in the dwellings (even amongst dwelling types) therefore, flow rates were not maintained for heating and hot water circuits.
- Heating manifold bypasses not set correctly for each dwelling therefore, EASHP constantly active with increased energy use.

- Because of the issues above the temperatures were found to vary at each dwelling
- External ventilation points installed without manual dampers, therefore infiltration possible in winter with associated heat loss and higher energy use.

Commissioning results varied widely from the spot test results indicating that resident energy use would be increased over the expected performance from the commissioning certification. Table 6.2 gives an illustration of the project energy due to installation issues over that indicated in the commissioning certificate.

Table 6.2 Energy Use from Installation Issues EASHP Unit

Item	Commissioning Result	Spot Test Result	Difference in results	Comment
Extract Ventilation Rate	31l/s	26l/s	17%	Ventilation terminal points not correctly set
Under floor Heating Temperature	40^0C	47^0C	7^0C Δt	Greater use of immersion heater
Hot water temperature	50^0C	55^0C	5^oC Δt	Greater use of immersion heater
Setting for Legionella Purge temperature to 60^oC	1 hour per week	1 hour per day	7 hours additional energy use	Greater use of immersion heater
Supply air	31l/s	34l/s	9%	Higher air change rate in dwelling with higher heat loss
Fan Speed – Normal/Boost (rpm)	1100 rpm / 2100rpm	1600rpm / 2700rpm	32% / 24%	More energy use on fan power

Observations from discussions with the site manager gave a clear indication that there was not sufficient time for him to monitor the commissioning issues. He recognised the issues with the commissioning certificates, but was more concerned with the results matching the

spot checks than to re-commission the units for improved energy efficiency. The key word was ‘time’, and as long as it could be ‘proved’, the units worked the unit performance would not be amended. A similar stance was taken by the clients representative due to time scales on the project. Therefore, as viewed at the start of the observations the energy performance of the technology remained a lower priority at the conclusion of the phase. The field notes illustrated this in the follow up site meeting.

Meeting at completion of Phase 1

> **Theme – Communication of Change**
>
> **Site meeting** – Observation – There was an acceptance that commissioning figures must represent the test results and average figure should not be used across the certificates. However, there was strong resistance from both the M&E site manager and site manager not to go back and re-commission the dwellings. The client representative was also aware of handover dates and did not want to miss agreed timescales. Therefore the spot checks were accepted and the corresponding commissioning sheets changed. The increase in energy use from the units was tolerated by the client, and it was agreed that interventions would be reviewed as long as they did not slow progress.

The initial observations highlighted the minor role energy performance played in the installation and commissioning of the technology. A functioning technology appeared to be the goal as opposed to a requirement of optimum energy performance. When this is viewed against the achievement of the Code for Sustainable Homes for the scheme, it can be clearly seen how the assessment method can be achieved without the technology

performing effectively due to installation and commissioning deficiencies. Therefore, the scheme may display a code 4 compliance, but have a technology that is far from energy efficient to Code 4. Interventions therefore, need to look to address the earlier stage issues and present solutions for the installation process to create a more closely controlled process. This will therefore, be developed further in the interventions section later in the chapter.

Site S2 investigation enable further comparisons to be made on the installation and commissioning process, and to identify common and emergent themes across the varied projects and technologies used.

6.3 Observations on Project - Site S2

Table 6.3 gives the site information for observation at project S1.

Table 6.3 Site Information for S2

Information	Comments
Site Location:	London - Southeast
No and type of dwellings:	750 – 5 to 8 storey blocks. Mixed used development with 65% Affordable Rent and 35% Private Sale over 7 phases
Phase of Development:	Each building completed as a phase
Low carbon technologies Used:	Communal Heating System with CHP as part of Code for Sustainable Homes Level 4 compliance
Building Regulations	Compliance with Part L1A 2010
Observation:	As part of periodic inspections for first, second fix installation and commissioning
Sub-contractor Arrangement:	Single sub-contractor for mechanical and electrical services
Observation Period:	30 minutes during each inspection with inspections every 4 - 6 weeks
Contract:	Design and Build
Engagement:	Client Engagement to inspect M&E services
Date: site period **Date: Observation/Intervention Period**	January 2013 – December 2015 October 2014 – July 2015

Background and Technology Description

The development has a central energy centre, which comprises gas boilers, combined heat and power (CHP), thermal storage and pumps and controls for the system to supply heat and hot water to all dwellings. The energy centre was installed at the start of the scheme during Phase 1, with an initial boiler capacity of 3.5MW. The CHP was planned for installation in Phase 5 when 60% of the development was occupied, which is in line with the Building Research Establishment (BRE) allowance for minimum occupation for a CHP installation. The system was designed for a flow temperature of 80^0C and Return temperature of 60^0C. The energy centre was metered for energy used both for the primary

gas use and heat energy to the dwellings. Each dwelling has a Heat Interface Unit (HIU) with a plate heat exchanger for individual control of heating and hot water supply. Each HIU has a heat meter and energy meter to record actual energy used within each dwelling.

Communal heating systems utilising boilers and CHP have become common within London on development sites over 50 dwellings since the introduction of the London Plan in 2011. The London Plan requires an energy strategy to be adopted as part of the planning application based on a pre-determined energy hierarchy. The hierarchy is in addition to the Code for Sustainable Homes and requires a strategy based on Lean, Clean and Green energy provision for the development.

- Lean – Passive design and construction of the building fabric, such as low U values and high air tightness;
- Clean – The provision of energy with low carbon contribution based on communal heating systems utilising CHP or Bio mass boilers;
- Green – The provision of renewable energy technologies where feasible.

The Greater London Authority (GLA) has a commitment to a London heat network (provision of communal heating distribution network across the London region for new build and refurbishment developments), and as such, all large scale developments must install communal heating with CHP unless there are mitigating circumstances. Therefore, communal based systems for residential developments have become ubiquitous for large-scale London wide housing developments. This represents a large and growing proportion of low carbon developments in London and the Southeast including for housing association schemes.

Observation Method

The observations were conducted similarly to site S1 for ‘first and second fix’ activities. An additional element for S2 was that the professional practice had been engaged in the design for the development from Phase 4 onwards (previous consultant being replaced at the end of phase 3 for underperformance). Therefore, there was additional access to design information not readily available in S1. This gave an added dimension to the observations, as the dynamic of the design input could be seen at the same time as the installation and commissioning issues. Attendance by the main contractor was sporadic, as with the S1 development, and again time constraints were the main reason for the lack of attendance. The professional practice design team were involved in the design, therefore the design presence was limited during the observations

Observations S2

Excerpts from the field notes represent the data indicating trends and activities associated with the installation and commissioning. The notes build on the themes from the site S1 observations to indicate trends across the activities observed.

Site S2 observations were initiated with a site meeting involving the main contractor, sub-contractor and designers to understand the development so far and to review the installation and commissioning processes for phases 3 and 4. There was a distinct similarity between S1 and S2 in the nature of the relationship between the site manager and the M&E site manager. Trust played a focal part within the themes of the conversations; however, the trust element had little to do with the energy performance, being mainly concerned with the delivery of the project. Therefore, the relationship between the two companies played a

significant role in the way the site manager saw the scheme, and was part of the early conversations regarding the development and progress:

Early Stage Meetings

> **Theme – Relationship and Trust**
>
> **Site Manager** – Observation – (when asked by the researcher about the construction team used on the project) – 'I like to surround myself with blokes I can trust. It's going to go wrong at some point, but I need to be able to pick up the phone and get some action'. Having trust and 'loyalty' was observed as a major contributing factor to the use of the subcontractor. 'I can ring [name removed] and he will sort it'
>
> **M&E Site manager** - 'we've worked with [name removed] for a long while, we know the score and I'll get it over the line whatever it takes'.

This theme of trust and mutual dependability was a common theme throughout the site observations at the senior level, and extended to the client representatives and design team. However, the installation and commissioning activities appeared no different from the general experiences on S1. There were disconnects between the senior level trust relationship and the abilities and actions of the installation and commissioning site staff. The emphasis appeared to be more on 'getting the job done' over 'how the job would be done'; leaving quality and process lower in the priority scale. This links to a common theme with S1; the lack of knowledge of the low carbon technology by the site manager is not seen as a problem for the success of the project. Where this knowledge element is low, the trust relationship is accentuated with the M&E site manager, as the scheme success needs to be delivered. Whilst this in itself is not uncommon within construction, due to the growth of many different specialisms, the lack of value or importance attached to energy performance

heightens the probability of higher carbon emissions for the development. It may also indicate why the questionnaire results in chapter 4 indicate a lower satisfaction levels with commissioning activities and the defects issues associated with the low carbon technologies. An exchange from the field notes makes it evident that performance is not the prominent criteria:

Early Stage Meetings

Theme - Knowledge and understanding

Site Manager – Observation – (when asked by the researcher the extent of knowledge of the low carbon technology) – It was clear from the notes that he was very sceptical of the low carbon element of the project, 'just doing it for an effect' was a common sub-theme from the notes. 'it's all to do with the London Plan, wouldn't be doing it otherwise; don't see what's wrong with boilers, good 'U' values and a bit of PV'.

Clients Representative - 'Client doesn't want it, we don't want it, but we've got to make it work as that's what's in the contract'.

M&E Site Manager - 'depends on what you mean by making it work'

Clients Representative – 'What's in the contract?'

M&E Site Manager – 'room temperatures and hot water tap temperatures'

Clients Representative – 'then that's what you've got to achieve to get this system signed off'

What is evident from this exchange during the meeting was that, similarly to S1, energy performance was not a primary consideration for the performance criteria from any of the

stakeholders present. From the observation perspective, it was evident that energy performance beyond the completion of the SAP assessment and the Code was not considered. The comment from the stakeholder group was that once the system was signed off on the assessment criteria any further performance review was not required. The elements of the installation and commissioning plan, whilst programmed within the scheme processes, were not considered as important as the SAP already recorded the carbon saving. Therefore, as this would be the only required documentation for the handover, performance beyond making sure 'it worked' was a low priority.

This was also explored with the designers, in this case, part of the professional practice. What was evident from the observation was the attention paid to achieving a handover of the building, and not the actual performance of the system at handover. Once SAP and the Code certificates were completed (limited evidence needed for these activities including manufactures data and not actual test and commissioning certificates), there was little additional attention from the design or site team to consider the commissioning beyond functional operation and delivery of heat.

Early Stage Meetings

Theme – Design and Design Responsibility

Designer – Observation – (when asked by the researcher the process for the development between the design and commissioning). The designer stated that the design was most often carried out without the ability to follow through onto site and commissioning, unless there was a problem. There was a reference to design for different requirements, Planning to indicate a CO_2 figure, design to 'fight your corner for space and cost' with the design team and contractor, and installation and

commissioning where there is little or no input from the design team.

Site manager - 'I need the Code and SAP assessments at handover to complete the contract for NHBC (National Housing Building Council – building construction insurance provider) and the client, after that anything else is a bonus'.

Clients representative – 'the system needs to run efficiently that's what its design for, but I'm yet to see any at handover. We spend the next few years putting thing right and trying to get it to work'

M&E Site manager – 'Never commissioned properly and never maintained….., it's a rush at the last minute to get the job done and the residents in'

Throughout the initial site meetings, the terms energy efficiency and carbon reductions were not evident as part of the discussions other than when referring to the SAP or Code compliance. Drawing together, the notes and observations there were 3 distinct themes. Firstly, the design and associated responsibility existed on 2 levels; the first to achieve a planning objective and the second to be constructed and function at handover. Secondly, knowledge and understanding indicated a lack of understanding of the systems from the main contractor who is ultimately responsible for the delivery of the scheme. Thirdly, trust is a significant element in the construction process, as observed by Wong et al (2005) however, there is a disconnect observed between the trust relationship based on delivery at the management level, and that at the operative level. Therefore, addressing these 3 elements, along with a structured goal for lower carbon use, is required to further close the gap on low energy technology performance.

Installation and commissioning observations showed very similar activities to S1. The field notes indicate a mixed level of experience across the installation team, not uncharacteristic for a construction site. However, the predominant observation was the lack of a co-ordinated approach to the technology, originating almost entirely from an absence of a common understanding, or holistic view of the system from manager to operative. Invariably the system installed was as the construction drawings indicated. However, the connection and operation of each element were seen as individual items, and not connected to a whole system. The implication of any one action was not viewed beyond the boundary of the area in which it was installed. Similarly, the commissioning was seen as being completed separately without an appreciation to the functioning of the technology as an entity. Therefore, 'heating at the radiator and hot water from the tap' was seen as the end state commissioning action as opposed to system efficiency or performance. This is indicated from the observations during the installation:

Dwelling Observations

Theme Knowledge and Understanding

Mechanical Services Installer – Observation – (when asked by the researcher about the communal system during the dwelling installation observation) – Installation was not seen as any different to an individual boiler installation. Airtightness and insulation requirements were not considered, as this was 'not part of my work'. Flow and return temperatures and issues with overheating were also not considered. This was seen as a commissioning item and not affecting the installation. There was an inability to see the complete system and its associated effects.

This was a common theme with the installers when asked about the system operation. There was a definite divide between the actions of installation and the eventual energy and carbon performance. Similarly, as observed in the site meetings, energy performance and carbon reductions were not subjects noted or volunteered during the installation activities. What was evident was the low carbon project 'existed' in the assessment and higher-level planning context, however, was not engaged at the installation and commissioning level. Therefore, two projects were in effect being constructed, dependant on the perspective of the stakeholders. One achieved academically through an assessment process giving an output based on Code and SAP information, the other a separate installation undertaken without low carbon considered. Between these two conditions, there was no bridge or information sharing mechanism to address performance issues. What was evident was that the site management, installation and commissioning teams were never a cohesive whole, but rather small collections of teams formed and reformed as the project progressed. At no time were the teams together on both the installation and the subsequent assessment. Garnett (2001) when researching lean construction processes also observed a similar team dynamic and argued that its effects eroded learning and development in construction. What was observed was the two processes of assessment and installation co-existing with little or no communication between the two end results. Therefore, one indicating a Code 4 compliance and the other displaying an operational system with poor energy and carbon performance.

This division extended to formal communication routes such as training and site meetings, and was illustrated when discussing communication with the installers. Compliance with the Code and SAP assessments were not seen as part of the installation and commissioning role. These were seen primarily as design issues, with all but two of the installers observed, having little or no knowledge of the assessment requirements or process for completion.

Therefore, critical goals set at the planning and design stages of the project were not a formal part of the installation and commissioning process, these only being discussed and completed at the client, design and management level.

Dwelling Installation

> **Theme – knowledge and Understanding**
>
> **M&E Installers** – Observation (when asked about compliance with Code and SAP assessment methods). These assessments were viewed as outside the installers concern. Others completed the assessments and the commissioning results were given to the site manager to pass on to the SAP assessor. There was little understanding of the requirements for compliance or the effects on the performance of the technology. 'not something I get involved in' was the predominant comment from the installation and commissioning teams.

A key word is 'involvement'. It captures the essence of how the process of low energy and carbon assessment can be progressing at a higher level with little or no input from the installers. The element of performance and achieving an energy goal is not seen to involve the installation process, and operates outside the activities of the site installer, both as an individual and as part of the subcontract team, if such a team actually exists in reality. It also indicates the difficulties inherent in the construction industry in that communication between teams, management and individuals is sporadic at best and mainly remains in a verbal form, which subsequently is not used for future development. This is seen in an extract from the observation notes during the installation and commissioning:

Dwelling Installation

Theme – management of the process

M&E Installer – Observation –(when asked about the communication of lessons learned and best practice). Communication was mainly between the installer teams. Requests for Information (RFI) were used to get details from the designers, however, mostly they got on with the job of installation 'with what we have'. Lessons learned were not discussed, and most commonly, the installers were moved onto other jobs as soon as the scheme was near completion. Therefore, very little was passed on and only a skeleton staff were around at the actual completion. 'Never get invited to meetings, just doing the job and let the foreman know what's going on, don't know if this gets anywhere, never here at the end anyway'. The disconnect between install and assessment is prominent in most observations with the installers and management.

Individual involvement was seen at the direct task level only amongst installers and participation in any energy performance goals were not communicated at this level. It was apparent from the observations that the lessons learn process was non existent at the scheme. This was also observed as a common theme at all the observation sites. Time constraints, churn of staff and the last minute activities of commissioning were identified as barriers to improvement by the both the installers and site management. The extract below emphasises these point:

Dwelling Installation

Theme – Management of the process

M&E Installer – observation – (when asked how installation and commissioning activates were carried out). The installation and commissioning activities were under constant pressure to complete to meet the handover date. Commissioning left until the last minute and constantly disrupted by other trades trying to complete. 'I can say for a fact half the commissioning is never carried out, as long as it works the flat is snagged and shut up for handover' – 'most commissioning is done a couple of days before handover, because we can't get into the dwellings. You just don't have time for the niceties, it's a quick in and out'.

Site Manager – Suggested that most if not all his staff, including himself, would not know what to look for from the commissioning and inspections. 'it's taken on trust that the commissioning has been completed' – 'we never have time to compare with Code as the code certificate comes out after completion' [scheme handed over].

Clients representative – It was noted that certificates were checked for inclusion in the handover manuals, but the technical content was not reviewed. 'I wouldn't know what I was looking at' was a common response when asked for a view on the content of the certificates in the handover manuals.

The role that each of the contractors play within the construction project creates a barrier to the ability to bring energy and low carbon performance into the day to day progress of the

development. What is apparent from the observations, and is also seen in the earlier interviews and questionnaire responses, is that the introduction of low carbon technologies and assessment methods have not impacted change in the installation and commissioning activities. These activities are still enacted almost entirely the same as before the introduction of the Code pre 2007. The observation indicates that from the main and sub-contractors perspective, whilst technologies have changed, their management, installation and commissioning methods have not reacted to the need for improved energy performance.

A lack of knowledge on the performance of the technologies is inhibiting the participation in these performance goals. However, the lack of actual performance data needed as part of the assessment procedure also encourages a disconnect between the processes of assessment and installation. If this is seen against a background of the inherent construction issues of time and cost, there is the 'justification' for never bringing the two halves of construction output and assessment together. Therefore, the need to improve the link through communication and monitoring would assist to close the gap in performance as is found amongst the literature (NHBC, 2014). This is evidently demonstrated in Tables 6.4 and 6.5, which indicates a range of post commissioning test results that demonstrate the actual performance of the system is noticeably different to the assessment process achieved and recorded for the development

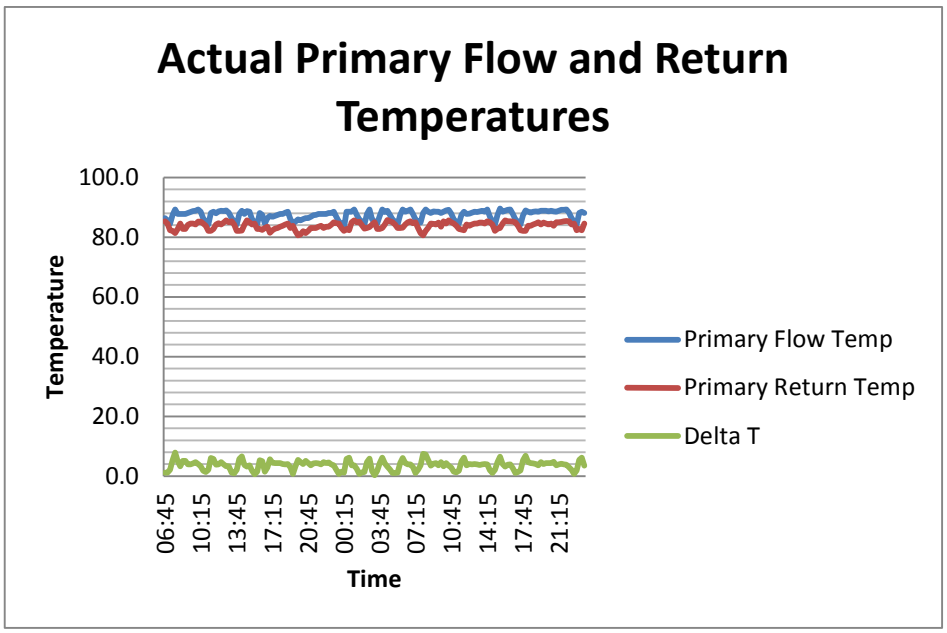


Figure 6.3 Actual Primary Flow and Return Temperatures Recorded at the Energy Centre during occupation

Table 6.4 shows the actual flow and return temperatures recorded when all the dwellings were occupied indicating an average ΔT (temperature difference) of 3.6°C against a design target of 20°C. Investigation of the system found bypass valves open on the distribution network and variable speed pumps on manual mode and set to maximum output. These issues created increased flow rates in the distribution network, decreasing the system efficiency. However, the scheme had achieved a code 4 certificate and commissioning certificates indicating compliance with the design. Table 6.5 demonstrates further performance issues within the system.

Table 6.4 Recorded results against required design conditions

Review Area	Actual Results	Design Targets	Difference
Primary Flow and Return Temperature	89ºC / 84ºC	80ºC / 60ºC	9ºC / 24ºC Over target conditions
Primary Flow Rate	8.6l/s	Variable to the load requirements from the dwellings	No control on primary flow rates
Hot Water Set Point	65ºC	60ºC	5ºC over target conditions
HIU Heating Set Point	Maximum setting 80ºC	60ºC	20ºC higher than target setting
CHP	Not operating	Used as lead boiler with thermal store	SAP and Code CO_2 reductions based on CHP operation for 55% of the heat load for the building with electricity exported to the grid. Therefore, no CO_2 reductions achieved

What was apparent from the spot check results was that the system had not been commissioned to the design requirement and was therefore, operating substantially outside its design target conditions. Photographs in figures 6.4 – 6.6 also indicate visually the level of the installation contributing to this lack of performance of the system:

HIU Set Point Temperature set to maximum

Poorly insulated pipe work in dwelling above HIU

Figure 6.4 Photographs of the Installation

No insulation on primary distribution pipe work to fire stop

Figure 6.5 Photographs of the Installation

No insulation to pipe work to HIU and partial insulation on cold water feed to HIU

Figure 6.6 Photographs of the Installation

Causes for this inability to meet the target conditions were sought amongst the observations and commissioning data and several factors emerged:

- Dwellings were set up to ‘work’ not commissioned to perform to target conditions
- No connection between the design performance and actual conditions
- Little understanding from the main contractor as to what performance was actually required

- No connection between the assessment compliance and actual system performance
- Little communication of best practice or performance standards amongst installers and management
- Fractured commissioning processes with ‘last minute completion’ and no overview of the complete system operation and efficiency

This lack of individual communication and knowledge transfer created an inability to engage beyond the individuals own experience. Whilst there was a general tacit level of knowledge of the low carbon nature of the technology, the lack of a co-ordinated approach to the installation and commissioning led to an ‘as long as it works’ attitude being tolerated on the project. This engendered the ‘acceptance’ of the low carbon element of the project to exist in the assessment paperwork only, whilst the actual installation reflected a much higher carbon output. Therefore, the commissioning process was viewed or understood as a ‘putting to work’ of the technology, and not as a process for efficiency in the system. The assessment CO_2 calculations at the start of the project were the only requirements for assessment compliance at the end of the construction process. Therefore, merely activating the technology before handover was seen as the main requirement, with no longer term understanding amongst the stakeholders of the lower performance implications for energy and low carbon efficiency.

Comparable installation and commissioning activities were seen in the third site used for observations S3. Here a similar communal heating system was installed however, this was mixed with individual heat recovery ventilation in the dwellings and communal PV panels for each of the blocks. The observations on S3, concentrated on investigating the client perspective of the low carbon technology installation and performance, and how this was

seen as part of the installation, commissioning and defects period. Therefore, gaining some comparisons across the sample sites based on the low carbon technologies.

6.4 Observations on Project - Site S3

Table 6.5 gives the site information for observation at project S3.

Table 6.5 Site Information for S3

Information	Comments
Site Location:	London - Southeast
No and type of dwellings:	550 – 8 storey blocks. Mixed used development with 85% Affordable Rent and 15% Private Sale
Phase of Development:	3 Phases of development observations for Phase1
Low carbon technologies Used:	• Communal Heating System with CHP as part of Code for Sustainable Homes Level 4 compliance. • MVHR in each dwelling • Communal PV on each block for 20% renewable energy contribution
Building Regulations	Compliance with Part L1A 2010
Observation:	As part of periodic inspections for first, second fix installation and commissioning
Sub-contractor Arrangement:	Separate sub-contractors for mechanical and electrical services
Observation Period:	30 minutes during each inspection with inspections every 4 weeks
Contract:	Design and Build
Engagement:	Client Engagement to inspect M&E services
Date: site period **Date:** **Observation/Intervention Period**	November 2013 – November 2015 October 2014 – July 2015

Background and Technology Description

The development technology for heating and hot water is similar to site S2 with central energy centre with Boilers, CHP and thermal stores. The additional technologies for this site are Mechanical Ventilation with Heat Recovery (MVHR) within the dwellings and a communal PV array on each block for a site wide 20% reduction in CO_2 from renewable energy technologies.

Observation Method

The observations were conducted similarly to sites S1 and S2 for ‘first and second fix’ activities. However, additional access was achieved with the Housing Association (HA) client on this scheme, therefore the observations concentrate on this perspective in relation to the installation and commissioning activities. The client had a permanent presence on the site throughout phases 1 and 2 therefore, having a closer connection with the site construction process than on S1 and S2. This perspective permitted the observations, over the three sites, to capture data from all of the three main stakeholder groups. Therefore, exploring all stakeholder perspectives, also linked to the questionnaire and interview data, gave a further dimension to the interventions developed.

Observations S3

The HA client had a permanent site presence and was present at some of the inspections and commissioning activities. They also had an active presence during the handover period therefore; their contribution to the observations recorded the client perception of the process, and the impact on the approach for the later sections of phase 1 and 2 works.

From the observations data a predominate theme throughout the interactions between the client and the construction team was one of ‘relationship and trust’. This was dominated by the client and constructor’s tendency to conduct separate pre and post meetings to review their strategy both before and after the main ‘site meetings’. These had evolved on the project during the course of the phase 1 works as compromise and conflict had grown between the client and constructor teams. This led to a ‘choreographed’ site meeting in which both sides managed an agenda where compromise on construction deliverables was

a recurrent theme. This engendered a prevailing sense of distrust on both sides, which had at its centre the construction contract value and cost. Therefore, the structure of the design and build contract, in which the construction cost risk was with the contractor, created a divide between contractor delivery and client demand for performance. It must be said that both parties felt that they were centred on delivering the scheme, as envisaged in the contract, however, the dichotomy between cost and performance formed the constant barrier between the two. The observations recorded this divide on several occasions and the following extract illustrates the divide and its effects on the project:

Site Meeting

> **Theme – Relationship and Trust**
>
> **Site Manager and HA Client exchanges** – The site manager was very defensive on any issues surrounding the performance of the low energy systems. The Employers Requirements (ER) document was used as the justification for the performance level. The term 'where does it say that in the ER's' was a repeated comment whenever performance was discussed. The HA Client was frustrated with the lack of engagement with discussion on performance. A defensive position of 'it must comply with the regulations' was the response from the other side of the divide.

What the excerpt demonstrates is that there was a resistance from the constructor to engage in discussions around performance criteria. The contractors perspective was that performance, beyond that which was interpreted in the contract, equated to cost and would not be carried out unless regulated or paid for as an addition. This is further demonstrated in the following exchange:

Site Meeting

Theme – design and Design Responsibility

Site Manager - There were a number of references that the employers agent had all the commissioning certificates and that they had been 'signed off'. When asked by the researcher had these been checked against the SAP calculations and CIBSE guidance, the typical response was 'it doesn't say I have to do that, so I don't do it'. The system working and the assessments signed off was seen as the end goal of the construction team. It was also implied that the maintenance teams could develop the system once handover had occurred, in this way the client could work with their teams to achieve 'what they wanted'. It was noted that this should not 'hold up' the completion and handover process to meet the contract program.

This disinterest with the energy performance was common across the construction team, evident throughout the installation, and commissioning with 'working' as opposed to 'performing' as the key word most frequently used. From the HA client's perspective they had experienced poor performance from several communal heating schemes and did not want to repeat the issues. However, it was apparent from the next exchange that they saw little hope of improvement on this scheme:

Client meeting after site meeting

Theme – Communication of Change

HA Client – Their experience was that low energy schemes, especially communal heating, were not effective on any of their H.A projects. Installation was seen as a main issue as there was always a long

> period of defects and attendance on the systems. However, it was seen that there was little opportunity to create change, as each project experienced the same lack of communication and understanding of the low energy technology. 'it's the same as the last project, cost rules and we just never state what we want; in fact I'm not sure we know what we want? – It has all gotten to be very complicated and I honestly don't think any of us really know how to get the lower bills for the residents'. The perception was that there was no learning from one scheme to another and the skills in the HA were low. Most 'knew housing, but this energy thing is outside our experience'.

This perception of complexity mixed with a lack of communication between the stakeholders was a common theme and captured the essence of the clients concerns on the project. This was discussed with the site manager and installers and the complexity theme was also prevalent in their responses.

> 'it's all got too complicated for house builders'

This was a common response amongst the constructors, as well as:

> 'If I don't understand it, the residents haven't got a chance, but its ticking a box and that's all that seems important'

What was apparent from the exchanges amongst the installers was a lack of commitment to the energy goals. The energy performance element was seen as 'someone else's responsibility' and disconnected from the actual installation and commissioning process. This was compounded by the lack of knowledge from the management structure across the stakeholder groups to challenge the performance issues. Therefore, the completion of the

energy assessment Code, SAP or BREEAM was taken as the compliance at handover leaving the longer term energy performance to maintenance and resident response.

Significantly, the comments predominantly concentrated on the interactive technologies including heating and ventilation (those that needed more than one variable in their installation, setup and operation). Here the interaction of several installers is required, along with the need to commission holistically if energy performance was to be achieved. However, when asked about the photovoltaic (PV) panels there was little comment from any of the stakeholders. The following extract indicated the isolated nature of PV in relation to the other low energy technologies, and was a factor in this low impact on the installation and commissioning issues:

Installation Observations

> **Client comment -**'Not connected in the flats, just on the Landlords supply, so we don't get any feedback from residents, therefore it's in a working unless we hear otherwise'
>
> **Client comment -** 'We can't claim the feed in tariff [government grant for energy used from PV technology for every KWh used], therefore, we get a bit of benefit for the communal lighting and rest goes on the grid, however we seldom check, and to be honest we don't really know because the bills are paid centrally'
>
> **Installer –** 'not our installation; [name removed] installed the panels and commissioned for the communal connection'

> **Clients Agent –** ‘Don’t affect the residents so no complaints, and the HA’s don’t even know its connected most times, its switched on and left’

From the observations, it was also evident that the PV installation was not connected to the individual dwellings in the blocks of flats, but formed part of the communal electrical network. This was primarily the result of the code and building regulations compliance, where PV is required as part of the code or SAP calculation. However, its connection is permitted to be communal as part of the compliance therefore, not requiring connection to the dwellings. As the communal connection is the most cost effective means of serving the blocks, this is the adopted method on most new build scheme including S3. Therefore, whilst the SAP and code are indicating benefit from the PV use, in actual operation, most if not all, the PV generated energy is connected to the Landlords supply. In S3 the connection contributes to the communal lighting and power, however this was small in comparison to the PV connected load. Therefore, this technology was seen as successful on the scheme, not in its ability to lower energy use for the residents or development, but as a cost effective means of connecting renewable energy for compliance, the majority of which, was not directly used on the scheme showing the carbon saving.

Conversely, the low carbon heating and ventilation technologies make their inefficiencies apparent in their operational use. What was significant was that whilst these performance issues affect the scheme, they were not attributed as affecting the ability to comply with the energy assessment criteria for the handover. Therefore, the building can be substantially under performing in heating and ventilation, and have a PV installation that does not directly contribute to the performance, as seen in S3. However, it will achieve a low carbon rating and certificate as the actual building performance criteria is not required as part of the

handover. The need for the installation and commissioning to correct these issues only become apparent long after the building is completed, and only when the client actively pursues the contractor for remedy. Therefore, at the time of handover as long as the certificates are in place the scheme is seen to have complied and is accepted by the client. The performance of the system does not become apparent, if at all, dependant on the H.A ability to monitor the development, until long after the system has been handed over.

These performance issues are again evident in S3 where overheating; energy performance and ventilation rates were below efficient conditions. Photographs Figures 6.7 and 6.8 indicate the issues observed with the insulation of the heating system pipe work. The photographs were taken on the upper floors of the completed blocks. After initial resident occupation when the external temperature averaged 17^{o}C.

Figure 6.7 Missing Installation on Primary Heating Pipe Work S3

Figure 6.8 Missing Installation On Primary Heating Pipe Work and Valves S3

Figure 6.9 Corridor Recorded Temperatures

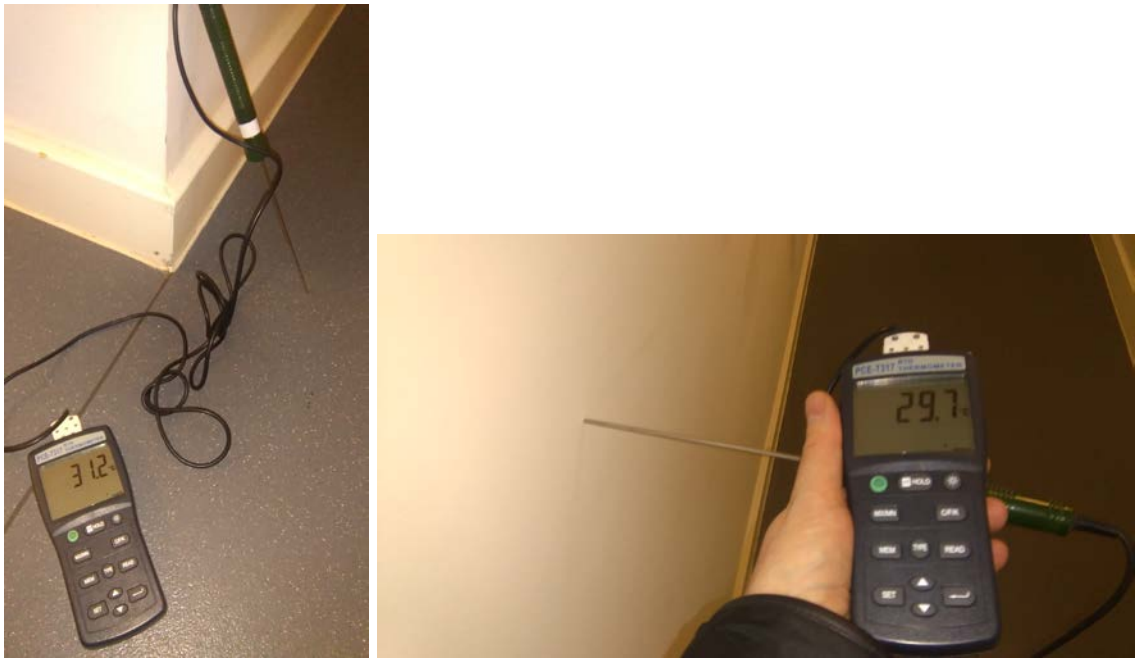


Figure 6.10 Corridor Surface Temperatures

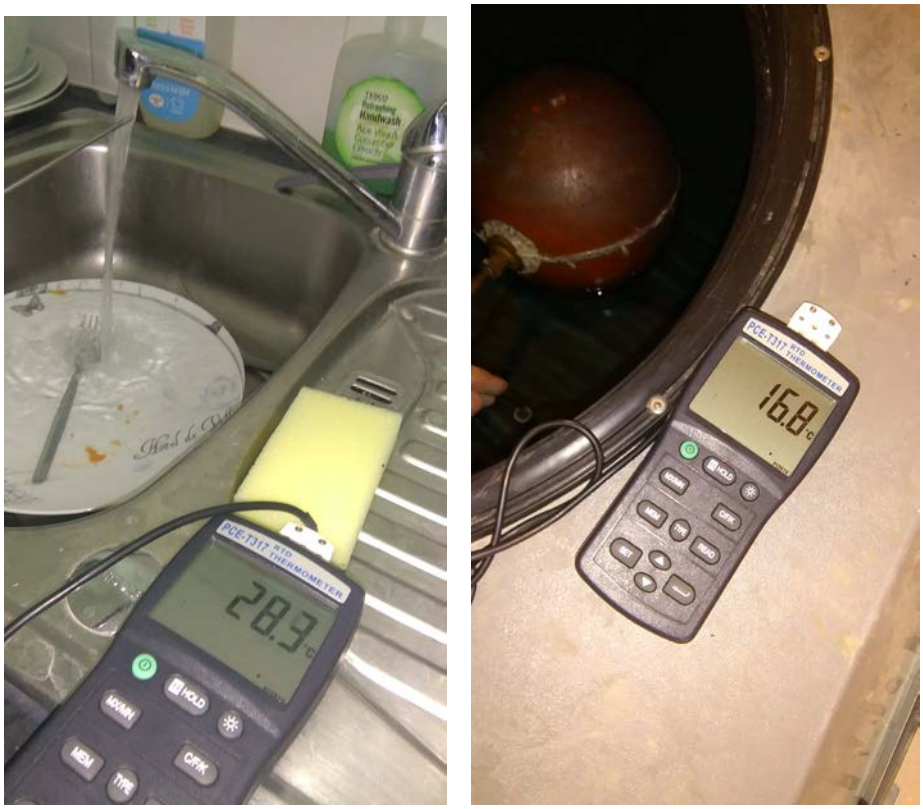


Figure 6.11 Dwelling and Main Tank Cold Water Temperature Test

The photographs illustrate the effect on the communal and dwelling areas caused by the installation issues for insulation of the distribution pipe work. Communal corridor surfaces ranged between 29ºC – 32ºC, with internal cold-water temperatures peaking at 29ºC – 35ºC before stabilising at 20^0C after 2 – 4 minutes, against a supply temperature of 16.8ºC, see figure 6.12 for cold-water temperature graph.

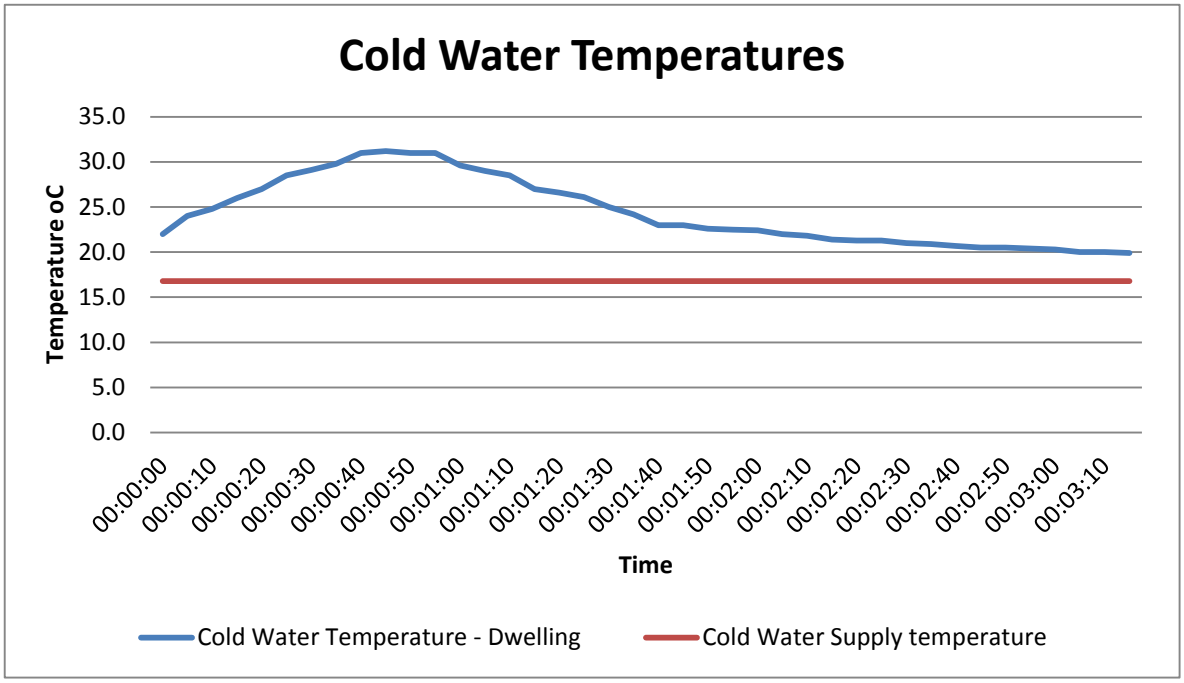


Figure 6.12 Cold Water Temperature Measurement within a Dwelling

The temperatures encountered, whilst slightly higher than S2, were in a similar range. Therefore, in addition to the performance up to handover, observed on S1 and S2, the effects of the heat loss was also apparent in the high internal temperatures within the building. When reviewing this with the main contractor during the defects period what was significant was that this was not regarded as an energy performance issue; with SAP and Code assessments being used to prove the installation had complied at the handover, and had been appropriately signed off at completion. The Contractor saw this as purely a comfort issue, dealt with, gauged on the number of resident complaints. Therefore, whilst poor insulation of the pipe work was not defended, and the contractor accepted the defect needed rectification, none of the stakeholders referred to energy or carbon performance as a consequential issue for remedy.

This was also observed with the dwelling heat recovery ventilation. Random samples of the dwellings accepted for handover indicated that the ventilation rates were below those recorded on the commissioning certificates. This was most noticeable in the fan speed settings for the units, which indicated the units set at higher settings to achieve the required ventilation rates. Photographs in figures 6.13 and 6.14 illustrate the installation of the mechanical ventilation with heat recovery (MVHR) and indicate the some of the probable reasons for the increased fan setting.

Figure 6.13 Installation of MVHR Duct Work - Flexible ductwork creating additional resistance in the system

Figure 6.14 Installation of MVHR Duct Work – Flexible Ducts over Extended Connections

Significantly, the duct work was carried out separately to the connection of the MVHR fan with an ad hoc arrangement for the installation, co-ordinated between the duct work installer and the ceiling and wall partition erectors. Also what became evident during the review was that the dwelling types were 'commissioned' and then all other dwellings were set to the same settings, thereby reducing time within each dwelling. Therefore, whilst commissioning certificates were completed for all units only single dwelling types were actually commissioned.

What became very apparent was that the energy performance for the building was seen as a separate function to the overheating or ventilation issues, with little or no inclination to deal with the situation beyond the comfort condition. The lack of effective installation and commissioning of the low carbon technologies not only had a direct and observable effect on the energy performance of the building, it also contributed to the evident comfort issues. Therefore, whilst performance was assessed and recorded as compliant the building was

operating outside the required parameters. However, what is significant was that due to the knowledge gap at installation and commissioning stages, neither the main contractor nor the client saw this as a noncompliance or contractual matter beyond the defect in hand. Therefore, even after attendance for a defect issue the underlying energy and carbon performance of the system was not seen as being at fault, more importantly it was not seen as part of the building issue at all.

6.5 Drawing Together the Observations

The observation method employed, as part of the action research, enabled an opportunity to be close to the actual process and to record, first hand, how stakeholders engaged in each activity. Spreading the observations across three different projects gave a unique insight, from the insider research perspective, into the 'real world' response to low carbon technology installation and commissioning. What has been significant is that there is an evident gap between what is seen as acceptable practice during construction and what is recorded as compliant through assessment. The observations indicate a 'two world' response to the low carbon technology, both operating in separate spheres, however, taken as reflecting the final building condition. The terms 'working' and 'performance' evidently divide these 'two world orders'; with 'finding a way to work' on the one hand and performance based assessment process on the other. One evidently interpreted by the construction stakeholders as an academic exercise, the other as a way to 'get the job done'.

The observations indicate that the recurring theme across the three sites has its foundation in knowledge, communication and trust. An unmistakable barrier in understanding exists amongst stakeholders, based on low carbon technologies that rely on an interactive approach for performance at the construction stages. This is compounded by the

management structure formed on the construction site, through the design and build process, which indicate that the teams are seldom a cohesive whole. Rather, the structure is one of a collection of smaller teams organically changing as the project progressed, with little or no monitoring of the requirement for energy and carbon performance. Therefore, critically the development of knowledge and knowledge exchange rarely achieved a consistent performance level. Tuckman (1977) identifies five stages of group development as seen in Table 6.6, which bond and structure a team. What is apparent from the observations, on all three sites, is that stages 2 and 3 were as far as the teams developed, with few reaching stage 4.

Table 6.6 Group Development Stages Tuckman (1977)

Stage of Group Development	Group Attributes
Stage 1 - Forming	Finding out about the task, rules and methods; acquiring information and resources, relying on the leader.
Stage 2 - Storming	Internal conflict develops; members resist the task at the emotional level.
Stage 3 - Norming	Conflict is settled, co-operation develops; views are exchanged and new standards (norms) developed.
Stage 4 - Performing	Teamwork is achieved, roles are flexible; solutions are found and implemented.
Stage 5 - Adjourning	Group disperses on completion of tasks.

Therefore, with the absence of monitoring of the system performance, the ‘ever present’ time constraints of the construction process, led invariably to the ‘path of least resistance’ with performance detached from the installed end result. If this is seen in the context of many of the working relationships remaining in stages 2 and 3, the evident resistance to overcoming the barriers between ‘working’ and ‘performance’ become more clear. Therefore, finding a more structured approach based on knowledge and monitoring would present a emergent strategy which could benefit the low energy and carbon installation.

Drawing the observations together, three significant interventions have emerged from the data gathered.

1. Monitoring of the installation and commissioning process with a primary view on system performance
2. Knowledge development for interactive low energy and carbon technologies commonly used for domestic installations
3. Process for a pragmatic delivery of system performance that can be followed throughout the construction process and explicitly recorded

After discussions with the stakeholder groups interventions based on these principals were trialled across the sample sites to observe any emergent changes to the construction process for low carbon homes.

6.6 Reflection on the Action Cycles

Continual reflection is an important asset of action research and allows a critical review of the process and the challenges encounter (Ivankova, 2015). Therefore, before moving to the investigation of the site interventions an exploration of the observation method and reflection on the process and outcomes is essential.

As identified by (Smith, 2001), the largest challenge has been to engage the main and subcontractors as part of the observations process. On all three sites there was a constant struggle to maintain engagement in the observations. This was especially seen from the subcontractors, who were predominantly individual self-employed and therefore, did not want to engage where this was perceived to affect their time on the project. Another barrier

was disinterest; installers saw their work within the confines of the task at hand and gave little interest beyond ‘the task that was given to them to perform’. Performance was considered as an additional function, and when discussed in numerous cases, met with a blank response or ‘ask the site manager, he’ll know more’. This is not to say that the construction site staff were unhelpful, on the contrary, observations were predominantly positive interactions. However, the wider view of an interactive approach was seen either as inappropriate to their task, or viewed as a negative reflection on their current function and therefore rejected.

Several site staff saw low energy and carbon performance as an important part of the development. However, time constraints and the ‘need to complete the job for handover’ meant, in reality, this had a small impact on the development. It did create an informal ‘low energy champion’ role amongst the installers, which did have a positive effect on the overall installation. This was witnessed on all three sample sites, however, the informal nature of the role did limit the effectiveness across all the installers.

All of the interactions were engaged in overtly with participants informed of the nature and context of the observations. Whilst observations were conducted unobtrusively, the researcher’s presence did have an effect on the work being carried out. It was identified that installers would cancel an observation if this were at a critical stage of the installation, thereby removing, what they saw as, a critical review. It was also acknowledged that there was a reluctance to give an opinion on the site processes regardless of the confidentiality reassurance. Therefore, whilst the ‘insider researcher’ role was emphasised and promoted throughout the sample sites, there was still an element of ‘outside’ experienced between the researcher and the stakeholders, especially when considering performance elements. This is identified by Merriam et al (2001) and the boundaries between the ‘inside’ and ‘outside’

need to be accepted. According to Hall (2000) and Gray (2011) the best that can be achieved is a negotiated position which enables appropriate data to be gathered. Therefore, the observations have limitations attached to the level of information shared during the sessions, and these limitations need to be borne in mind when making an interpretation of the data.

A significant element that has emerged is the amount of time required to arrange, conduct, write up and analyse the data collection. Whilst the insider research experience, within the field, acknowledges the time constraints of the construction site process, the often fractured nature of the observations was not envisaged at the start. Dickens and Watkins (1999) indicate this untidy nature of action research and tendency for the cycles not to go as planned. To an extent, this has been experience, leading to data not always being fully collected or observation abandoned or cancelled. Therefore, whilst the plan was not always able to be retained, the data does reflect the nature of the construction process and its participant stakeholders.

Reflecting on the validity and reliability of the observations an emphasis has been given to both the position of the insider researcher and the collection of multiple data to convey the evidence. The perspective of practitioner researcher (Gray, 2011) has given, the ability to have a comprehensive understanding of the processes, from 25 years of experience within the construction industry. This has assisted in giving validity to the action research process, however, it is also prudent to state, as observed by Brewer (2000) that it is essential ‘not to exaggerate the generalizability of the findings’ (Source: Gray, 2011:p416). Therefore, for validity these observations are based on data gathered for the action research and to initiate change in the researcher’s professional practice. From the perspective of reliability, evidence has been sourced from a number of strands of enquiry including the interviews and

questionnaires, supported by the observations, installation and commissioning data from the sample sites. This therefore, strengthens the quality and validity of the data used to identify the gap, and to support the results of the interventions in the action cycle.

This chapter has address the research sub questions namely:

> How do construction professionals communicate when installing and commissioning low carbon technologies?

In answering this question through the observations, test and commissioning data has enabled the research to look at the possible interventions strategies, which could be developed to improve professional practice.

Chapter 7 will investigate the creation of intervention cycles spread across the sample sites, and indicate the results from the strategies adopted. The findings will then be explored in Chapter 8.

Chapter 7

The Action Research Cycles – The Interventions and Reflection on Change

7.1 Introduction

This chapter explores the interventions, which emerged from the observations site data collected in the last chapter. Each of the intervention cycles are indicated, combining their impacts on the installation and commissioning activities. The interventions have developed progressively throughout the research, and as such, have been applied as they emerged at each of the sample sites. The cycles are therefore, explored individually based on the site applications, and as a collective development towards the emergence of a new working practice on future projects. The interventions are seen as individual actions and part of a graduated approach to a new working practice, they are indicated within the same chapter so that links can be made between the cycles. The chapter will conclude with a reflection on the interventions process and the resulting effects on the sample sites.

7.2 Interventions for Installation and Commissioning Process

The observations detailed in chapter 6, along with the reconnaissance information, including the questionnaires, interviews and focus groups indicated emergent themes from the data to inform the intervention cycles. What was evident from the observations was that three key barriers emerged from the pre-intervention dialog and monitoring of the stakeholder actions. Table 7.1 indicates the common pre-intervention barriers across the three sample sites:

Table 7.1 Common Pre-Intervention Barriers on the Sample Sites Taken from the Observations

Pre-intervention Barriers	Traits of the Barriers	Outcomes
1. No monitoring of the installation and commissioning	Poor installation standards	System becomes inherently inefficient within the building structure, therefore, possess long term performance issues
2. Limited Knowledge across the construction teams for the low energy and carbon installation	Inability to challenge performance standards	Early stage, high level challenge is not carried out and team do not understand the implications of underperformance of the system
3. No process link between the assessment performance and the actual performance of the system	Actual performance not as assessed performance	No structured process in place to control each stage of the system performance requirements, from design to completion, therefore, a cyclical return to item 1.

Significantly, these three barriers predominantly involved the interactive low carbon technologies, highlighting a cyclical process, which demonstrated contributory factors to the gap in low carbon performance. Each of the barriers formed the basis for the emergent interventions strategies, the outcome of which developed the structure for a new working practice. Figure 7.1 illustrates the flow process from the barriers, through the action cycles to the new working practice:

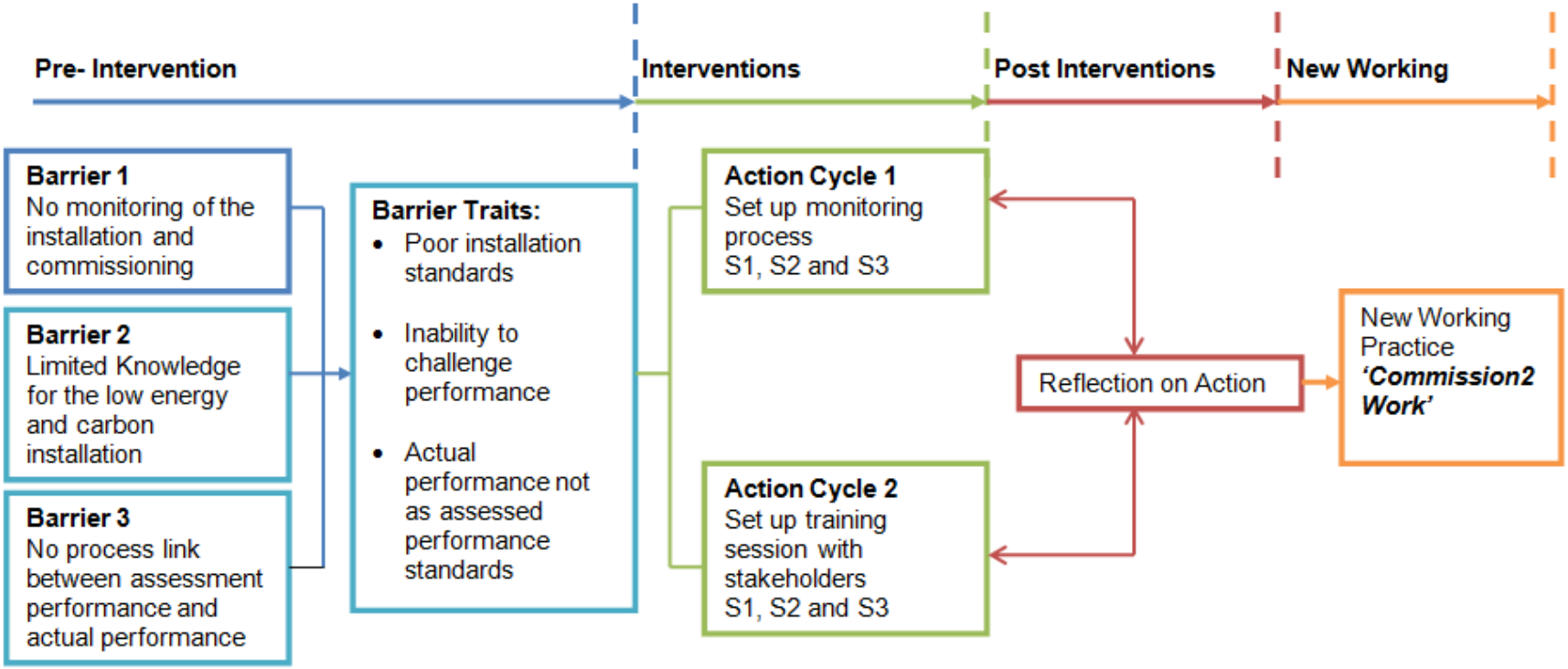


Figure 7.1 Illustration of Barriers and Intervention for the Action Cycles

The intervention cycles, as indicated in figure 7.1, are seen as the basis of a set of Critical Success Factors (CSF), which form the source of a new working practice. (Rockart, 1982) first used CSF in the context of information systems and project management and defined it as:

> 'Those few key areas of activity in which favourable results are absolutely necessary for a particular manager to reach his or her own goals - those limited number of areas where 'things must go right.'

This definition from the theory delineates the aims of the action cycles for improving the performance outcomes for low energy homes. Abraham (2003) further identifies eight CSF for the construction industry these being:

1. Structure of Industry
2. Competitive Strategy
3. Market Conditions
4. Political Environment
5. Organisational Structure
6. Employee Enhancement
7. Technical Applications
8. Process Benchmarking

Whilst the first four are external issues influencing the organisation the last four are internal issues under the direct control of the company. The action cycles for this research centre on the last two factors, and as acknowledged by Abraham, these internal factors give emphasis to 'the accommodation for change' (Abraham, 2003:p9). Therefore, as identified from the barriers seen in the observations, the technical and process benchmarking factors are

pertinent to the creation of change within the professional practice recognised by the research.

Developing on from the observations, the interventions cycles were discussed with the stakeholders on each of the sample site before being put into action. Where cost or time implications were involved in the intervention agreement was required before starting on site. Consequently, these intervention were limited, but still indicated a change response where engaged. There was reluctance from the site stakeholders to engage in any interventions that had a direct effect on the contract programme. Therefore, some of the cycle interventions were abandoned due to site time constraints. Mills (2011) observed this reluctance and disengagement, which was often associated with the fear of the unknown and an unwillingness to adopt change. Tomal (2010) argues that an understanding of the change process is essential for action research based primarily in problem solving. Therefore, due to the phased nature of the schemes, the cycles adopted an adaptive strategy, whereby methods used between the schemes was shared and adapted as the interventions progressed. Whilst some strategies were abandoned, the learning could be transferred to the cycle on another site. However, the struggle to engage the site stakeholders was experienced throughout the action cycles and did impede the ability to fully investigate the interventions.

Take up of the interventions was inevitably different on each of the sample sites and this is reflected in the level of involvement and engagement from the stakeholders. However, as identified by Ivankova and Sticks, adopting ‘multiple ways of seeing and hearing’ (ibid, 2007:p9) by using the mixed methods approach has allowed multiple ways of making sense of the actions through the practitioner researcher approach. Therefore, whilst the

engagement was varied between the sites, the insight gained across the sample gave significant data for the research, some of which was not expected.

7.2.1 Intervention Cycle 1 - Monitoring

The monitoring cycle was set up in a similar way on the three sample sites. This took the form of an extension to the observations; however, the extended role now included an interactive element on the installation and commissioning processes. The intervention was structured to review installation and commissioning, as scoped in the contract, and to raise performance issues during the process to identify relevant critical success factors. The contractual scope in each case did not include a performance criteria for the low carbon technologies, rather stating that the technologies should be to ‘manufacturer’s requirements’ as limited within the employer’s requirements.

Significantly, none of the sample sites agreed to have the intervention performance issues added to the contractual obligations for the completion of the project. However, they were willing to take part in the intervention for monitoring to gain any future benefits. There was an inherent weakness in the performance element of the monitoring, whereby at critical points in the project, unless the performance issue was a contractual requirement it was often ignored. Therefore, whilst performance was discussed, and the benefits could often be appreciated by the installers, the direction from the main contractor was predominantly one of compliance only. Figure 7.2 illustrates the process for the monitoring cycle across the sample sites:

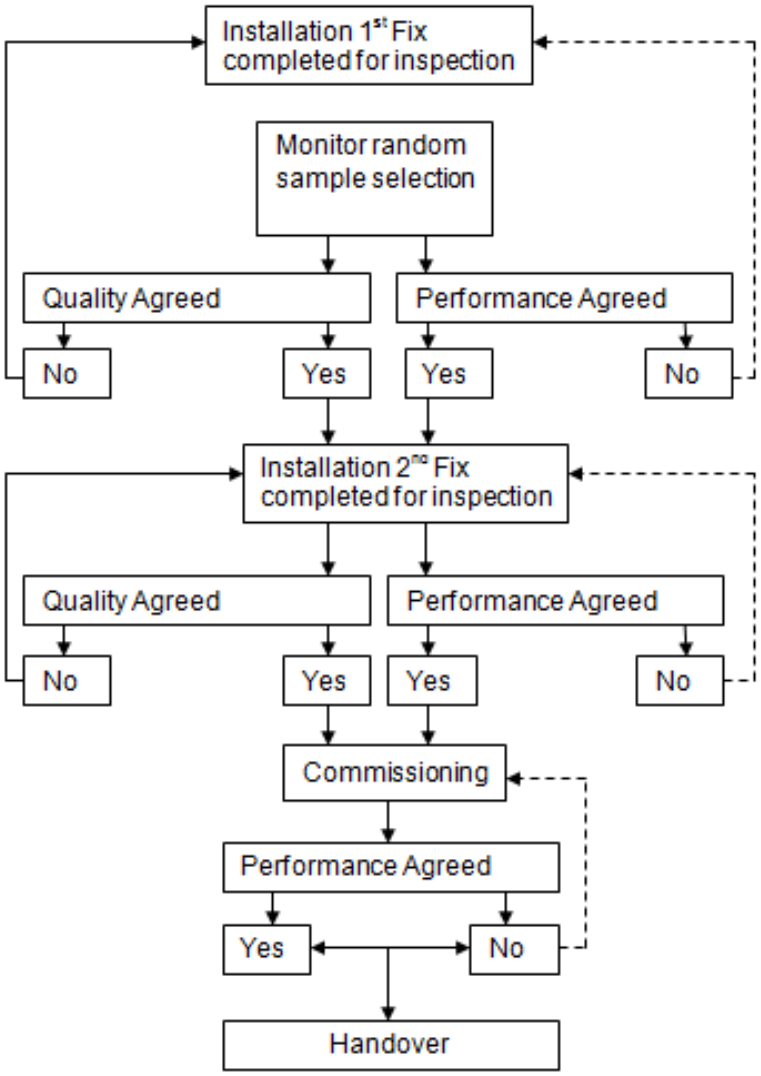


Figure 7.2 Illustration for Monitoring Intervention Cycle

The dashed line for the performance elements indicates that this was not a direct feedback item, accepted or undertaken by the construction stakeholders, if considered outside the contractual requirements. This was also acknowledged by the client's agent, and the direct client, with the term 'best endeavours' often used across the stakeholder groups when referring to the energy and carbon performance. Significantly, intervention performance beyond the contractual obligation was seen as achieving an optimal goal, by the majority in

the stakeholder groups, with a functioning system accepted as the ‘normal’ requirement, as referred to in the following extract:

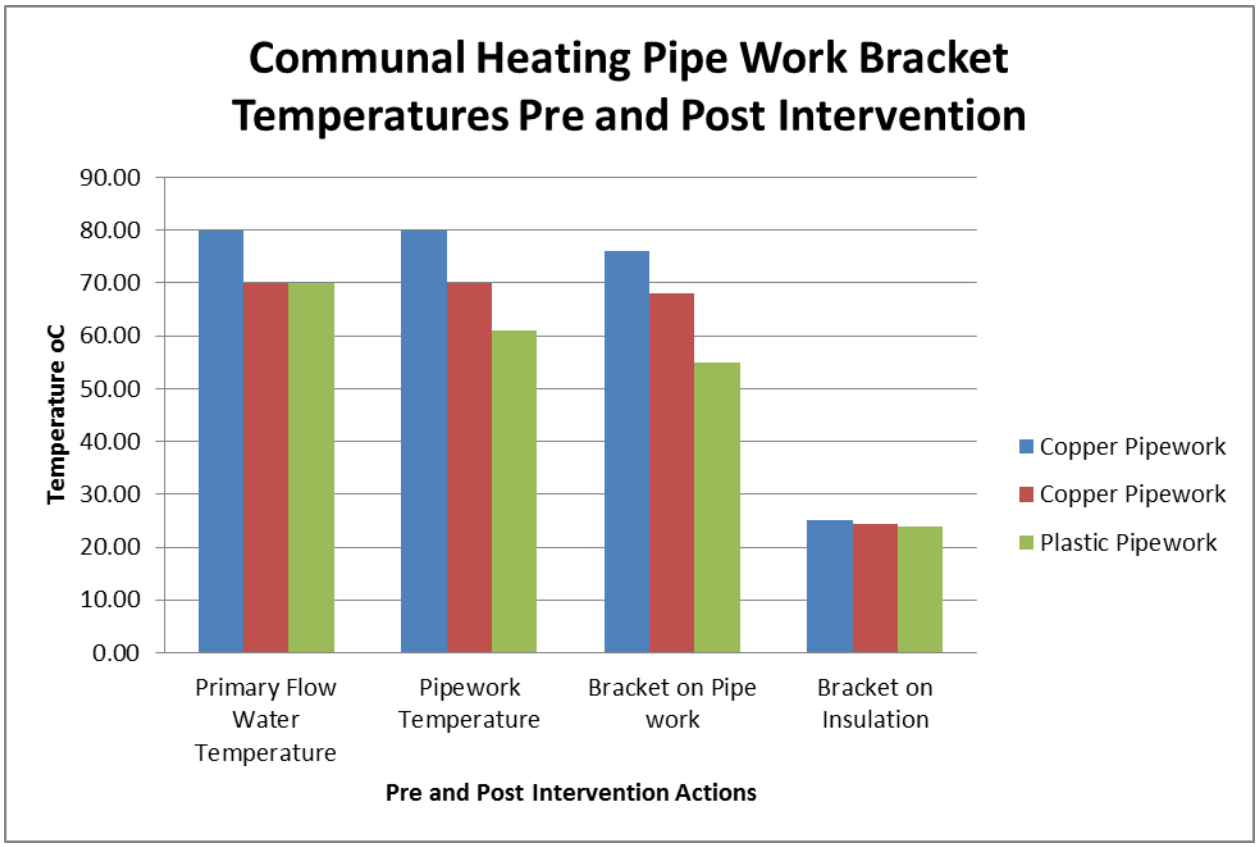
Client Agent

> ‘let’s get it as good as we can get, but without spending too much time and too much money – we have to get it built at the end of the day’

However, the monitoring intervention cycle did influence the early 1st and 2nd fix installation issues surrounding insulation of duct work and pipe work on S1 and S2. Resistance to quality and performance issues raised, through the practitioner researcher role, was minimal as there was little impact on time and cost. This was demonstrated in the intervention to change the installation of the heating pipe work support brackets, where the bracket was secured around the insulation as opposed to the pipe work. The installers on S2 and S3 stated that this saved time on insulation, not needing to cut and join the insulation at each bracket position. On a performance level, this also assisted in reducing the heat transfer from the pipe work and brackets to the building fabric, as the brackets were insulated away from the surface of the pipe work (see table 7.2). However, whilst this was discussed with the stakeholders as beneficial for the building performance, cost and time constraints were still seen as the primary benefits to the construction team.

Table 7.2 Difference in Temperature on Support Brackets for Primary Heating Pipe Work on S2

Pipe Work	Flow temperature	Pipe Work Temperature	Bracket on pipe work ^0C	Bracket on insulation ^0C
Copper Pipe Work	80^0C	80^0C	76^0C	25^0C
Copper Pipe Work	70^0C	70^0C	68^0C	24.5^0C
Plastic Pipe Work	70^0C	61^0C	55^0C	24^0C



What is evident from Table 7.2 is that there is an average 42^oC reduction in the heat transfer to the bracket by securing the pipe work support around the insulation. This intervention therefore, reduced space overheating and heat loss in the system performance.

Photographs in figure 7.3 indicate the insulation changes made on S2 because of the intervention feedback loop on the monitoring

Pre-Intervention – Bracket around pipe work with heat transfer to building fabric

Post Intervention – Bracket around insulation substantially reducing heat transfer to the building fabric

Figure 7.3 Insulation Pre and Post Intervention on District Heating Pipe Work

The monitoring intervention cycle did indicate that the ability to make a critical and simple change could have a positive effect on the performance of the building and technology. Raising this as a critical success activity did engage the change with the site teams. However, the willingness to change installation practices on site was more challenging if it went beyond simple change. Actions that were seen by the installer as additional work were

often resisted or ignored. This is demonstrated when monitoring the set up and performance of the exhaust air source heat pump (EASHP) on S1. Initially it was agreed, as part of the monitoring intervention with the site manager and installers, to maximise the performance of the heat pump by optimising the heat output, thereby lowering the electrical energy used. Hot water temperature settings were to be co-ordinated with the blending valves (to control hot water temperature by mixing with mains cold water) on the baths to achieve 43^{o}C - 48^{o}C (NHBC requirement to reduce scalding). The under floor heating flow temperatures were also to be optimised to reduce the heat pump output temperatures, whilst still achieving the required room temperatures. Each process required adjustment at the heat pump and the blending valves, for the baths, and the heating manifold (distribution and thermostatic control point) for the heating circuits. The pre-intervention strategy was to set the blending valves and manifold and adjust the heat pump to achieve the temperature required. This led to higher output from the heat pump and therefore, wasted energy. The intervention strategy was to adjust both to achieve the optimum setting. This was initially monitored for the first week and required additional time in each dwelling to correctly set the temperature to reduce the heat output from the EASHP. Feedback from the installers, as indicated in the follow extract, found this to be time consuming and unproductive:

Installer

> ‘Balancing the two is taking too long, we always set the valves [balancing] and adjust at the boiler, these heat pumps are no different and they can go up to 60^{o}c, so what’s the problem’

Site Manager

> ‘get it as good as you can, but I can’t hold off fitting the bath panels for ever. I’ve got to achieve an output at the tap and for the under floor, that’s it, so not sure how long we can tolerate this’

Whilst increased performance was achieved, the working practice and time constraints resulted in the intervention being abandoned and adjustment made at the ASHP only. Therefore, the technology and its energy performance was given a lower consideration to the requirement of ‘setting to work’ of the system. A key word used repeatedly in the intervention cycle by the contractors was ‘tolerate’. This referred to actions on performance outside the requirement to operate, which were not seen as a primary concern, therefore, ‘getting in the way’ of the project at hand. What was evident from the intervention was that the installers did not consider energy performance issues beyond those immediately covered by the set up of the system to work. Figure 7.4 indicates the heat pump temperatures recorded in the sample dwellings pre and post intervention:

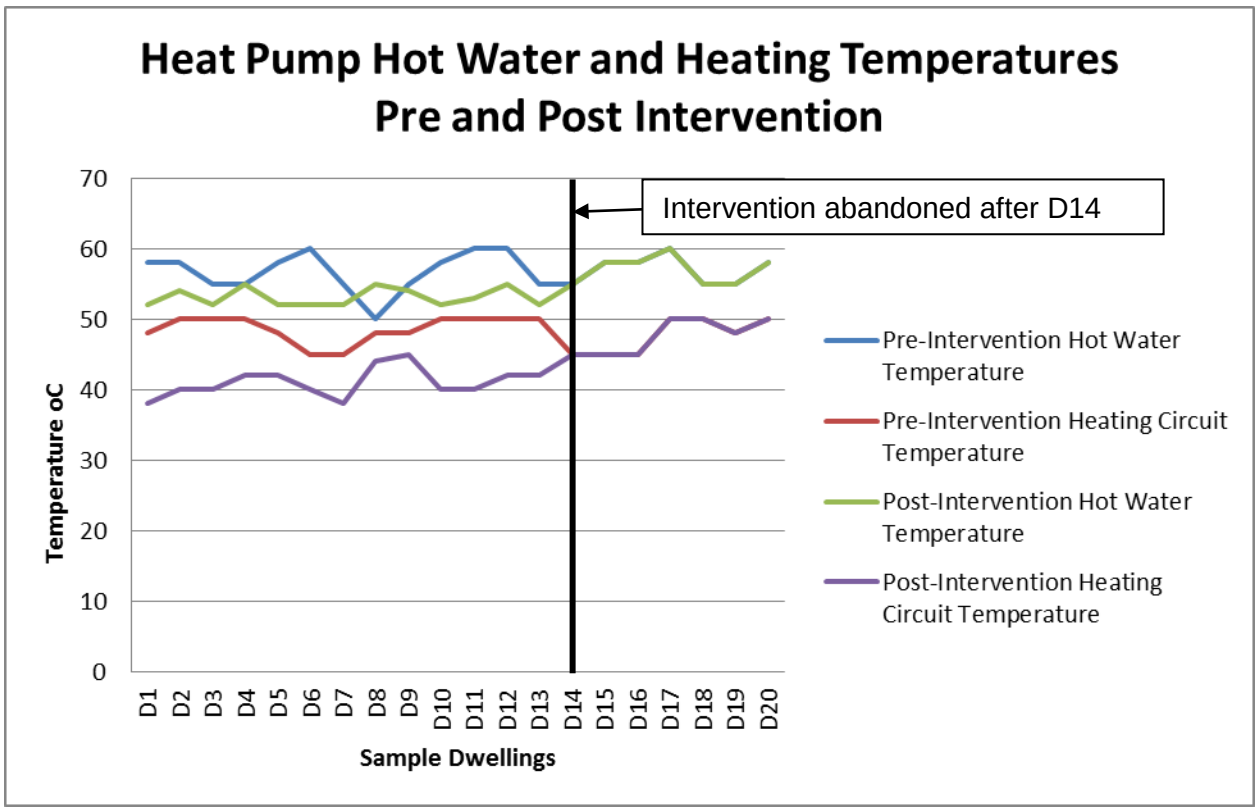


Figure 7.4 Heat Pump Temperatures Pre and Post Intervention

Figure 7.4 demonstrated that lower operating temperatures were achieved at the heat pump if a co-ordinated approach was taken to the commissioning of the heat pumps and the hot water circuits. The interventions were only taken up to dwelling D14, therefore, after D14 both hot water and heating temperatures returned to the higher settings as the intervention was abandoned. Average operating temperatures for pre and post intervention (taken up to D14) was 57^0C to 53^0C for hot water and 48^0C to 41^0C for heating, therefore indicating a reduction respectively for heat output from the commissioning exercise. However, the reductions were not seen by the installers as worthwhile compared to the additional time required in each dwelling to achieve the intervention settings. Significantly, the reductions, whilst beneficial to the residents, were not cost effective for the subcontractor if not otherwise obliged to complete. This again identified the evident split between operation, performance and cost in the installation and commissioning process. Therefore, indicating

that a critical success factor for improving energy efficiency on the heat pumps, would need to be mandated through the contract to ensure success at the site operation level.

Reflecting on the first intervention cycle, engagement and participation was a significant hurdle throughout the monitoring cycle. A contributory factor to the reluctance to commit on the part of the contractor was not only the time and cost implications, whilst these were disincentives, a lack of understanding of the performance issues also reduced commitment. However, it was demonstrated that performance could be improved from simple interventions, which had significant effects on the performance on the technologies installed. The results indicated that the pre and post conditions showed time and cost remaining as the critical success factors (CSF). Therefore, knowledge enhancement, monitoring and the critical requirement of low energy performance would need to be mandated to develop and change the nature of the CSF.

The second intervention cycle concentrated on knowledge of the low energy performance elements, based on information sharing and training. The stakeholder groups were approached to undertake a series of information exchange interventions, both on and off site, to gauge the impact of knowledge sharing and exchange.

7.2.1 Intervention Cycle 2 – Knowledge Sharing (Training)

This intervention cycle was split into two separate intervention activities, one remote from the site devised as a training session in energy performance derived from site activities, the other based on site knowledge share. The split in approaches emerged from the first intervention cycle, where stakeholders at S2 indicated a willingness to be involved in both remote and on site knowledge share. Whereas S1 and S3 stakeholders were more inclined

to site based knowledge sharing, not willing to commit to a wider stakeholder process. The interventions were therefore set up as indicated in table 7.3

Table 7.3 Knowledge Sharing Interventions on S1, S2 and S3

Development	Knowledge Sharing Activity	Participants
Site S1	On-site training with heat pump manufacture	Installers/site manager/client
Site S2	Off-site seminar for communal heating system performance Follow up review on site	All site managers and supervisors/client/designers. Site manager
Site S3	On-site training with HIU manufacture for dwelling set up	Installers/site manager/client

Site S1 intervention invovled the manufacturer of the heat pump technology to give advice on the installation and commissioning to the installers and site manager. The intervention was supported by the site and client stakeholders to investigate a more effective installation and commissioning process for the heat pump as a result of the observations and first intervention cycle. The manufacturer's specialist team were engaged to review the installation and commissioning and to comment on standards and share expertise for performance. Figure 7.5 indicates the process for the site intervention on S1:

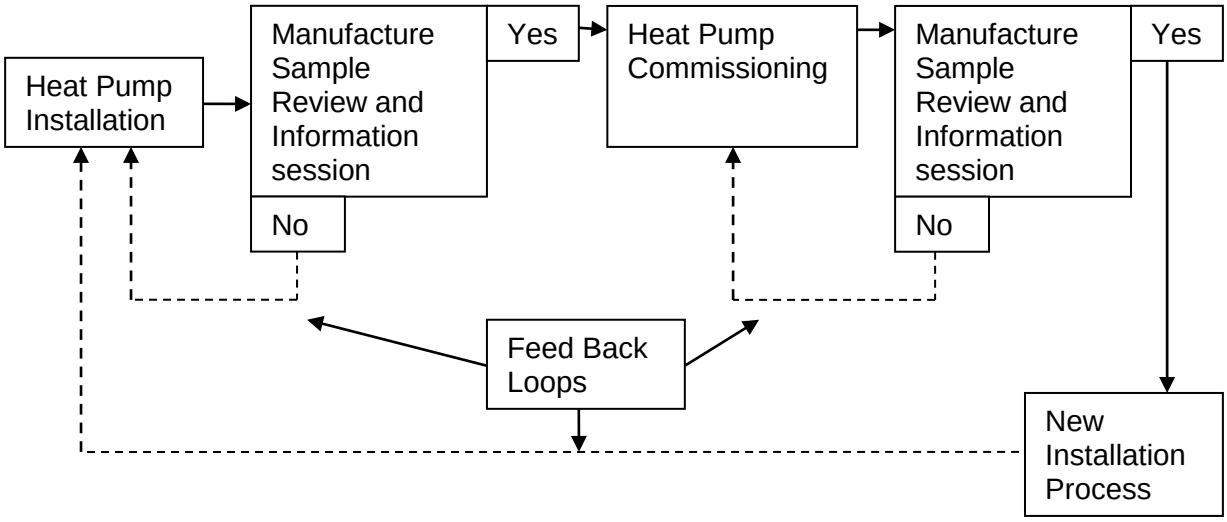


Figure 7.5 Heat Pump Intervention Process S1

The manufacturer attended site for five session, each lasting approximately 2 hours, to review a sample of 5 dwellings with the installation team (See appendix 10 for sample inspection sheets). The intervention identified four main performance issues (in addition to those from intervention cycle 1), which were discussed and demonstrated to the installation teams, the site manager and client. These can be seen in Table 7.4.

Table 7.4 Interventions for EASHP from Manufacture Training and Site Review

Intervention	Outcome
1. Reducing flexible duct work lengths on terminal and heat pump unit connection points	Reducing resistance in ventilation ducts and allowing reduced fan speed to reduce energy use
2. Pump speed set up to reduce flow rate. Pump speed setting 1 – 3, reduced from 3 to setting 2.	Return temperature reduced increasing the efficiency of the heat delivered to each heating circuit
3. Selection of weekly rather than daily purge setting for hot water temperature increase to 60^0C for legionella prevention	Hot water temperature increased from average 53^0C to 60^0C per week only therefore reducing daily energy use for temperature rise.
4. Reducing fan speed for ventilation whilst maintaining required ventilation rates in each room	Ventilation rates at terminal positions controlled to allow fan speeds to be reduced

All stakeholders saw the last three interventions as positive, as the methods were simple and easy, both to see directly and to understand and therefore, these were adopted across the site. Significantly, the site manager involved the defects managers to check these outputs as part of the defects checklist. This had not been carried out on the previous pre-intervention phase therefore, defects related to higher energy bills were revisited on phase 1 and settings reduced. In this way, defects related to the technology performance were reduced. However, it must be said that the recording of heating and hot water defects on all the sample sites were difficult to interpret. Defects were recorded as ‘faulty heating’ and ‘unit not working’ without further explanation of the defect issue, and could not therefore be used in the research.

A criticism of the research was that the defects process was not able to be structured to define the low energy technology issues. The defects were dealt with through a ‘help desk’ recording and actions process, which did not form part of the intervention review. Therefore, the defects lists record actual resident descriptions and call out response, but without the technology issues included.

Intervention 1 proved more difficult to engage as the ductwork had already been installed therefore, ventilation rates at the terminal points, once set to the required level (28l/s or 31l/s dependant on the heat pump size), predetermined the final fan speed. There was reluctance to change the ductwork runs once installed beyond shortening the terminal position flexible ducts, where they could be accessed. This did have a noticeable effect, as many terminal points were considerably longer than the maximum 750mm length stipulated by the manufacturer, creating higher resistance points. Beyond this, the last intervention point was abandoned and not considered further on the scheme, but was recorded by the site team for future projects. However, it was noted that this simple action again gave a reduction in the fan speed and subsequent energy use, which would have otherwise been left as a later resident issue.

The interventions did highlight the lack of knowledge amongst the installers and the tendency, due in part to time constraints, to leave the units at their factory settings as this extract from the training sessions indicates:

Installers

> ‘I would never have looked for the setting for the legionella purge; daily or weekly I would not have thought about the energy use – So simple, but I’ve never done it before’
>
> **Observation** – (from the discussions at the technical sessions with the heat pump specialist) - Installers stated that the units came set on pump setting 3 and the legionella purge setting was never reviewed therefore, they were left on factory setting. During commissioning the units were set for heating and hot water outputs, but adjustments were rarely made once the under floor heating came up to temperature and

the hot water operating. It was noted that the flow and return temperatures on domestic systems are rarely checked, 'it's on or off and move on to the next flat'. It was stated that the system was set up with the flow temperature agreed with the under floor heating manufacturer and not the conditions required by the heat pump. Therefore, a standard setting had been agreed for the flats and all were set to this condition without further checks. It was noted that underperforming heating loops were tackled as part of the defects period, if they were reported.

Client

Observation – (from client attendance at the training session) – Simple checks were noted and questioned why these were not standard for the installers. Need to make minimum standards for defects checks.

It was significant that there was a link made between the performance, the installers practice and the co-ordination activities for the main contractor as a consequence of the intervention. Therefore, the knowledge sharing intervention gave some empowerment to each of the stakeholders to input into the performance of the technology. What emerged was a willingness to engage, to an extent, in the performance of the technology across the stakeholder groups. However, the engagement was as a consequence of simple and repetitive actions and did not lead to wider commitment to the low energy and carbon output for the development.

The result of the intervention clearly indicated that response to carbon reductions was at a relatively superficial level, with no real concerted effort to improve performance. However, a change in performance was demonstrated and this was adopted and recorded by the construction team (see appendix 9 for a sample completed post intervention test sheets and thermal images). Therefore, this demonstrates that increasing knowledge, even when the resistance to change is evident, can still contribute to performance if undertaken at the critical stage of the installation and commissioning. However, it must be said, that unless there was actual contractual obligation the perception was of 'additional works' to achieve performance. Therefore, unless performance is mandated and monitored the likelihood of sustained change is very low. It was evident from the intervention cycle that the disconnect between installation and performance is substantial, needing a concerted effort to bring about optimum performance within industry.

Site S3 had a similar intervention 'on site' review to S1, in this case for the communal heating system. Two areas of system performance highlighted the disconnect within the installer's view of the working system. Firstly, the intervention for the communal system established that the HIU set points within the sample units were at their maximum of 80^0C, and had not been adjusted for the secondary flow temperature for hot water and heating in the dwellings (60^0C / 70^0C respectively). Secondly, the external bypasses (used during the commissioning of the pipe work) on each floor for the primary system, had been left open after commissioning, causing the central pumps to operate with a flow and return temperature almost matching at 80^0C flow and 78.5^0C return (design 80^0C flow and 60^0C return). The dwelling HIU and communal primary systems were commissioned separately leaving open bypasses as part of the final dwelling commissioning. What was significant was that the installers did not recognise the energy and heat loss implications of the flow and return temperatures, as this was not a direct commissioning requirement. Therefore, as the

system operated and hot water and heating was achieved, the system performance was not reviewed or questioned. This was evident in the following extract during the intervention:

Installers

> **Observation** – (during HIU review) – Separate commissioning for the plant room and the dwellings. Dwelling commissioning for heating and hot water only concerned with dwelling side of the heat exchanger therefore, primary temperatures not noted as long as secondary side was working. It appeared the sample HIU was completed then all others set up the same. Primary side commissioned with bypasses open earlier in the installation, bypasses not subsequently closed. Variable speed pumps set to manual operation. Building Energy management system (BEMS) recording as seen with no control set up.

As part of the intervention, the HIU installation was reviewed with the HIU manufacturer and installer to explore the performance of the dwelling. Each of the sample HIU's were inspected, but as an extension to the first intervention cycle, the energy performance was discussed with the installers as part of the change process. In this way knowledge sharing was seen as an additional facet of the exercise. It was evident from the discussions that the principles of achieving a low energy output were not part of the subcontractors commissioning process. There was a fundamental difference of understanding of the operation of the communal heating system as opposed to an individual boiler installation.

Installer

> Observation – output from the radiators and hot water was seen as the main requirement. Discussion on lowering flow rate and return

temperatures were seen as additional work and not in the requirements for the scheme. ‘It’s similar to a boiler’ was a common response to the setup and commissioning of the HIU. Discussion on heat removal from the communal system to make it more efficient were seen by the installers as a ‘new idea’ and not part of their past installation knowledge.

The installers were receptive to the energy performance information, however indicated that there was a complete disconnect between the performance needed and their experience to deliver what was required.

Site Manager

‘To achieve what’s required here we need a much tighter link with the designers and installers as both need to make sure this is efficient’. The discussion identified a greater degree of involvement at the commissioning stages, and one that had not been undertaken before on previous schemes. Closer involvement with the design and manufacturer’s were seen as important. It was also noted that greater care needed to be taken in the dwelling where simple gains were lost due to not checking or recording actions.

It was demonstrated that the dwelling installers commissioned in isolation to the main communal system. This was not done out of an expedient method of installing and commissioning communal heating systems; but from a lack of understanding of what was required from the low carbon communal system. Therefore, commissioning certificates were completed, in isolation, without the

energy performance considered. The learning from the intervention challenged the concept of a commissioned system as captured in a statement from the site manager during the review:

Site Manager

> 'I can have all the certificates and a completed O&M and it's still not working as it should, how do I guard against that – we need someone watching over the lot and something that actual says what's required'

The intervention revealed an element of the gap between the installer's concept of performance and the actual performance of the system. It also confronted the fact that commissioning was carried out with little communication between the site teams. The intervention demonstrated that engagement through monitoring and knowledge transfer did improve the communication level, encouraging installers and site managers to question standards. Significantly, whilst the two intervention actions were developed and demonstrated improvement, there was no wider engagement in energy performance. The installers saw the energy and carbon performance as outside the contract, and consequently an issue dealt with as a separate energy reduction project. Subsequently, higher energy bills noted from the metering and billing provider in the first year were seen by the constructor as maintenance issues, and not as a result of the lack of commissioning or management during construction.

On site S2 the intervention differed in that a course of 'off site' seminars were conducted with the contractor involving the site managers and supervisors (see appendix 10 for the seminar presentation). Between January – March 2015 six 2 hour seminar were conducted to give information on low carbon installations. The seminars were conducted, by the

researcher, with the aim to give working knowledge and to enable initial challenge by the main contractor on sub-contractor installation. These knowledge gap areas, having been identified, in the observations and the monitoring intervention cycles formed the basis of the presentations. The seminars involved an interactive exchange with the site teams on installation and commissioning to enable discussion on key installation processes. A significant outcome from the seminars was engagement and communication across all of the site management and supervisor teams for the company. What emerged from the activity was an almost universal expression of confusion and lack of knowledge of energy performance. The following extract indicates a common theme from the seminar sessions

Site manger

> **Observation -** during the seminar feedback session – The site managers expressed concern at their lack of knowledge for the M&E installation on low carbon projects. There was a consensus that they could not possibly know all that was going on, and that supervision was required on the site. However, there was a keenness to have some simple tools to help challenge installation standards. The point was raised that they had to 'trust' the commissioning certificates, as there was no way to re-test within the time scales and knowledge on site. 'We pick the 'tried and trusted' subcontractors so we don't have to check, but maybe we should be checking'

It was evident from the intervention feedback that regardless of the monitoring, there is a tendency for trust issues to affect the construction process, often shaping the contractor relationships from an early stage in the construction. Where these are seen as 'tried and

trusted' relationships then the installation activities and commissioning results are rarely questioned.

Site Manager

> 'They know what we want, how to get it done and without taking us on from a cost point of view' – 'we all have our days when it doesn't go right but on the whole they get it done, but this performance issue is a different kettle of fish'

Significantly, the relationships when discussed in the intervention seminar, were often only at the senior level, with the actual installation and commissioning being engaged by unknown individual self-employed contractors. Therefore, what was seen at the senior level as being a 'known contractor', may at the site level be an unknown self-employed operative. Unchecked installation and commissioning, unless picked up as a defect issue remain unknown, and performance issues only dealt with if directly challenged during the defects period. As optimum carbon reductions are not a critical success factor or key performance indicator, they invariably remain unaltered throughout the life of the technology. Therefore, the known subcontractor performance is subsequently not seen against low carbon performance, but on completing a project at agreed cost with minimum defects. The seminar responses also identified that mechanical and electrical subcontractors, by the nature of the installation, were considered the most problematic on site. Invariably it was seen that the known contractor was often:

Site Manager

> 'the lesser of two evils as we always struggle with the M&E' (mechanical and electrical).

What was clear from the feedback was that the more complex nature of the low carbon installations challenged the ability of the subcontractor to perform, and the main contractor to manage, within a process they did not fully understand. Manu et al, (2015) recognises these challenges and argues that mutual control mechanisms must be in place to improve the quality and performance of low carbon homes. Therefore, the concept of critical success factors, as a basis for knowledge growth and energy performance, was acknowledged from the intervention feedback. However, without a control mechanism a majority thought that improved performance would not be achieved.

The seminars set out a selection of simple visual reviews (see appendix 10) to allow the site managers to engage in installation checks, whilst understanding why those checks were important for the installation and commissioning process. The sessions focused on low energy communal heating systems and general installation practises common to the site. What emerged from the sessions was a willingness on the part of the site managers and supervisors to engage in the process. Also, to see the benefits of having key working knowledge of basic installation and performance methods, which could influence the installation. What was revealing was that the concept of optimum energy efficiency and carbon reductions was not seen as attainable currently on site. It was seen as a specialist discipline, and the connection to the building process, as a whole, was not readily made. Time and cost constraints were a repeated discussion point in all of the sessions with typical comments of ‘but it’s got to get built’ and ‘it keeps changing how do we keep up’ prominent in the debate.

A noticeable benefit from the seminars, with all the site managers and supervisors in the organisation, was the significant investment for the site stakeholders, which did give

credence to the intervention. Therefore, in conducting such a larger company wide seminar session, the action influenced the elementary view of improving quality in their low carbon housing project. This can be evidenced further, in that, the seminar sessions were followed up with a site visit after the sessions were completed. Significantly, standards for the pipe work and ductwork installation had changed on the site, with the bracket around the insulation, and protection to the ductwork, being adopted on the later phases. The intervention also increased communication on S2 and at the company level, demonstrating the company wide learning approach had a positive effect on communication. However, time was still one of the main contributory factors inhibiting further participation for the intervention. Therefore, change was limited without the time to engage and contribute further.

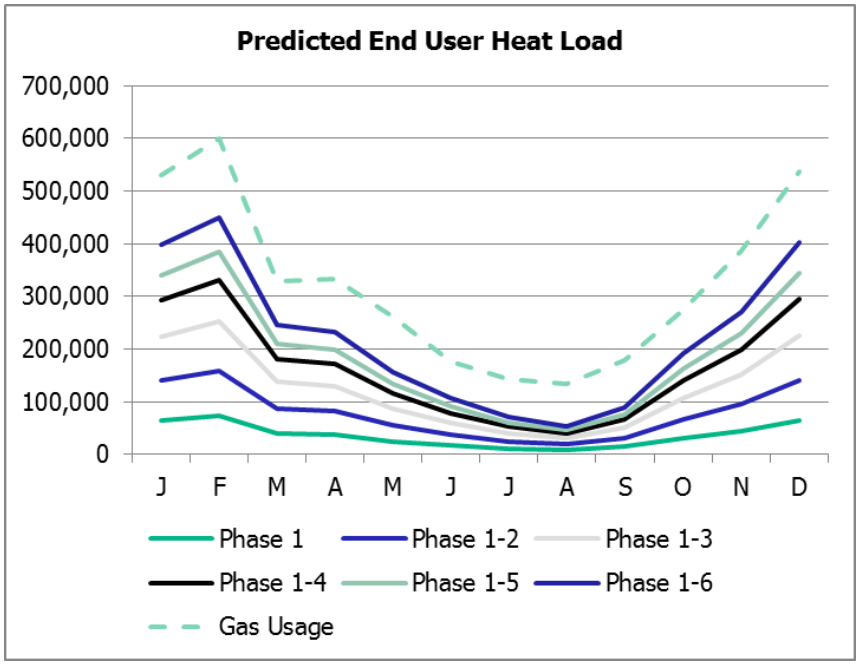
Building Information Modelling (BIM) was discussed as a result of the review to extending the monitoring and checking process. This was seen in the discussions as the next step to integrating design and site activities. However, it was observed by several of the site managers that the services subcontractors, invariably being small or sole traders, would not have ready access to this technology. This was therefore, identified as a potential barrier to using this technology on domestic construction, regardless of its possible coordination benefits.

From a knowledge perspective, the sessions were of mixed effect; the participants in the sessions each retained some key knowledge, using them to initiate change. However, without a refresher session many of the participants lost momentum once back in the site environment. What did emerge, was a small core of managers and supervisors within S2, and the company at large, that did retain the key working practises. This was developed further by the site team to purchase simple temperature and ventilation monitoring

equipment, which was used on S2, to sample the installation and commissioning activities. This had a further unexpected result, in that, there was increased engagement between the site, monitoring and client team that extended beyond the intervention action.

This increased engagement and communication instigated a client-sponsored review of the energy performance of the S2 energy centre (main heat and hot water plant room), in addition to the contractual requirements for completing the phased works. This was a significant, and unexpected, outcome of the increased engagement and lead to the examination of the performance of the main energy centre. This involved a site team and researcher investigation, which enabled a reduction in the size of the plant designed for Phases 3 onwards. The original design of 9MW heat load for the development was challenged using the monitored dwelling heat meter information from phases 1 and 2. The appraisal enabled the total site heat load to be reduced to 4.0MW therefore, establishing that the original design had overestimated the heat load by 56%. Table 7.5 indicates the reduction in heat demand and the projected energy using the heat meter data from phases 1 and 2 to project to the completion at phase 6.

Table 7.5 Predicated Heat Load Reductions for S2



Whilst it is recognised that this was not an outcome of the intervention, the engagement never the less, had an effect on the performance of S2 through the on-going phases. Therefore, this demonstrated that once performance was reviewed, as part of the construction process, wider energy performance issues could also be explored as part of a whole development review.

It must be identified however, that this was a separately funded work stream, and not considered part of the contractual delivery for the project. It is also important to recognise that this separate engagement was carried out at the design level and did not extend beyond the review of the energy centre load. It could be argued that the exercise identified an overdesign issue, and that if followed through to the site system performance, could have further reduced the energy use and carbon emissions on the project. It is however, significant that the seminar intervention did encourage a wider company examination of

energy performance, which instigated this further action. Therefore, whilst this particular outcome was not intended, the intervention demonstrates that engagement can lead to a consideration of energy and carbon performance.

Reflecting on the second intervention strategy, the seminar sessions did give access to a wide group of site stakeholders, which allowed energy performance to be discussed and communicated in an open and controlled context. The strength of the intervention was in the engaging all the site managers and supervisors, giving wider credibility to the concept of energy performance. However, the weakness of the sessions was not having a structure for follow up refresher sessions. This therefore, saw many managers returning to previous practise due to time and cost constraints.

7.3 Drawing Together the Interventions

The two intervention cycles sessions do identify that significant improvement can be gained from performance to the installation and commissioning strategies for low carbon technologies. The monitoring cycle highlights that simple changes, that do not directly affect cost and programme, once directed, are more likely to be adopted by the construction teams. However, these are not primarly based on performance improvement, but are assessed and considered on their ease and cost of adoption. Furthermore, where a carbon performance criteria is not explicit within the employer's specification, it is not seen as a primary concern and does not form part of the installation and commissioning cycle. The intervention cycles demonstrate that the exchange of tacit and explicit knowledge, when dealing with low energy and carbon technologies, is limited. Further, the activities of operation and performance are seen as separate entities, with the skill to install and

commission often disconnected from an understanding of performance, beyond the point of ‘switch-on’.

Engagement in knowledge sharing during monitoring and training sessions does indicate the willingness to adopt change however small the actual change achieved. Both the monitoring and training cycles demonstrate the effects of such change on energy and carbon reductions. Therefore, in observing these effects their inclusion in a set of critical success factors would improve the practical application for low carbon performance. However, there is still a substantial hurdle to engage in such change unless the contractor is contractually bound to meet performance criteria. This again states the case for targeted low carbon critical success factors to be adopted in a comprehensive monitoring process

7.4 Reflection on the Interventions

The intervention cycles proved considerably more difficult to undertake than was envisaged at the beginning of the action cycle. The level of engagement proved to be challenging to maintain amongst the installer and site management teams. In addition, this commitment to respond and co-operate, with change interventions, was often not supported at the installer level. The observations cycle did give a clear demonstration of the disengagement with energy and carbon performance amongst the participants. What emerged was a clear divide between the carbon assessment recorded performance and the actual construction response to the installation and commissioning process. The interventions cycles established that performance levels could be achieved with minor changes to the current working practices on the sample sites. This therefore indicates, that whilst substantial change is required to installation, commissioning and training practices, small but progressive change is possible immediately.

Whilst the interventions explored the actions and reactions to the installation and commissioning processes, the approaches had limited effect beyond the cycle's duration. This was, in part, due to the time constraints for the intervention cycles, but also on the effects of the contractual obligations and programme outside the scope and influence of the research. This said, the company wide seminar sessions did have a observable effect on communication within the company, and the monitoring cycles, where engaged, had a direct effect on performance.

From the perspective of the insider researcher there was some difficulty engaging with the construction teams when seen in the role of client's observer. The trust relationship between the researcher, installer and site manager was questioned when the observations and interventions challenged the level of energy performance. This was dealt with by ensuring that contractual obligations were not challenged within the research, and that the observation records were kept confidential throughout the action cycles. However, observations and interventions were abandoned due not only to time constraints, but also to trust barriers not being overcome as part of the research plan and engagement. This said, the level of change instigated, whilst small, was significant to create an understanding of the current installation and commissioning actions..

The action research cycles, using a mixed methods approach, has enabled the collection of rich interpretive data for the research problem. Gathering concurrent qualitative and quantitative data has given a greater insight into the problem than could have been achieved from one or the other methods alone. The synergy of the methodology has allowed the pragmatic nature of mixed methods and action research to 'illuminate and assess change over time without sacrificing credibility or validity' (Ivankova, 2015:p59). Therefore, as

argued by Herr and Anderson the action research is seen ‘not only producing conceptual knowledge, but also exploring new ways of knowing’ (ibid, 2005:p58).

This has been clearly demonstrated in using the action research methodology for investigation of low energy and carbon performance in domestic construction. Allied to the approach of the practitioner researcher, using an ‘insider perspective’, the methodology has facilitated a collaborative view point to the research problem. The philosophical stand point of pragmatism has reinforced the research giving credence to the collection of data to lend meaning and understanding to the research. However, bias is an inherent problem of the ‘insider researcher’. The use of qualitative and quantitative data together within the action research cycle enables a stronger case to be made for validity of the results and finding obtained. Waterman (1998) argues that the process of validation is strengthened by the interventions cycles of action research. Gray also indicates that the process of the cycles ‘allows for refinement of ideas and practices’ (Gray, 2011:p328) therefore improving the case for validity.

Credibility has been established from the extensive use of the reconnaissance and observational data feeding into the intervention cycles. Lincoln and Guba (1994) point to the strengthening of credibility through the creation of confidence in the accuracy of interpretation of the data. Using three sample sites, with varying low carbon technologies, within the action research with mixed methods has enabled the observations and interventions to be tested amongst wider participant groups. The interpretation within the research using qualitative and quantitative methods has improved credibility by triangulating the results to indicate clear outcomes. Therefore, using observational feedback compared with test results have demonstrated a credible interpretation of the data gathered during the action cycles.

Badger warns against claims of generalization of results in action research, arguing that due to the contextual nature of the research ‘tentative generalisation’ may only be achievable (Badger, 2000:p202). The research does not therefore, claim a wider case for generalisation in the construction industry. However, it offers an insight from the professional practitioner perspective for the problems surrounding performance of mass built low carbon dwellings. The observations and interventions therefore, have demonstrated improvement is possible in a complex construction environment requiring change to improve performance.

Part 3 The Findings

Chapter 8

Discussion of Findings from the Research

8.1 Introduction

The purpose of this chapter is to explore the findings from the reconnaissance, observation and intervention cycles. The research questions are examined to demonstrate the extent to which they have been answered, and how the answers have contributed to further knowledge in the field. The interpretation of the data is explored to understand the barriers and future gateways to enable a change in practice. The culmination of the findings is to outline an emergent new working practice that will contribute further to the change process.

8.2 Summary of Research Questions and Key Finding

The research questions are discussed to bring context to the interpretation of the findings in relation to the observations, interventions and existing theory. Koshy et al argue that the purpose of action research is to 'improve practice or implement change as a result of research' (Koshy et al, 2011:p146). Mertler also argues that sharing the findings of action research helps 'bridge the divide between practice and theory' (Mertler, 2012:p219). Therefore, each of the questions has been addressed in turn to build a journey through the action cycles, to answer research question and to indicate the recommended change implementation as a result of the research. Therefore, as a start to the journey the findings from the first research question are addressed in turn.

8.2.1 What are stakeholder perceptions of low carbon technologies in new construction developments?

The research has made evident the stakeholder perception that low carbon technologies have a mixed level of success within new mass low carbon developments. Prominent amongst the negative perceptions was the process of installation and commissioning, and the observed performance issues experienced on new schemes. The survey and interviews revealed a compelling argument, that the confidence in construction professionals to deliver low carbon homes is challenged. This challenge, revealed throughout the research, returns consistently to four key themes: time, knowledge, cost and trust. These are not, in and of themselves, new to the issues of performance within construction. However, the meaning and interpretation taken from the research, gives a new insight into the practices and change implementation needed to improve low carbon technology performance.

Engagement with the literature revealed that in the decade since Part L of the Building Regulations 2006, there have been two changes to the Building Regulations in 2010 and 2013. There has also been the introduction of the Code for Sustainable Homes in 2006, with two level changes for Code 3 and Code 4 compliance, and the 'Building Greener Futures' policy (DCLG, 2007). In addition, in London there has been the introduction of the London Plan in 2011 with amendments in 2014, with an obligation to increasing carbon reduction with connections to district heating networks. More recently, further changes have indicated a slowing of the carbon reduction commitment on the part of the UK government, with the removal of the Code for Sustainable Homes and 'allowable solution for offsite reductions in 2015/16 (DECC, 2015). Also from June 2016 the Department of Energy and Climate Change (DECC) has been disbanded by the new conservative government. However, within

London, the London Plan 2014, has maintained its commitment to zero carbon from October 2016, with a mixture of on and off site contribution to the reductions.

The research revealed that these changes have had an effect on the introduction and engagement of low carbon technologies into the domestic construction sector. Figure 4.10 in chapter 4 clearly indicates the spread of technologies used and the levels of experience with low carbon technologies. It demonstrates that after a decade of change the levels of experience are still very mixed, with all but PV and ventilation, indicating substantially higher levels of inexperience across all stakeholder groups. This supports the research of Heffernan et al (2015) and Abdulkadir et al (2015), indicating that barriers through skills and knowledge gaps are still prominent. This said, Figures 4.11 and 4.12 demonstrate that differences are experienced in the construction process as a result of the intervention of regulation and guidance. However, the implementation is perceived as unclear and costly, with a majority believing they will not deliver zero carbon homes. This is clearly seen in the interviews and site observations, where performance of the technologies was evidently not fully understood; with cost and time considered the main motivators of the installation and commissioning process.

A significant finding from the research is that often the technology is selected at the local authority planning stage not primarily for its performance, but for planning preference, expediency of assessment or cost. Interpreting these perceptions of low carbon technologies, in the light of the site observations, there is clear evidence that this is not primarily undertaken as a benefit for the development, but as a consequence of a planning decision based on target setting. It was observed that in the sample sites the technology had been selected and approved as part of the planning process with subsequent adoption by the design and build contractor. This may indicate a contributing factor to the disconnect

between the technology and the installation, with a lack of buy-in, knowledge or trust in the technology from the outset of the project. This supports research by Bevan and Lu (2012), which indicated that when unfamiliar technology was used ‘parts of the jigsaw’ (ibid) could be missed signifying an effect of this disconnect. The research also supports their argument of a social-technical constructs used in the selection of technologies with beliefs and interests playing their part. However, this research shows that these social and technical constructs persist beyond the technology selection to the installation and commissioning process. Demonstrating that the individual beliefs and interests of the actual installer further compound the ‘missing parts of the jigsaw’ (ibid) eroding the technology performance potential further still.

In observing the disconnect between the perception of the technology and the performance the research has uncovered an insight into professional practice. Exploring the themes of knowledge and experience, revealed a pattern of education and training that is contributing to the performance gap. The research indicates that 88% of the respondents had no formal qualifications for low carbon construction, with the main source of training emanating from manufactures or other ‘in house’ seminars. Figure 4.13 shows that the most common form of information gathering was from practical sources obtained within the stakeholders organisation, or from onsite experience. Information from professional and technical bodies was not as common, other than for the designer group, indicating that most information was either manufacturer or experienced lead. This form of knowledge sharing is predominantly tacit to tacit exchange (Nonaka,1991) with little transfer to explicit knowledge.

Bonner (2000), Lee (2000) argues that with the greater percentage of construction knowledge embedded within staff and not recorded, the majority is either lost or not communicated effectively. This was evident within the research and indicated in the

interviews and observations where little or no explicit information was found to be used, with the majority of the data indicating no knowledge sharing. This, to an extent, supports the research of Bakker et al and the 'the paradoxical nature of learning' (Bakker et al, 2011:p494-503), whereby the short-term nature of projects lead to fractured learning and poor knowledge transfer. When this thinking is applied to low carbon technologies the evidence of the survey, interviews and observations clearly indicate this same paradox within low carbon technology learning. However, with the interactive and performance related nature of low carbon technologies, not only is there an effect on the primary installation, but on the whole concept of low carbon performance. Therefore, the research clearly demonstrates, from the observations and interventions, that whilst the primary installation is struggling, the performance element is hardly considered.

A final point on the technology perception is evident within the research, in that, the technology with the greatest support, PV, was the least interactive with other technologies and likely to be installed by a specialist contractor. The remaining technologies either formed part of the heating, hot water or ventilations systems, therefore interacting with other technologies, installers and users. This nature of interaction has a direct influence on the perception of the technology from all the stakeholder groups. This is significant in that the PV in blocks of flats is rarely or never connected to the individual dwellings, but forms part of the Landlords communal electrical distribution, as this is the most cost effective method.. Most, if not all the energy produced is not used on the development, but exported 'off site'. The PV technology, whilst being seen as a prominent low carbon contribution on the development, has no connection with the performance of the dwelling. Therefore, the perception of this positively performing technology is not necessarily based on the low carbon benefits or performance for the dwelling, but on its ability to give the required carbon target through SAP without the need for concerns of performance within the flat dwelling.

This is not to say that PV has no benefit, it clearly does in many environments. However, it contributes to the understanding of why it is perceived as positive, whilst delivering little or no contribution to the 'on site' building performance in flats and multioccupancy buildings.

The second research question leads onto the exploration of the installation process for low carbon technologies through the observations and interventions cycles, as part of the action research.

8.2.2 How can the installation process of low carbon technologies be better communicated during the construction?

The reconnaissance and planning cycles demonstrated that amongst the stakeholder groups surveyed and interviewed there was an observation that installation of low carbon technologies was rarely monitored. Significantly, Figures 4.16 and 4.17 indicated that monitoring the installation of low carbon technologies was the least common activity, with between 67% - 83% amongst constructors and designers respectively agreeing. This was further supported by the observations cycle, which confirmed that monitoring was not a common activity on the sample sites. Significantly, what emerged from the research was that even where there was little experience of the technology, monitoring was regarded as a low priority.

The research, through interviews and observations, offered one explanation for this lack of monitoring, beyond the low priority status of the task identified. They indicated that the relationship between the main contractor and the subcontractor is based on trust, familiarity of use and a predetermined price profile. Therefore, whilst the main contractor often stated a lack of knowledge of the technology installed, as seen during the observations, the trust to

deliver remained embedded with the subcontractor. What is significant, is the term ‘to deliver’, as this illustrates the on-going problem of the disconnect between system function and low carbon performance. This supports the research of Hartmann and Caerteling (2010), which shows that the main contractor was willing to compromise on technical ‘know-how’ and co-operative skills if the quality of the work was viewed as ‘acceptable’, and the price conformed to the market requirement. Therefore, the research identified this within the area of low carbon performance, demonstrating that this dynamic of ‘blind trust’ is a contributory factor to the performance gap.

The evidence also pointed to a distinctive element of the design and build contractual arrangement, where it is common to review designs before starting on site. However, once on site, designs are invariable amended either for site conditions, or to drive cost efficiency from the contract. This is commonly referred to as a Value Engineering (VE) exercise, with the survey (see Chapter 4) indicating a 80.7% response rate to the question of VE activity as ‘always’ or ‘sometimes’ carried out. Figure 8.1 indicates the reasons for the VE taken from the stakeholder groups:

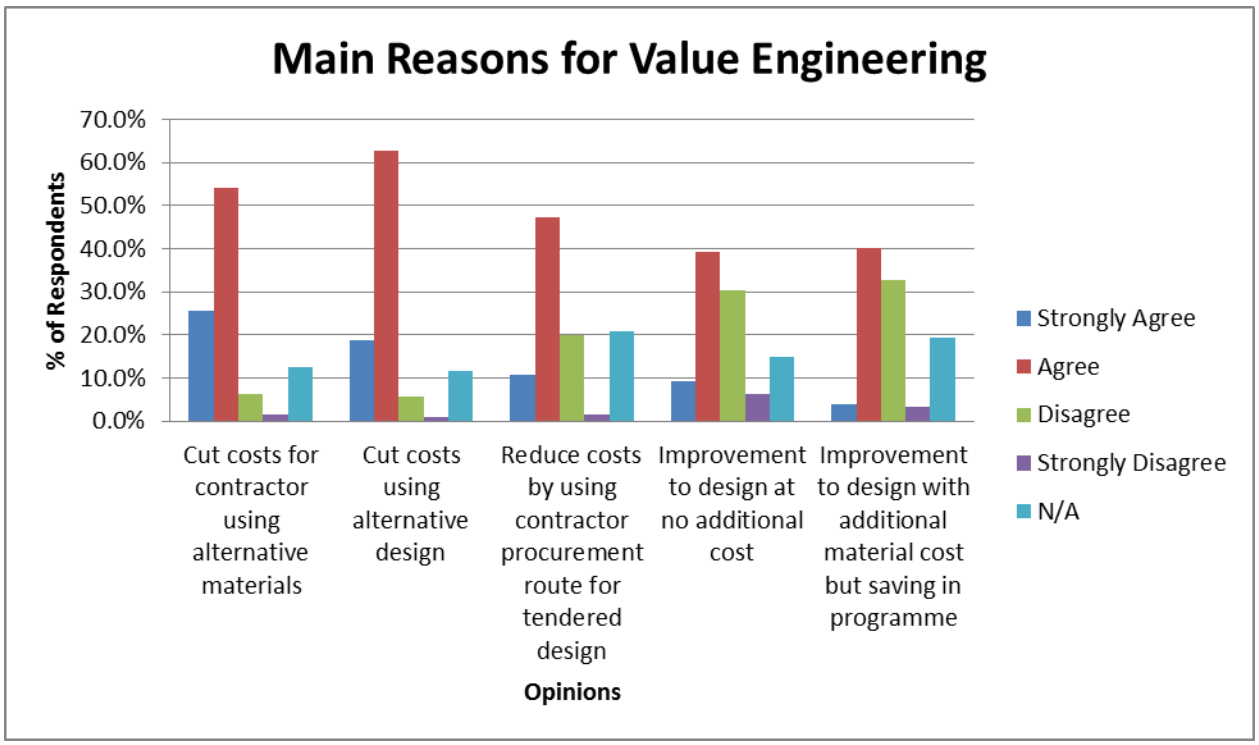


Figure 8.1 Reasons for VE exercise

The figure indicates the two main reasons identified as cutting costs related to alternative materials or design. Taking this into consideration with the perceptions on performance, skills level and trust perspectives, the research has identified a gap, not currently seen within the literature. This indicates that whilst low carbon technologies have had an observable upward impact on cost and design (Sweett, 2005), the drive to control that cost, and secure profit margin, has been a significant objective in technology selection. If, as is often the case, the technology has been selected as part of the planning process, the only area left to exploit cost savings is within the materials, installation and labour. Therefore, as demonstrated in the research, the actual 'real world, on-site' installation method has been adapted to suit previous known skills, and not to deliver the performance otherwise achievable. This highlights the disconnect between the design to achieve performance and the installation to connect and work.

The research observes that without monitoring and designer site presence, the installation activities differ greatly from the design review at the start of the project. Therefore, the technology is installed to operate relying on the existing skill set of the installer, without any further attention or direction to performance beyond that achieved from 'switch-on'.

An intervention cycle was therefore engaged on three sample sites to carry out monitoring actions with the construction participants, to observe if the interventions, through monitoring, could have an effect on the technology performance. The research revealed four significant outcomes from the installation activities. Firstly, the collaborative aspect of action research, engaged from a professional practitioner perspective, enabled an open and 'real world' view of the research problem. This said, the access and involvement in the research proved difficult to maintain if cost or time constraints were encountered. This had both a negative and positive effect. The removal of involvement impeded the gathering of direct installation data, however, it demonstrated the research finding that performance was considered a lower priority target, or not recognised as part of the installation requirements.

Secondly, where interventions were identified by the installer as easy and simple, the site teams adopted these with observable performance enhancement recorded over the pre-intervention state. These were identified by the installers as part of the intervention. However, it was observed that this did not lead to further engagement with performance standards beyond those reviewed and trialled. The research has shown evidence that learning through monitoring and intervention can have a limited, but positive effect on the technology performance. However, that learning, as clearly demonstrated, needs both a structured approach and a mandate for engagement. This needs to be embraced by all the stakeholder groups, with the development of the employers requirements (ER) to more robustly state the performance criteria required. In addition the contractor needs to identify

installation and performance as critical success factors, enhancing the priority of the monitoring of the installation for low carbon technologies. The research recognises the incremental nature of the learning process required, and has demonstrated this in the small, but noticeable benefits of the interventions. However, change cannot be enacted without knowledge, direction and action, and as demonstrated, these need to be spread across all stakeholder groups to implement change.

Thirdly, both the ‘on-site’ and ‘off-site’ training sessions had a degree of success instigating small, but significant changes to the performance of the technology. However, it must be stated that without a contractual obligation and a set of performance criteria, the changes lacked the authority or importance to make larger performance improvements. The research therefore, supports Manu et al (2015) who argues that mutually agreed controls could actually provide the basis for trust that is then predicated on ‘demonstrated trustworthiness’ and a ‘Trust Platform’ (ibid). Kadefors (2014) has the opposing view that control is detrimental to the development of trust with the subcontractor. However, as seen from the evidence in the research, unless such controls are in place low carbon performance will continue to be a lower priority in the construction process.

Lastly, communication between installers, main contractors and clients during the installation was seen as infrequent, disjointed, with no apparent dialog beyond time, and cost issues. The research demonstrated that pre-intervention performance of the technology was not a discussion item. Both first and second fix installation were carried out with little review beyond co-ordination between trades for installation programming. Observations demonstrated that completing the task to basic function, without subsequent regard for other performance criteria was considered the ‘norm’. A co-ordinated performance objective, communicated across the installation groups, was not apparent at any of the sample sites,

with standards of installation varying according to the individual installer. Significantly, many of the installers were individual self-employed tradesmen, with minimal installation based communication beyond that of site direction for programme completion. Therefore, a finding from the research was that due to the lack of knowledge of the technology and monitoring, each installer had their own 'method' of installation, which reflected their own 'world view'. Therefore, this inhibited communication between the participants, reducing the level of shared knowledge. This tacit based knowledge therefore, did not extend beyond the individuals work area, thereby creating ad hoc solutions to performance to suite each unique working environment, never reaching the wider development performance.

One reason for this working structure can be seen in the building services labour force distribution as evident in the literature. The sample sites reflected this evidence in that the majority of M&E companies are structured with 44% having 2 – 13 employees, and 52% operating as sole trader and single employees (Office for National Statistics, 2015). Therefore 96% of companies and individuals operating on construction sites in the UK are from small and sole trader companies (ibid). The significance revealed in the research, and as found by (Hseih, 1998) and (Lin and Gibson, 2011), was that such small subcontracting companies lack structured internal processes for document management, quality control and staff management. It also indicates an explanation of the overriding importance of time and cost, as seen in the literature (Hartmann and Caerteling, 2010), and as revealed in the research.

It is also interesting to observe the reactions to Building Information Modelling (BIM) from the site stakeholders. Whilst this is emerging at the design and developer level as a tool to managing quality of design, a majority of the actual installer teams do not have access or training to use this information and design process. Therefore, whilst BIM is often cited as

being used on a development, the actual extent of use is often limited to the design and management teams, and often not present as part of the individual installer practice. Therefore, in a similar way to SAP and Code, the BIM design is often different to the final installation, due to a lack of engagement or connection with the installation and design teams during the construction phases. This can again be contributed to small company structures when looking at the installation process. The emphasis is placed on short-term delivery and minimum performance standards, and not the requirement to achieve optimum carbon reductions, or see the wider implications of an holistic approach to installation and commissioning. Subcontractors, as observed, often emerged through the low carbon construction process without the means to deliver and communicate effectively the requirements for performance. Therefore, the observed issues with installation and performance standards, and the lack of communication between site stakeholders can be understood in this context. This also stands to strengthen the view point of Manu et al (2015) for the need for mutually agreed controls to contribute in the engagement with performance.

Significantly, Druker & White (1996) point out that site employees come from a wide range of skilled and unskilled backgrounds. Oswald et al (2015) and Loosemore and Lee (2002) also argue that there is little examination of inter-cultural communication and learning issues, which also feeds into the process of communication on site. This ‘real world’ view of the construction demographic lends further support to the need for control, which without implementation will prolong the underperformance of low carbon technologies.

In answering the research sub-question from the evidence, stronger controls need to be implemented to achieve improved communication and performance. The interventions demonstrated that ‘on and off’ site monitoring and training can have noticeable effects on

the performance and communication level, creating a first step in the process to achieve optimum performance.

The final research question investigates the commissioning process and the implementation of improved performance.

8.2.3 How can the commissioning process be enhanced to improve performance?

Inextricability linked to the installation process, commissioning facilitates the on-going energy and low carbon performance, through providing the optimum settings from which user activities can build. It is accepted by the research that the effect of human behaviour on household energy consumption is significant (Bailey, 2010; Kelly, 2011; Lomas, 2010) and estimated to account for 51% of the variance in monitored heat demand due to preference and usage (Gill et al, 2010). However, with low carbon technologies, especially heating systems and communal systems in particular, the installation and commissioning of the technology dictates the base energy use from which, the individual dwelling user cannot easily escape or adapt. Therefore, as demonstrated in the research, the installation and commissioning activities have a direct effect on the longer term energy and carbon use of the technology.

Significantly, the research findings highlighted commissioning to be ineffectively conducted, with 68% either agreeing or strongly agreeing that commissioning was failing to achieve its objectives. Considering the importance of commissioning to safeguard optimum performance, this is a damning indictment on this construction process. The research revealed a number of contributing factors including deficiencies in programming, monitoring

and the involvement of the design team in the commissioning process. Importantly, for the commissioning process, over 70% of construction and design stakeholders indicated that commissioning activities were often disrupted, which if taken with the other issues, reveal a failing process.

From the literature, Noyne et al (2013) identify the importance of commissioning in achieving low and zero carbon performance. Turner et al also recognizes the effects of effective commissioning especially on design and build projects where 'design/build delivery blurs the lines between design phase and construction phase' (Turner et al, 2012:p54). They also recognise that:

> 'design/build projects may be more vulnerable to the risk of expending too much of their fee on early project stages, without enough fee left over to perform the later critical technical work, including hands-on functional performance testing, system tuning', (ibid, 2012:p58).

This 'blurring of lines' is demonstrated throughout the research, and the lack of 'functional performance testing' (ibid) is witnessed both in the observations and interventions cycles. This was clearly demonstrated on each of the sample sites where time and cost were often used as a contributing factor in the installation and commissioning processes. However, as observed in the interventions cycle functional performance testing, regardless of time and cost, remained at a very coarse level with no finer granular level performance commissioning for the technology. This indicates that the 'real world' performance, in the cases observed, bear little resemblance to the compliance assessments (SAP/EPC and Code for Sustainable Homes) used to indicate the energy and carbon performance at the wider UK level. With these assessment methods being the primary forms of compliance, and

with little monitoring or commission process observed, technology performance lacks the priority to achieve current and sustained ‘real world’ energy and carbon reductions.

The findings from the action cycles demonstrate a commissioning process, which is not based on energy and low carbon performance, but on the more prosaic task of putting the technology into operation. This was evident throughout the observations cycle, which indicated that installation and commissioning activities did not extend beyond rudimentary commissioning and simple activation. This supports research by Noyne et al (2013), carried out in the commercial field, which suggests that of the five levels of commissioning, most remained at level 3 ‘is it connected’, with level 4 and 5 for ‘delivery and optimisation’ not considered or enacted. The research has shown that unchallenged, this status quo would remain prevalent in the construction process, with little or no incentive to increase low carbon performance. What the research has also established, through the intervention cycles, is that small and simple changes, monitored and controlled, can be part of the change process to improve commissioning technology performance. This is demonstrated through the interventions of pipe work insulation, indicating a 41^{o}C reduction in the heat transfer to the structure, and a 5^{0}C reduction in under floor heating supply temperatures for the heat pump technology. The observable advantages of increased performance are evidenced in the research, and whilst small in their initial impact, could act as a catalyst for further change. However, without structure, management and to an extent censure, the research indicates that the process will not be derived from a purely self-regulated or altruistic stand point.

It has been recognised that most of the literature for commissioning and installation covers commercial and complex buildings (Noyne et al, 2013), or buildings outside the UK (Wray et al, 2000), with little in the way of literature for low carbon mass-produced homes. Therefore,

the research contributes to knowledge by concentrating on the domestic installation and commissioning activities, and applying learning from the the commercial field, to low carbon homes. The research also gives a ‘real world’ dimension through the lens of the practitioner researcher to the change process, and future implementation of an installation and commissioning process for low carbon homes.

8.2.4 What intervention processes can achieve an effective installation and commissioning strategy in new mass low carbon homes?

The research findings demonstrate that a structured and mutually agreed monitoring process, set within a ‘real world’ learning environment, both ‘on and off site’, can contribute to the reduction of energy and carbon emissions. The research supports Hartmann and Doree (2013) in their argument that knowledge emerges through collective action, thereby becoming a shared experience. The research has found that by engaging at a practitioner level, within the day-to-day process, change can be instigated, albeit demonstrated in a small way in the interventions cycle. The findings further support Hartmann and Doree (2013), in their observation of the difficulties of completing documented tasks that are seen as outside of the day to day management and work flow of the project. This is evidenced in that, any activity outside the contractual requirements was seen as optional and not a priority to the process at hand. This is also seen by Chen and Kamara (2008), who argue that the most effective and efficient way of capturing information is ‘at a point where they are and a time when it is needed’. This is demonstrated in the research where the on-site training sessions enabled a response to be adopted directly on site. Therefore, engaging in a performance monitoring process, whilst also seen as part of the flow of the project, can instigate improvement in the performance of the technologies.

Heffernan (2012) states that the need for collaboration, flexibility in approach and the development of a context under which low carbon homes can be constructed, are seen as the main drivers to achieving low carbon homes. As demonstrated in the research, from a standpoint of social learning theory, the emergence of engagement through collaboration with the stakeholders did allow change to be enacted. Mathur et al argue that engagement through social learning theory instigates ‘awareness, changing attitudes and affecting behaviours’. (Mathur et al, 2008:p110). However, this also needs to be observed through the lens of ‘power play’ as identified by Lohne et al (2015), and the ethical considerations of the subcontractor in actually completing the installation and commissioning process as contracted.

Using research by Taylor (2004), concentrating on ‘social imagery’, (defined as what is and is not acceptable behaviour in communities), Lohne el al (2015) argue that an understanding can be achieved of judgements made and actions taken during the construction process. This is repeatedly observed in the interventions cycle, where the actions of the subcontractor are directly influenced by their role on the project and their relationships with the surrounding stakeholders. Where monitoring and commissioning are not seen as a priority function, the subsequent behaviour of the individuals reflect this lack of importance, enabling minimum performance to be acceptable. If this is explored from the perspective of the small company or sole trader response; the need or necessity to improve low carbon training skills, or go beyond the level of functional operation, are not seen as critical success factors. The tendency to work to achieve the minimum standard emerges from this acceptance of a status quo, that is not challenged by monitoring or assessment. Therefore, as observed by Lohne et al (2015) a ‘fuzzy commissioning’ (ibid:p261) is created which almost ensures that optimum performance is not achieved, leading to the commissioning process continuing long after the actual process has been recorded as completed.

The findings of the research do clearly indicate that active monitoring and targeted training can contribute to the performance standards for installation and commissioning. However, the construction process is both complex and fragmented (Wilson and Rezgui, 2013), with a step change in that complexity through low carbon domestic construction (Connaughton and Weller, 2013), as discovered throughout the research process. Williams and Dair (2006) state that stakeholder commitment is fundamental to overcoming the barriers to effectively achieve low carbon homes, and this has been further evidenced in this research. Therefore, as a result of the findings an installation and commissioning monitoring model has emerged for use on future projects, which uses the learning from the research to create a structured approach to the performance issues.

8.3 Commission – 2 – Perform Process

Through the exploration of the reconnaissance, observation and intervention cycles the findings have developed an outcome for a possible new way of working. This new working practice could contribution to the installation and commissioning processes, continuing to refine practitioner based research. Koshy et al state that the purpose of action research is to 'improve practice or implement change as a result of research' (Koshy et al, 2011:p146). The practitioner research has demonstrated the effects of the small, but observable changes from the interventions. Subsequently, the 'Commission 2 Perform' process is a result from the findings of the research to support change, and transform research interventions into a working practice (see appendix 11). It uses the observations and intervention outcomes to structure a simple process to span from 'design to completion', using a collaborative approach to instigate change. The process has, at its centre, the research findings, which indicate that active monitoring, communication and incremental work based learning are key features of the contribution to improved low carbon performance in the construction cycle.

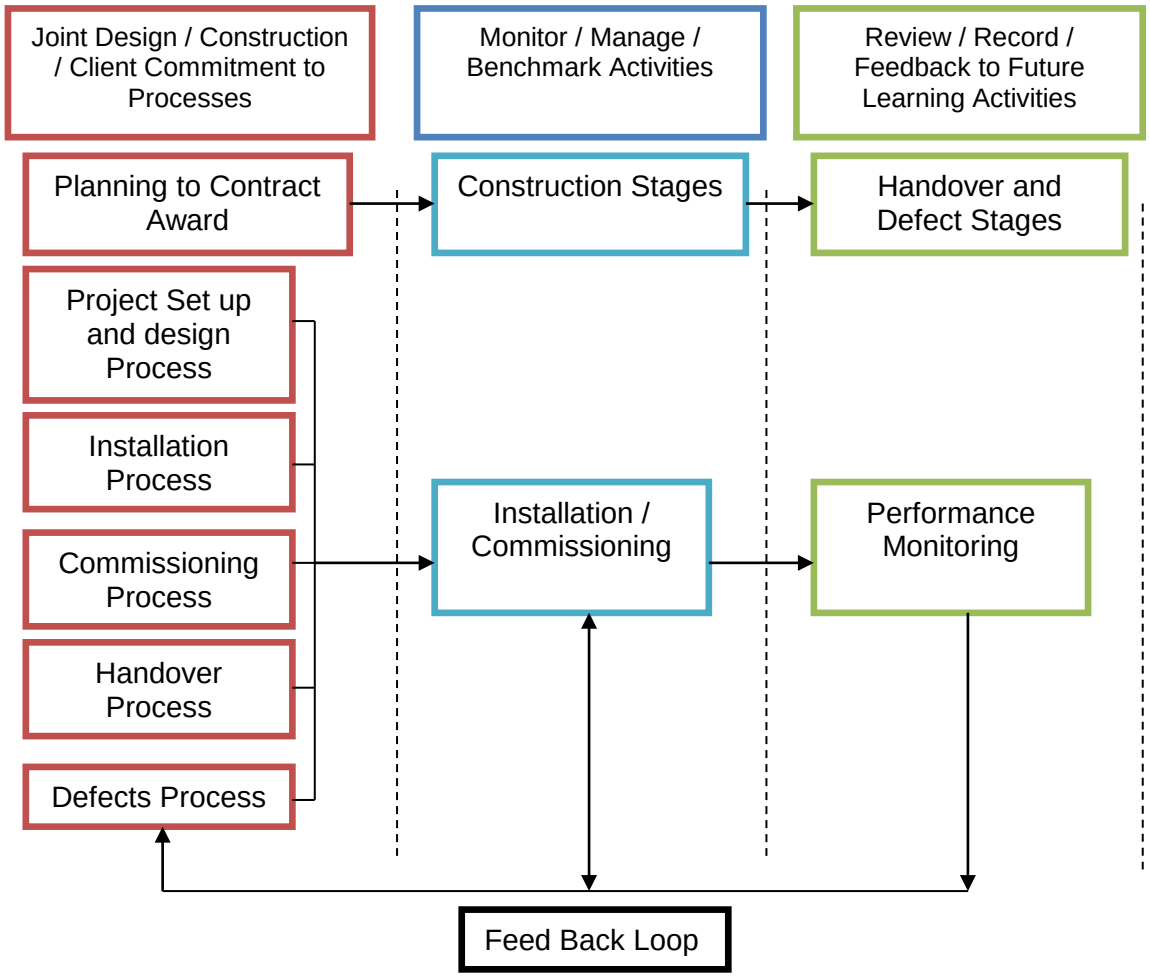


Figure 8.2 Commission – 2 – Perform Process Diagram

Figure 8.2 illustrates the commission – 2 – perform process from the Local Autority planning stages, through contract award, construction and post occupancy performance monitoring stages. The process development intends to enable a collaborative route to achieve improved performance levels for LZC technologies and low carbon construction.

The process needs to be embedded in contractual practice and form part of the clients requirements for change to allow active collaboration form all stakeholders. This form of mandating the process responds to the research findings, and the literature, including Manu et al (2015), who indicate mutually agreed controls as a positive contribution to

trustworthiness in construction. Ozorhon (2013) also identifies that improvements in quality and the application of new processes within construction are needed to fully realise energy efficiency. This also reflects the wider industry goals where Osmani and O'Reilly (2009), observed, in their study of house builders that regulation and legislation is seen as the most effective driver for low and net zero carbon homes. Therefore, the necessity for compliance through process, using a collaborative approach, is required to move a complex and fragmented industry such as construction to sustained change.

8.4 Critical Evaluation and Reflection on the Research

The aim of this practitioner lead research project was to investigate and improve installation and commissioning practices for mass low carbon homes. This has been an enlightening, but challenging task considering the breadth of installation and commissioning as a subject area, coupled with the time constraints on the project and the professional doctorate. It is also fair to say, that there were significant challenges in engagement with the stakeholders involved, and in particular engaging with the actual subcontractors on site. As a result of these challenges, four main limitations have been recognised within the research:

1. The research was primarily focussed on the observation and implementation of interventions for improved installation and commissioning for low carbon technologies, which represents a fraction of the domestic construction industry activities. Therefore, the activities and pressures of the overall construction process were not fully investigated, and as such, could have implications for the research findings. This said, the research has identified the limitations of the installation and commissioning of low carbon technologies that result from current practice that can improve through a change process.

2. The observation and interventions were limited to 3 sample sites due to time constraints and the recording and management of data gathering. This limits the data gathered and the opportunity to observe and compare the processes within a wider selection of construction environment. However, as this is a practitioner research lead project, considerable construction knowledge, gained over 25 years, has contributed to the research design to reduce the effects the limited sample may otherwise suggest. Ivankova (2015) recognises this influence of the practitioner researcher and the contribution this brings to research. Gray also argues that the researcher brings:

   > 'understanding of the strengths and weaknesses of the organisation, as well as its developing needs' (Gray, 2011:p402).

   Significantly, it can also be seen throughout the observations and interventions that the stakeholders bring their previous experience to the sample projects. Therefore, whilst an increased sample for observations and interventions would have greatly expanded the data sets for the research, the sample sites did give clear evidence of the level of activities and change process on the construction sites observed.

3. It was not possible to fully implement the interventions on all of the sample sites, as there was resistance to following through the process due to time and cost constraints perceived by the stakeholder groups. This said, the results from the interventions did clearly demonstrate change, and the effects for improved practice. Unexpectedly, where the interventions where disrupted or abandoned this did contribute to the understanding of the improvements required in practice to bring about further change. The interventions on each sample site were conducted in a

real life situation. The triangulation of the observation and intervention data with the earlier questionnaires and interviews, with the wider stakeholder groups, does contribute to the validity of the data. Caution therefore, must be exercised in generalising these results. However, the credibility of the approach of the practitioner researcher, within the action research methodology, indicates the results have a high degree of reliability based in a rich source of contextual data taken from a 'real world' setting (Gray, 2011).

4. The action research methodology, embedded through the practitioner researcher role, has been central to realising the research aim and delivering the academic outputs and practical solutions. Common to all research methodologies, action research presents some limitations, and has received criticism for the potential for a lack of rigour (Gray, 2011). Badger also argues that because of the contextual nature of action research, the research may only be able to give 'tentative generalizations' (Badger; 2000:p202). However, by accepting pragmatism as a philosophical foundation for mixed methods research (IvanKova, 2015), it can be argued that action research also share these same philosophical standpoints.

> 'pragmatic epistemological principles provide a useful philosophical rationale for action research studies that use both quantitative and qualitative data' (Ivankova, 2015:p54)

As argued by Lyons and DeFranco (2010) mixed methods with action research 'assists the practitioner researcher to a new appreciation for a data driven decision making process' (ibid:p149). Therefore, whilst accepting the limitations of the research method, the use of mixed methods within action research has taken the

strength of the combined models, through a pragmatic philosophy, to improve the rigour of the research study.

These limitations highlight the complex nature of the construction industry and the difficulties, which are encountered when carrying out research in an area of wide and varied stakeholder involvement. Mills (2011) argues that practitioner researchers use a reflective approach when addressing and reviewing their daily practice. This stance being used to critically explore problems and improve them. Therefore, reflection has been used throughout the research study to address such limitations of complexity; however, in a 'real world' study an acceptance and understanding of such limitations adds to the context of the research and its findings.

8.5 Chapter Reflection

This chapter has explored the findings from the action research cycles and addressed the main and supporting questions posed by the research. The findings, which have emerged from the reconnaissance and observation data, have given clear evidence of the problem and justification for the intervention cycles. The interventions and their emergent findings confirm that change is possible to enact improvements in performance of low carbon homes. However, the findings also show the difficulty of facilitating and maintaining that change in a complex 'real world' construction environment.

A significant result of the findings demonstrates that mixed methods within action research cycle has facilitated integration with the professional practice and theory, which as Herr and Anderson argue, lays the foundation of 'new ways of knowing' (Herr and Anderson,

2005:p3). Mills (2011), also support this by indicating that action research incorporates a reflective stance to allow professional practice to critically examine and improve practice.

In support of Alias et al, the study has observed that construction research has mainly concentrated on the traditional factors of time, cost and quality within conventional construction, and does not identify those factors ‘critical to sustainable buildings’ (Alias et al, 2014:p216). Therefore, the findings, modest in their contribution, have explored the installation and commissioning of low carbon technologies to further advance the literature and improve professional practice. This will also be developed further in future with the use of the ‘Commission 2 Perform Process’, to support the communication and development of change.

Chapter 9

Conclusions

9.1 Introduction

This thesis has explored the theory, observation and practical implementation of low carbon technologies within the context of new mass low carbon homes. This final chapter presents how the research aims and questions have been met, and discusses the implications of the research for the stakeholder groups engaged, and on the wider construction industry. It provides a conclusion to the research, indicating the limitation of the study, contribution to knowledge, and offers suggestions for future research in this area. The chapter concludes with a reflection on the journey through the professional doctorate and the practitioner research activities, revealing the learning and personal professional growth throughout the thesis.

The research has demonstrated that within construction, the processes of installation and commissioning for delivering low carbon new homes are dependent upon, and formed by, social interaction as much as technical knowledge. The failure of the transition of the tacit and explicit knowledge bond amongst repeatedly forming and disbanding technical groups, with varying skills levels, creates a culture of ‘fractured response’ that offers a challenge to the progress of low carbon homes. Therefore, whilst making a modest but significant contribution to knowledge; the research has shown that change, however small and incremental, can be achieved through a structured and controlled engagement in the low carbon technology construction process.

9.2 Aims of the Research

The aim of this project was to observe, understand and improve the installation and commissioning process for mass low carbon homes, through observations and interventions within ‘real world’ professional practice context. The research explored, through an action research methodology, the planning, developing and evaluation of two complementary interventions to drive change. The interventions sought to address the need to better understand and monitor installation and commissioning in mass low carbon homes. The interventions took the form of structured monitoring and targeted training sessions to demonstrate that improvements were able to be achieved, even in a ‘minimal involvement’ environment.

Table 9.1 provides a summary of how this research project has satisfied the research questions set out in the introduction in section 1.4 ‘Research Questions’. It displays the development of the research through the progressive stages of the action research cycle, demonstrating the path through reconnaissance, planning, action and reflection. It also specifies the research tools and methods used to obtain the data used to explore and define the findings from the research to enable conclusion to be drawn from the research.

Table 9.1– Summary of Research Findings (adapted Shaw, 2010)

Aim	Research Questions	Summary of Finding	Evidence					
			Q	CD	OB & SE	FG & CF	SSI	INT
How can installation and commissioning strategies for low carbon homes be improved?	What are stakeholder perceptions of low carbon technologies in new mass domestic construction developments?	• The survey and interviews revealed a compelling argument, across a broad section of construction stakeholders, that the confidence in construction to deliver low carbon homes is challenged. • Clearly seen in the interviews and site observations where performance of the technologies evidently was not fully understood • Demonstrates that after a decade of change the levels of experience are still very mixed, with all but PV and ventilation indicating substantially higher levels of inexperience across all stakeholder groups • Reconnaissance and planning cycles established that amongst the stakeholder groups surveyed and interviewed there was an observation that installation of low carbon technologies were rarely monitored						
	How can the installation of low carbon technologies be better communicated during the construction?	• The research clearly demonstrates, that a structured monitoring intervention during the installation and commissioning directly affected the level of energy performance • Targeted training sessions both on and off site raise the level of engagement amongst the installation and commissioning stakeholders • Continual structured engagement is required to maintain consistency of approach to low carbon installation • The findings of the research highlight a clear disconnect between low carbon assessment and actual commissioning requirements. These element need to be brought closer together to have meaning at design and commissioning stages						
	How can the commissioning process be enhanced to improve performance?	• The research demonstrated that there are significant challenges in engagement with the stakeholders involved with low carbon homes development. Therefore, a structure process is required, agreed and engaged by all stakeholders to enact change and improve performance • Contractors need to address the issues of fragmentation during the installation and commissioning process • Performance criteria needs to be set at the outset of the project and monitored and recorded for actual compliance						
	What intervention processes can achieve effective installation and commissioning strategies in new mass low carbon homes?	• The research findings demonstrate that a structured and mutually agreed monitoring and targeted training process set within a 'real world' learning environment, both on and off site, can contribute to the reduction of energy and carbon emissions • Engagement through monitoring and target training is key to need for carbon reductions						

Note: Q = Questionnaires; CD = Commissioning Data; OB = Observations; SE = Stakeholder Engagement

FG = Focus Group; CF = Critical Friend; SSI = Semi Structure Interviews; INT = Interventions

9.3 Conclusions

The conclusions can be summarised within three main headings, conclusions from the evidence, research methodology and practical implications for the research. Each will be reviewed in turn, addressing the concerns and problems raised in the introduction.

9.2.1 The evidence

The research has explored the problems raised within professional practice concentrating on the effectiveness of installation and commissioning for mass low carbon homes. In conclusion from the findings, four key areas have been identified, which influence this effectiveness, these being direction, compulsion, training and monitoring. Firstly, direction emerges from the evidence demonstrating that clear performance criteria must be given and enshrined within the contractual process. It is evident from the observations and interventions that the mandatory elements of compliance for low carbon performance, namely SAP, EPC and the code for sustainable homes, do not influence or affect the commissioning and performance criteria for the completed project. The disconnect between assessment and delivery is clearly shown and demonstrates that the development can be assessed to be low carbon without the building actually performing as such. Therefore, without direction on the energy and carbon performance, or a process whereby this is managed, monitored and validated, the construction delivery reverts to past practice where energy performance is not considered.

This leads to the second element, which is compulsion. It is demonstrated throughout the reconnaissance, observations and interventions that unless the criteria for energy and carbon performance is mandatory it is not given a high priority. It is clearly seen that a priority is given to the assessment procedure and therefore, this takes a leading role in the

planning and design processes for the concept design. However, this is where the priority remains; even though an Energy Performance Certificate (EPC) is mandatory at the completion of the scheme. The transition to installation and commissioning performance is not made as it is not required as part of the mandatory validation for the project completion. Therefore, once the EPC is issued the project is presumed to achieve the carbon reduction level, and is given certification of compliance, regardless of the actual performance. The actual performance therefore, remains an area of opinion and conjecture as opposed to validation and mandatory compliance. It is argued from the research, that whilst this remains the case, performance will not substantially improve for low carbon development. Therefore, without the drive of a mandatory standard, which can be tested and validated, there is little compulsion or interest to develop or attend training, with the subsequent knowledge growth this could provide.

The third element identified is the continuing lack of training in low carbon technologies. The evidence recognises that there are several components contributing to this. Most evident amongst these components, as already identified, is the disconnect between what needs to be achieved at completion for mandatory compliance, and what is accepted as functional from the actual technology performance. The acceptance of ‘as good as it gets’ energy and carbon reduction performance is evident throughout the research amongst all the stakeholder groups. It can be seen from the observations, that training and the associated knowledge to critically evaluate the optimum performance is lacking, and without compulsion, it remains a low priority in the construction process.

In addition to this, the size and structure of building services subcontractor companies presents a challenge to the process of training, and the acquisition of new knowledge to benefit low carbon performance. With 96% of services subcontractors consisting of less than

13 employees, of whom 52% are sole traders, carbon performance training which is not required as part of a mandatory installation or commissioning compliance, remains low priority. The literature and this research support this, recognising that technical ‘Know-how’ is often sacrificed to ‘acceptable standards’ when considering the subcontractor at the bid stage (Hartmann and Caerteling, 2010). Therefore, assuming that the subcontractor will acquire the training level from an altruistic perspective, when cost is often the motivating element for the bid and subsequent delivery of the scheme, is unrealistic. What is evident from the research however, is that if peer training is undertaken as part of the construction and monitoring process, then improvements in performance can be readily achieved. It is suggested that if this peer training was a permanent feature of the installation and commissioning process, this could increase improvement and also contribute to sustained knowledge transfer. However, this has not been explored in the research and would need to be part of a future study.

Finally, monitoring and control of the installation and commissioning process is critical in achieving improvement in performance. Through the observations and interventions, it is clearly apparent that monitoring and control, of the low carbon projects reviewed, commands little priority or attention. The process relies on a trust basis between contractor and subcontractor with scant validation of any performance issues for energy and carbon reductions. Censure is mainly managed through cost control; however, with a low priority on performance standards, the subcontractor’s concentration on these elements is limited. As seen in the research, both at the reconnaissance and observations stages, commissioning is often disrupted and, due to programming issues, left until the last minute. The subcontractor dedicates most time to programme control and avoiding the associated implications of withholding of payment. Therefore, the research concludes from the evidence that without

effective monitoring based on direction and compulsion, the opportunities to close the gap on performance will remain a challenge.

These conclusions, through the evidence, have altered the conceptual framework as presented early in the research and within Chapter 3 (figure 3.2). The following conceptual framework indicates the development as a consequence of the research:

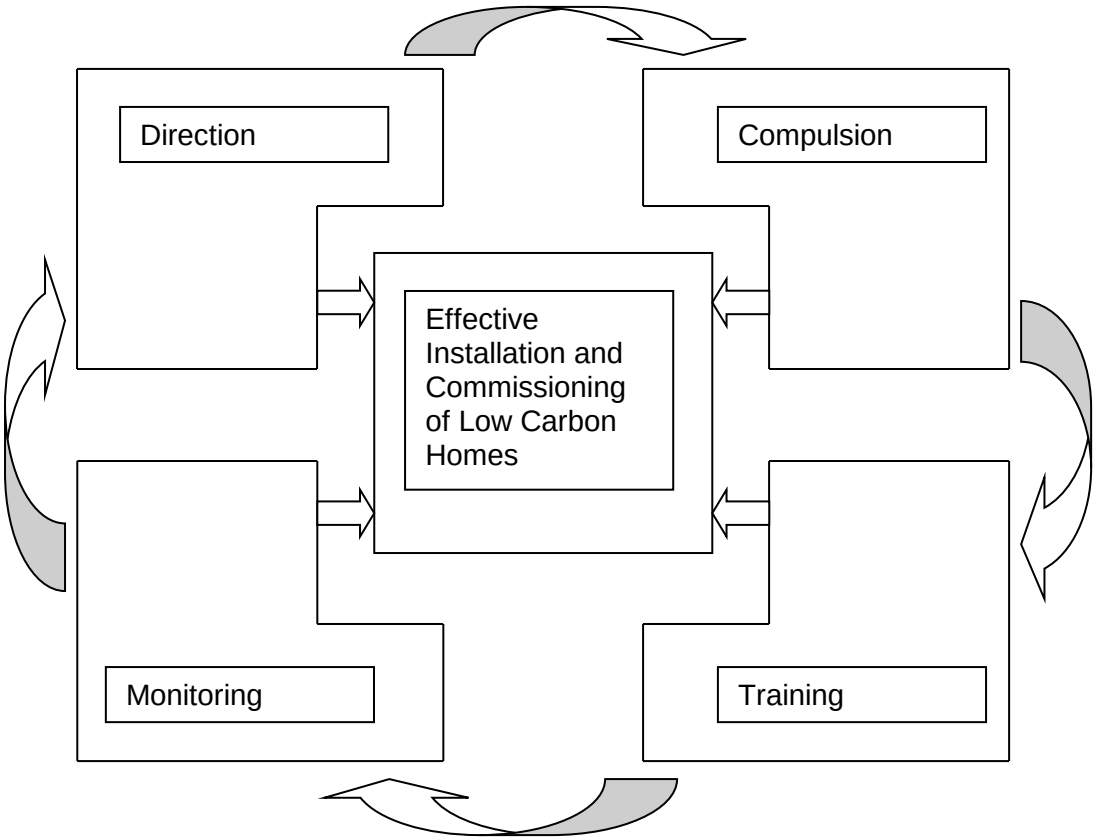


Figure 9.1 New Conceptual Framework based on research findings

9.2.2 Research Methodology

Pragmatism serves as a philosophical foundation for this action research project using a mixed methods approach (Ivankova, 2015). Combining both qualitative and quantitative methods within action research has enabled the exploration of the problem using both empirical (knowledge from experience) and rational (knowledge from reasoning) processes to achieve the best answers within a 'what works' approach (Ivankova, 2015:54). The conclusion from this research is that this approach offers an opportunity to continue debates and research, which are established as much on the social interactions and the process of construction as the low carbon technical issues.

Action research with mixed methods methodology, conducted from a practitioner researcher perspective, has given a unique viewpoint to the understanding of construction factors in low carbon technology performance in new mass housing. Professional practice seen through the lens of this insider role has enabled engagement and collaboration with the stakeholders, and has given a perspective not achievable from other research methods. This close collaboration, within the action research, has allowed data to be gathered directly from professional practice and from 'real world' projects, and to validate using triangulation across both the quantitative and qualitative methods. This same approach has also addressed issues of bias within the study by using not only the validation, but reflection based on a 'critical friend' to assess reliability of the data gathered. Using the evidence from the literature combined with the reconnaissance, observations and interventions has reduced the elements of bias through reliability and validation.

This research demonstrates, as also seen by (Garnett, 2001) that construction projects can be suitable environments for the use of action research as a change mechanism. The

research process can influence change because the collaborative approach establishes the grounds for participation and eventual adoption by the professional practice. The observations and interactions could have created further improvement if more interaction had been achieved at the individual level. However, from a critical perspective the lack of continual engagement does limit the research findings, and caution therefore, needs to be expressed when viewing the evidence against the wider generalisation of the findings. This said, the use of content analysis for the rich descriptions from the observation and interventions, compared with the surveys and commissioning results, do demonstrate a compelling case, through the action research methodology, for improvement in practice.

Reflecting on the action research it is considered that the approach has permitted a ‘voice to be heard’ from the construction perspective. Using this methodology has therefore, allowed a ‘real world’ problem to be researched from a practitioner standpoint, and has add a contribution to knowledge in this critical area of carbon reductions.

9.2.3 Practical Implications of the Research

The action research project has demonstrated that it is possible to create an observation and interventions process that can influence reductions in carbon emissions on new domestic construction projects. The research has opened a window on the ‘real world’ experiences of low carbon domestic construction, using rich descriptions, alongside survey and commissioning data, to explore the issues to improved technology performance at the construction stages. Lending a voice to the many and varied participants, has given a unique insight into current practices. It has also created an understanding and appreciation of the challenges to the implementation of change in this cost and time driven arena.

The research identifies that a coherent and structured change process is required based on defined direction, compulsion, key training and monitoring to effect improvement in technology performance. It has shown that the research interventions are most effective when engagement is achieved across the stakeholder groups. It also indicates that due to the predominantly small size and structure of the building services subcontractor, that direction and compulsion from the client and government is critical to enable the change in priority to be fully realised.

The research clearly demonstrates that the lack of monitoring is affecting the outturn performance of the technologies. It has further shown that an increase in monitoring linked with key 'on site' technology training, has real practical implications for improvements to installation and commissioning performance. However, for this to be implemented effectively a rethink is required for the contractual relationship between, clients, consultants, main and subcontractors. The pragmatic implications of cost centred tendering is a dominant force within construction. Therefore, direction and compulsion need to level the playing field to enable training and monitoring to play a more central role. This is evident in the research and acts as a significant barrier to the change process that was instigated throughout the interventions.

The development of the 'Commission – 2 – Perform' process has been a significant practical implication from the research. The process documentation (Appendix 11) is a direct outcome from the research findings and has been supported by two of the stakeholders taking part in the research project. The process has been adopted on several new construction developments with the aim to improve the communication, implementation, monitoring and commissioning of the low carbon technologies installed. This said, it is still a voluntary process instigated on behalf of the client and adopted by the contractor. This is an inherent

weakness for the process, and time will tell if this can be developed to fully adopt the interventions from the action research.

The research has demonstrated the practical implication that change through monitoring and training can achieve significant improvements in energy and carbon performance. It has also highlighted, from the practitioner perspective, the elements of change required to effect sustained improvement. In highlighting these elements, the research has demonstrated the real barriers that exist to the change process, and in no way underestimates, the level of challenge required for change to be enacted. Therefore, from a practical perspective the research has given a voice to this issue of relatively limited research through stakeholder engagement. It has also opened the debate for further research in an area, which could have dramatic effect on the reduction of CO_2 in technology performance.

9.4 Limitations of the Research

Within these conclusions, the research has demonstrated that the aim of answering the research questions has been achieved. However, there are three main limitations on the research. Firstly, the interventions on the sample sites were not fully achieved with some interventions abandoned due to time and cost constraints. The research was undertaken in collaboration with the client and site teams, however, participation was voluntary. Dependant on the site conditions this did have an element of unpredictability as to the level of cooperation that was offered. It is also observed that stakeholder commitment had varying degrees of success, with engagement often linked to an interest in the subject. Where little interest was expressed, in low energy and carbon performance, engagement was significantly more of a challenge to sustain. This created a degree of separation between

interested and non-interested groups. The company wide training sessions did have a high degree of success in direct engagement, as these were compulsory attendance sessions with mixed manager and worker peer groups. However, once back to the site environment this tended to revert to the split group structure seen on the other sample sites. This indicates that there was a limited adoption of the interventions, and without compulsion some teams remained unengaged with the research. However, whilst expressed and accepted as a limitation, it did also give insight into the need to develop the 'commission 2 perform' process into part of the contractual documentation to encourage full participation in the installation and commissioning processes.

Secondly, the observations and intervention cycles were trialled on a small number of sample sites; this has limited the amount of data collected and analysed as part of the research. The number of sites explored was mainly due to the time constraint for the professional doctorate, and managing the research time and access requirements for each of the participants. However this said, the strength of the professional doctorate study has a strong grounding in the access and knowledge of the practitioner research, and as such, the experience of practice has been used to contribute to the access during the action research period.

Finally, adopting the theoretical perspective of pragmatism, as the foundation to the research, and using an action research methodology to engage in practitioner research, the interpretive paradigm is therefore 'self-selecting' in its approach. Further to this, action research is uncommon in construction studies; therefore, the challenge of credibility to the findings needs to be addressed. To counter the claims of lack of rigour and bias, the supporting mixed methods approach was integrated into the action research. This integration permitted a wider use of data gathering to demonstrate credibility in the findings

and conclusions to the research. Further to this, the use of the survey, reflection and focus group input to drive the areas of research reduced the effects of bias in the findings.

9.5 Contribution to Knowledge and Practice

This research has made a modest, but significant contribution to knowledge and practice when exploring installation and commissioning new mass low carbon homes. From the perspective of the reconnaissance phase, the research has opened up a wide and rich range of stakeholder data, containing opinions and perceptions of new mass low carbon technology and construction. This data has illuminated a lack of performance in the installation and commissioning stages of construction that is hitherto subject to limited research. Using this data, the research has planned and executed an observation and interventions strategy that has explored the 'real world' problem of low carbon technology performance.

These 'real world' observations and interventions, from a practitioner researcher perspective, have created a novel exploration of the actual processes as identified in the surveys. These observations have strengthened the credibility of the research, demonstrating at first hand, barriers to change and improvement viewed from the unique perspective of the insider researcher. This viewpoint of mass low carbon homes has received little attention in the literature; therefore, the lens of the research brings new understanding to the problems of low carbon technology performance.

The interventions have demonstrated that change, even where small and incremental, has a direct effect on the performance of the technology. It has also shown that the barriers to that change are significant, and whilst this research has demonstrated a step towards the

transformation of practice, the instigation of the new working practice will be part of a continuing research journey.

Finally, the use of mixed methods within action research within a 'real world' construction environment has brought a unique perspective to the research. The methodology has permitted the use of both empirical and rational processes to create a new understanding of performance of low carbon technologies within construction. The culmination of the research has created, not only an improved understanding of the processes at work in low carbon construction, but has produced a new working practice that can be further developed alongside future research.

9.6 Future Research Opportunities

The research has highlighted the need for the on-going exploration of change interventions to improve low carbon performance, and to bring closer together the empiric and rational processes of change. As an output from the research, the 'Commission 2 Perform' process will need to be developed incrementally to encourage the engagement of all the construction stakeholders in a continual change management process. To this end, the development of the process into the contractual structure would go some way to recognising the requirement of the findings.

Linked with the change process there is an opportunity to carry out further research into knowledge management, and the transfer of the change management process to the wider low carbon construction environment. The research has shown the somewhat insular nature of installation and commissioning, especially with low carbon domestic construction. Enabling a more holistic approach to the achievement of improved energy and low carbon

performance may further assist in the goal of sustainable knowledge transfer in the construction field. This approach could also cover the implications of BIM within the installation and commissioning process, and how the technology could become more accessible at the installer level. To this end, the further development of mixed methods within action research offers an opportunity to explore the meaning and further implementation of change in the complex environment of construction

Lastly, whilst outside the research boundary, the exploration of the practitioner researcher experience in low carbon domestic construction in other European countries may improve the interventions strategies already adopted in the UK. In these current times of change, both in low carbon construction and our relationship with our near continental neighbours, improving the practitioner knowledge process may find common areas of future development.

9.7 Reflection on the Thesis and the Research Journey

Arriving at the end of this research journey has highlighted the great distance that has been travelled since the start of this professional doctorate. Looking back at the aspirations and goals of the research has demonstrated that every journey is an exploration into an undiscovered country, however experienced and knowledgeable that traveller was at the start. From a professional perspective, the discipline acquired in applying a methodological approach to a 'real world' problem has contributed to the development of the researcher in the field. It has therefore, illuminated a means of exploration, which centres the acquisition of knowledge at the heart of professional practice and continual lifelong learning and discovery.

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Appendix 1

Focus Group Information

Minutes of Meeting

Prof Doc – Focus Group Meeting

Held on 6th February 2014 at 10.00am – Main Office - Orpington

For and on behalf of:

Minutes issued on 20th February 2014

Name Removed - HA	✓
Name Removed - PM	✓
Name Removed - CM	✓
Name Removed – M&E	✓
Name Removed – M&E	✓
Name Removed – M&E	✓
Terry Keech - Calfordseaden	✓

Apologies for Absence

None

ITEM	SUBJECT	ACTION
1.	Focus group were welcomed and introductions given. An outline of the Prof Doc was given and the research method was generally discussed. The meeting was time limited to 1hour 30 minutes to allow for other commitments of the group and to manage the discussion. TK introduced the agenda for the discussion based on three questions to be discussed with the group. These were given as follows: 1. What are stakeholder perceptions of low carbon technologies in new construction developments? 2. How do construction professionals communicate best practice when installing and commissioning low carbon technologies? 3. How is the commissioning of low carbon technologies co-ordinated within the construction programme? The group were given a copy of the questions to ensure these were understood and each question was taken in turn. There was some discussion on question 3 and ……. Suggested that this may be an area they had little knowledge.	**Note**
2.	**TK open the first question: What are stakeholder perceptions of low carbon technologies in new construction developments?** General discussion on low energy technology was primary based around the fact that it had to be used as opposed to wanting it to be installed. The consensus was that if it wasn't a regulation or assessment requirement it would not be installed. The following comments have been taken from the notes to represent the comments made by the group: Code and planning lead the discussions not the technology PV used communally and not connected to dwellings in flats D&B we are often given the solution from planning Not much training on technologies, but have to use them for Code Funding states we have to use 'renewables'. PV seems ok, but has many issues for heating systems and MVHR. Hard to know which one is good and bad New district heating used in London, not convinced it's working. Reductions in CO2 are important and we need to develop Only used because of planning. Some better than others; PV most effective and have had some good experiences using the technology I have seen more defects with district systems and heat pumps. What	**Note**

about ‘fabric first’ too much concentration on technology

Code was discussed and there was a feeling that it was a ‘good thing’ to move construction and design forward. However, there was a feeling in the group that multiple requirements from planners, regulation and, in some cases GLA (on larger schemes) was creating lots of confusion.

Moving onto the second question - How do construction professionals communicate best practice when installing and commissioning low carbon technologies?

3. A noticeable area was that the general level of communication from the focus group was on the management level and not so much on the day-to day. This could be because all the focus group was at a senior level. Only the site manager…….. had experience of the installer level to any degree, and here it seem like a ‘bit of a mixed bag’ of understanding and communication. Key items raised were as follows:

Don’t see an awful lot of communication on site. More like get it in as quickly as possible and move on. Post mortems are sometimes carried out, but there is little continuity on the next scheme

Don’t get involved on many sites. Design and then contractor handles scheme without our input. RFI often shows that ‘they’ are not following design

Management level is normally good, but I do not have much communication at the subcontractor level. It does appear to depend on the team used

Management communication is normally good. However the lower down you go the less communication

Depends on the site. Some are good, some bad. Training is an issue both design and installation. Bit of blind leading the blind

Sites are good and bad and depend on the teams. Site Managers are rare at the moment so some difficulty in management of subcontractors. Money is an issue, and getting M&E bias

4. **To the final Question - How is the commissioning of low carbon technologies co-ordinated within the construction programme?**

An interesting point was discussed on the time allocation and the ‘rushed’ nature of the run up to practical completion. There was again a general consensus, that whilst everyone wanted to get the job right, there was also a need to get the job done. Services were the last item

ITEM	SUBJECT	ACTION

to get completed and were perceived as ‘always caused a problem’.

There was a good discussion on the reoccurring problems on site and how difficult it is to programme for some of the eventualities. An interesting point was the repeated use of the term ‘black box’ referring to the fact that M&E only understood what was going on. Also the individual nature of the subcontractors was pointed out, and how each could be just a self-employed person completing his or her area with no programme beyond the daily site requirement. Key areas discussed and raised were:

We do get programmes off all our suppliers; however the commissioning section is always hard to define with all trades in at the end. Commissioning certs are always completed as required

I have seen one or two programmes at the start of the scheme, but these are not updated or followed through to allow coordination

I find the same. Commissioning happened somewhere at the end, very rarely programmed and often not completed

When we are on site there is very rarely a programme for commissioning. It’s all pretty ad hoc

Programmes are discussed at every meeting, but somehow it’s nearly always a rush at the end for handover. Not seen the M&E programme, but that is a specialist area

Construction programmes are updated at each meeting, however the M&E bit is just allocated a space and it’s often late. We often do not have expertise to challenge M&E issues or commissioning results

The discussion was very open and frank and it was good that everyone participated fully in the discussions. The formal part of the focus group completed, but the discussion did continue. What has come across is a real gap in the process from planning to the actual delivery. What has been of interest is how process has rolled on without a real overview of what is actually happening on the site

5. TK thanked all for taking part in the discussion and for the good overview of thoughts and ideas. TK to be in touch on a regular basis during the research to ask questions and test ideas. All agreed.

Meeting completed (overtime – lasting 2hours)

ITEM	SUBJECT	ACTION
6.	**DATE OF NEXT MEETING**	
6.1	By individual contact	**All to note**
7.	**DISTRIBUTION**	
7.1	As per front sheet.	

Signed: .....

Terry Keech
for and on behalf of calfordseaden LLP

Appendix 2

Early Questionnaire Structure – Example (not Used)

Ref:

Questionnaire for Constructors of Low Energy Homes

The following brief questionnaire has been design to collect information from construction professionals involved in 'Low Energy Homes', to understand the approach to the Construction at the planning and site construction stages of the project. **The definition of Low Energy Homes for the questionnaire is based on homes that have been built to at least Code for Sustainable homes Level 3 or Ecohomes 'Very Good'.** All information collected is confidential, and names / addresses are not required and will not be used as part of the research. The Information gathered is to be used to gain an understanding of the opinions and approaches to the design and construction of low energy homes, taken from the constructor's perspective. It also seeks to understand, where information is available, how the construction alters from the original design during the site post tender and construction stages, and what effects this may have, if any on the outcome of the project. This information will be used as part of my thesis for my Professional Doctorate titled: **'The construction industry approach to delivering mass low energy homes'.** It is part of two further questionnaires aimed at Designers/Project managers and Residents to try to gain an understanding from differing perspectives.

The questionnaire is divided into three colour coded sections:

1. Information on role and experience – Role and Experience
2. Information on Installation approach – Installation Stage
3. Information on the final product at completion and hand over - Completion and Handover

Information for Completing the Questionnaire

Please complete all questions and give brief additional information wherever possible, as it will help to further interpret your responses. The information can be **written by hand** on a **printed copy** or **typed directly** into this **'Word' version**. Where typing into **'Word' version** please **Highlight** instead of the requested **'Circle'** for the relevant questions where a selected response is required. Please stay within the text box for **'Brief'** responses.

Thank you for your time in completing this questionnaire.

Questions:

Role and Experience

1. What is your role in the construction process? Please circle the box as appropriate.

- Estimator
- Building Surveyor
- Quantity Surveyor
- Building Services Engineer – Mechanical* / Electrical* bias (* delete where not applicable)
- Site Manager
- Project Planner
- Project Manager
- Project Director
- Developer
- Other, please state……..

2. What is your position with in your organisation? Please circle the box as appropriate/

- Apprentice
- Installer
- Foreman
- Manager
- Senior Manager
- Director
- Managing Director
- Other, please state……

Role and Experience

3. How many 'Low Energy Homes' projects have you worked on over the last 10 years? Please circle as appropriate.

EcoHomes (all levels)	0, 1 – 3, 4 – 6, 7 – 10 - 10+
Codes for Sustainable homes Level 3	0, 1 – 3, 4 – 6, 7 – 10 - 10+
Code for Sustainable Homes Level 4	0, 1 – 3, 4 – 6, 7 – 10 - 10+
Code for Sustainable Homes Level 5	0, 1 – 3, 4 – 6, 7 – 10 - 10+
Code for Sustainable Homes Level 6	0, 1 – 3, 4 – 6, 7 – 10 - 10+
Passivhaus	0, 1 – 3, 4 – 6, 7 – 10 - 10+
Other please state:	

Text Here:

If the period of your working involvement in projects has been shorter than 10 years please specify how long you have been working with Low Energy Homes:

Text Here:

4. Do you have any specific training in the field Low Energy Homes? Please circle the boxes for as many as are relevant to you.

- Seminars by product providers
- Seminars by technical providers
- 'In House' seminars by staff member
- CPD Courses with certificate
- Attended short course run by recognised body (such as CIBSE, RIBA, RICS etc.).
- Distance learning short course run by recognised body (such as CIBSE, RIBA, RICS etc.).
- Other please specify

Text Here:

5. Do you have any recognised qualifications in the field of Low Energy Homes? Please circle the boxes for as many as are relevant to you.

- Diploma Level
- Degree Level
- Post Graduate Level
- Other (Please State)

Text Here:

Role and Experience

6. In your own opinion what level of practical experience do you feel you have in the field of Low Energy Homes? Please circle the box next to the statement relevant to you.

- No experience and new to the field of low Energy Homes
- Limited experience and currently under supervision of a senior member of staff
- Limited experience but with no requirement for supervision as you have experience of housing in general
- Fair practical experience, but need more involvement to obtain a better experience level
- Good practical experience of the field of Low Energy Homes
- Extensive practical experience of the field of Low Energy Homes
- Project manager / team member (*delete as appropriate) overseeing low energy projects with limited experience of low energy homes
- Project manager/ team member (*delete as appropriate) overseeing low energy projects with good experience of low energy homes
- Please give a brief reason for your response:

Text Here:

7. As an installer within the project, what Low Energy systems have you been involved with and to what extent? Please circle the relevant statement in the scale for each technology below:

o	Solar Photovoltaic	Experienced	-	Limited experience	-	No experience
o	Solar Thermal	Experienced	-	Limited experience	-	No experience
o	Ground Heat Pump	Experienced	-	Limited experience	-	No experience
o	Air Heat Pump	Experienced	-	Limited experience	-	No experience
o	Wind Turbine	Experienced	-	Limited experience	-	No experience
o	CHP	Experienced	-	Limited experience	-	No experience
	Communal Heating	Experienced	-	Limited experience	-	No experience
o	LED Lighting	Experienced	-	Limited experience	-	No experience
o	MVHR*[1]	Experienced	-	Limited experience	-	No experience Passive
	Building Design*[2]	Experienced	-	Limited experience	-	No experience
o	Biomass	Experienced	-	Limited experience	-	No experience

Other please state:

Text Here:

Role and Experience

8. If your role is management within the project, what Low Energy systems have you been involved with and to what extent? Please circle the relevant statement in the scale for each technology below:

o	Solar Photovoltaic	Direct involvement – Limited involvement – No involvement
o	Solar Thermal	Direct involvement – Limited involvement – No involvement
o	Ground Heat Pump	Direct involvement – Limited involvement – No involvement
o	Air Heat Pump	Direct involvement – Limited involvement – No involvement
o	Wind Turbine	Direct involvement – Limited involvement – No involvement
o	CHP	Direct involvement – Limited involvement – No involvement

[1] Mechanical Ventilation with Heat Recovery
[2] Work with building fabric for air tightness, U Values, solar shading etc.

- o Communal Heating — Direct involvement – Limited involvement – No involvement
- o LED Lighting — Direct involvement – Limited involvement – No involvement
- o MVHR — Direct involvement – Limited involvement – No involvement
- o Passive Building Design*[3] — Direct involvement – Limited involvement – No involvement
- o Biomass — Direct involvement – Limited involvement – No involvement

Other please state:

Text Here:

9. With a score of 1 – 6, with 1 being the least effective and 6 being the most effective. How would you rate the Low Energy systems you have been involved with? Please circle the relevant number in the scale for each technology below:

- o Solar Photovoltaic — 1 - 2 - 3 - 4 - 5 - 6
- o Solar Thermal — 1 - 2 - 3 - 4 - 5 - 6
- o Ground Heat Pump — 1 - 2 - 3 - 4 - 5 - 6
- o Air Heat Pump — 1 - 2 - 3 - 4 - 5 - 6
- o Wind Turbine — 1 - 2 - 3 - 4 - 5 - 6
- o CHP — 1 - 2 - 3 - 4 - 5 - 6
- o Communal Heating — 1 - 2 - 3 - 4 - 5 - 6
- o LED Lighting — 1 - 2 - 3 - 4 - 5 - 6
- o MVHR — 1 - 2 - 3 - 4 - 5 - 6
- o Passive Building Design*[4] — 1 - 2 - 3 - 4 - 5 - 6
- o Biomass — 1 - 2 - 3 - 4 - 5 - 6

Please give brief reason for your response:

Text Here:

[3] Work with building fabric for air tightness, U Values, solar shading etc.
[4] Work with building fabric for air tightness, U Values, solar shading etc.

Installation Stage

10. For which of the following are you employed by the construction project? Please circle from the selection below and go to the next question number indicated:

- Directly for the Main Contractor ***(please go to question 11)***
- Directly for Sub-Contractor ***(please go to question 16)***
- Self-employed working for the Main Contractor ***(please go to question 11)***
- Self-employed working for a Sub-Contractor ***(please go to question 16)***

11. As a Design and Build Main Contractor, of the following statements, which best reflects your opinion/s of the planning process for low energy homes. Please circle the boxes for as many statements as relevant to your opinion:

- The planning process is effective in its approach to deliver low energy homes
- The planning process is not effective in its approach to deliver low energy homes
- The planning process gives a clear message to the construction industry on what is expected to achieve low energy homes
- The planning process does not give a clear message to the construction industry on what is expected to achieve low energy homes
- The planning process is complex and needs to be simplified to enable low energy homes to be delivered
- The planning process is flexible and allows interaction on how the low energy homes are provided
- The planning process is not flexible and does not allow interaction on how the low energy homes are provided
- Other, please state:

Text Here:

Installation Stages

12. Within London the current 'London Plan' gives a hierarchy of compliance for low energy homes (Lean, Clean and Green), which encourages the use of communal heating systems as part of the 'Clean' section, with combined heating and power (CHP) installation. This is used by local authorities in their planning requirements. As the Main Contractor, of the following statements, which best reflects your opinion of the effect communal heating and CHP are having on low energy homes? Please circle as many boxes as relevant to your opinion:

- An effective way of contributing to low energy homes
- Only effective if used on larger scale domestic projects over 100 units
- Only effective if used on larger scale mixed used developments including commercial and resident over 100 units
- Not effective on small scale projects under 50 units
- Effective regardless of the size of the development
- The design of communal heating systems are not fully understood and have affected the efficiency contributing to low energy homes
- The design guides for communal heating systems need to change to reflect installation in thermally efficient dwellings
- The design guides are adequate for designing communal heating for low energy homes
- Communal heating has created overheating in low energy homes through inadequate design
- Communal heating systems with CHP are complex to maintain
- Communal heating systems with CHP are expensive to maintain
- Communal heating systems with CHP are complex to operate
- Communal heating systems with CHP are expensive to operate
- Communal heating systems with CHP are expensive for residents to use
- Communal heating systems with CHP are cheap to maintain
- Communal heating systems with CHP are cheap to operate
- Communal heating systems with CHP are easy to operate
- Communal heating systems with CHP are easy to maintain
- Communal heating systems with CHP are cheap for residents to use
- Other please state:

Text Here:

13. Briefly what main change would you make to the planning process for low energy homes?

Text Here:

Installation Stages

14. Where you are the Main Contractor, what do you procure your Consultant design team to complete during the construction process on site? To answer please circle as many of the numbers as relevant in the scale for each statement below:

	Performance Design	Detailed Design	Site inspection	Commissioning
o Architect	1	2	3	4
o Structural Engineer	1	2	3	4
o Building Services Engineer	1	2	3	4
o Code Assessor	1	2	3	4

o Other please state below:

Text Here:

15. Where you have procured your Consultant design team for performance design only, who completes the detailed design? Please circle as many as relevant from the list below:

- o Sub-Contractor undertake the detailed design with their own consultant team
- o Sub-Contractor undertake the detailed design without consultant team
- o Sub-Contractor uses performance design, completed by others, with no further detail
- o Other please state below:

Text Here:

16. In your opinion which design approach is the most effective for the installation stage during construction? To answer, where 1 is strongly disagree and 4 is strongly agree. Please the circle scale number, as appropriate below, for each statement:

- o Consultant performance design with sub-contractor detailed design 1 - 2 - 3 - 4
- o Consultant performance design and detailed design 1 - 2 - 3 - 4
- o Consultant performance design with no further design by the sub-contractor 1 - 2 - 3 - 4
- o Other, please state below:

Text Here:

17. Where you have been involved on construction projects for Design and Build contracts, how often is a value engineering exercise undertaken on the agreed tendered design? To answer where 1 is 'never carried out' to 6 where 'always carried out'. Please circle the scale number as appropriate below.

Never carried out 1 - 2 - 3 - 4 - 5 - 6 Always carried out

Installation Stages

18. Where you answered question 17, in your opinion, what have been the main reasons for the Value Engineering exercise? To answer where 1 is 'strongly disagree' to 4 where 'strongly agree' Please circle the relevant number in the scale for each statement below:

- o Cut costs to increase profit for contractor from inferior materials 1 - 2 - 3 - 4
- o Cut costs to increase profit for contractor from inferior design changes 1 - 2 - 3 - 4
- o Reduce costs by using contractor procurement Route for similar materials 1 - 2 - 3 - 4
- o Reduce costs by changes to the design Based on contractor experience 1 - 2 - 3 - 4
- o Improvement to design at no additional cost 1 - 2 - 3 - 4
- o Improvement to design with additional Material cost 1 - 2 - 3 - 4
- o Improvement to design with additional Material cost but saving in program 1 - 2 - 3 - 4
- o Other please state below:

Text Here:

19. Where you are installing to the design drawings and specification of low energy homes, in your opinion how effective is the design information you are given to install. To answer where 1 is 'strongly disagree' to 4 where 'strongly agree' Please circle the relevant number in the scale for each statement below:

- o The design information can be installed with no alteration 1 - 2 - 3 - 4
- o The design information can be installed with minor alteration 1 - 2 - 3 - 4
- o The design information can be installed with major alterations 1 - 2 - 3 - 4
- o The design information cannot be installed without substantial alteration 1 - 2 - 3 - 4
- o Installed with your own experience regardless of information 1 - 2 - 3 - 4
- o Design for low energy technologies need more detail as complex to install 1 - 2 - 3 - 4
- o Design for low energy technologies need less detail as simple to install 1 - 2 - 3 - 4
- o Other please state below

Text Here:

Completion and handover

20. During the installation stages how do you monitor the installation progress? To answer where 1 is 'always carry out' to 6 where 'never carry out. Please circle the relevant number in each scale for each statement below:

- o Regular meetings are carried out to review the installation with Information circulated to all relevant staff 1 - 2 - 3 - 4 - 5 - 6
- o Manufactures on site to undertake installation training 1 - 2 - 3 - 4 - 5 - 6
- o Key staff check installation quality and report to senior manager 1 - 2 - 3 - 4 - 5 - 6
- o Manufacture information circulated without follow up checks 1 - 2 - 3 - 4 - 5 - 6
- o Installer carry's out their own checks with no review by management 1 - 2 - 3 - 4 - 5 - 6
- o Self-employed staff check their own work 1 - 2 - 3 - 4 - 5 - 6
- o No progress monitoring carried out 1 - 2 - 3 - 4 - 5 - 6
- o Other please state below:

Text Here:

21. Where you have been involved on low energy projects as a contractor, what is your opinion of the approach to low energy homes during commissioning? To answer where 1 is 'Very Common to 4 where 'Very Uncommon' Please circle the relevant number in the scale for each statement below:

- o The main contractor requires the subcontractor To have a full commissioning program 1 - 2 - 3 - 4
- o The main contractor does not monitor the Commissioning programme 1 - 2 - 3 - 4
- o The sub-contractor has a full commissioning program 1 - 2 - 3 - 4
- o The sub-contractor uses the commissioning program To complete all commissioning works 1 - 2 - 3 - 4
- o The sub-contractor does not have a commissioning program 1 - 2 - 3 - 4
- o The commissioning is always left too late in the project 1 - 2 - 3 - 4
- o There is not sufficient time to complete commissioning 1 - 2 - 3 - 4
- o The sub-contractor employs a specialist Commissioning engineer to run the commissioning activities 1 - 2 - 3 - 4
- o Low energy domestic projects do not require a Specialist commissioning engineer. 1 - 2 - 3 - 4
- o The commissioning period is carried out With no disruption to the commissioning activities 1 - 2 - 3 - 4
- o The commissioning programme is often disrupted by the Activities of other trades not completed on time 1 - 2 - 3 - 4
- o There is a co-ordinated approach to commissioning By the mechanical and electrical sub-contractors 1 - 2 - 3 - 4
- o The sub-contractor understands the holistic approach Required for low energy homes when undertaking Commissioning and co-ordinates with all required Trades 1 - 2 - 3 - 4
- o Little or no commissioning is carried out before handover Of the dwelling 1 - 2 - 3 - 4

o The designer is present at commissioning 1 - 2 - 3 - 4

Completion and handover

22. Where you have been involved on low energy projects as a Contractor, what is the magnitude of recorded defects in the first year? Please circle box as appropriate:

- More defects on low energy projects
- Less defects on low energy projects
- About the same amount of defects

If you have additional comments on questions 21 and 22 please add below:

Text Here:

23. Where you have answered question 22. Are the defects mainly? Please circle as many boxes as are appropriate:

- Issues for low energy heat pump technology for heating and hot water
- Issues for low energy district heating with CHP
- Issues for low energy technology ventilation with heat recovery
- Issues for low energy technology natural ventilation
- Issues for metering of heating energy used in communal heating systems
- Issues for billing of heat energy used by residents in communal heating systems
- Issues for low energy biomass boilers
- Issues for Photovoltaic panels
- Resident issues with control of heating controls in the dwelling
- Issues with insulation for overheating in dwellings
- Issues with airtightness for overheating in dwellings
- Issues with communal heating system for overheating in dwellings
- Issues with communal heating system for overheating in communal areas
- Resident issues in using the low energy technologies in their home due to complexity
- Other please state:

Text Here:

Completion and handover

24. Where you have answered question 23. Are the defects resolved? Please circle boxes as appropriate:

- Quickly as they are simple to resolve
- Take some additional time to resolve as repeated visits are required to resolve the defect
- Substantial time taken to resolve as the issues are considered complex and repeatedly not resolved
- The defects are not resolved and go over the defect liability period
- The defect is not resolved and there are fundamental issues to achieve resolution

Where you have ticked one or more of the last three boxes, please briefly bullet point the issues below:

Text Here:

25. Where you have answered question 24. Are the issues caused by one or more of the following?

Resident Use issues	Very often	-	Often –	seldom -	Never
Performance of technologies	Very often	-	Often –	seldom -	Never
Lack of commissioning	Very often	-	Often –	seldom -	Never
Poor installation	Very often	-	Often –	seldom -	Never

Other please state below:

Text Here:

Completion and handover

26. Where you have been involved in the defects period what has been the general resident response to the low energy technology, where expressed. Please circle the relevant statement for each technology you have worked with below:

- o Solar Photovoltaic — Very Positive – Positive – Negative – Very Negative
- o Solar Thermal — Very Positive – Positive – Negative – Very Negative
- o Ground Heat Pump — Very Positive – Positive – Negative – Very Negative
- o Air Heat Pump — Very Positive – Positive – Negative – Very Negative
- o Wind Turbine — Very Positive – Positive – Negative – Very Negative
- o CHP — Very Positive – Positive – Negative – Very Negative
- o Communal Heating — Very Positive – Positive – Negative – Very Negative
- o LED Lighting — Very Positive – Positive – Negative – Very Negative
- o MVHR — Very Positive – Positive – Negative – Very Negative
- o Passive Building Design*[5] — Very Positive – Positive – Negative – Very Negative
- o Biomass — Very Positive – Positive – Negative – Very Negative
- o Other please state below:

Text Here:

27. In your opinion, based on the projects you have worked on, are low energy homes delivering their outcomes as envisaged at the installation stages of the project. To answer where 1 is 'not achieve their outcomes' to 6 'fully achieved their outcomes'. Please circle each section number as appropriate:

- o For residents moving into a new low energy home — 1 - 2 - 3 - 4 - 5 - 6
- o For Landlords managing a low energy development — 1 - 2 - 3 - 4 - 5 - 6
- o For Developers of low energy developments — 1 - 2 - 3 - 4 - 5 - 6
- o For design of low energy projects — 1 - 2 - 3 - 4 - 5 - 6

Please give any further brief points below:

Text Here:

Completion and handover

28. To understand a little of your own personal feeling on energy use outside your professional working environment, please give your opinion on the following statements? Please circle as appropriate for each statement.

Saving energy is not important - Strongly agree, agree, disagree, strongly disagree

Climate change is happening now - Strongly agree, agree, disagree, strongly disagree

I can make a change to the climate Through energy saving - Strongly agree, agree, disagree, strongly disagree

Saving money is more important Than saving energy - Strongly agree, agree, disagree, strongly disagree

Energy bills are high and Should be reduced - Strongly agree, agree, disagree, strongly disagree

Energy security is more important Than energy saving - Strongly agree, agree, disagree, strongly disagree

Renewable energy (solar panels, Wind, ground energy) is just a Gimmick - Strongly agree, agree, disagree, strongly disagree

Saving energy means reducing comfort Levels in the home - Strongly agree, agree, disagree, strongly disagree

Saving energy is easy to do in the home - Strongly agree, agree, disagree, strongly disagree

Any other comments please feel free to add below:

Text Here:

Thank you for your time to complete this questionnaire it is very much appreciated. If you were approached to take part in a one to one interview session to gain further information on low energy homes, would you be interested. It is envisage that the interview will take approximately 45minutes and all information used will be completely in confidence. No names or project details will be used in the data collected. Please tick as appropriate below:

☐ **Yes. I would like to take part in a follow up interview. My contact details are below and I'm assured that these details will not be made available to anyone, and not used in the data study or final dissertation.**

Name: Contact Number:

☐ **No. I would not like to take part in a follow up interview.**

Thank you.
Terry Keech. E-mail: tkeech@calfordseaden.co.uk (Word/PDF Versions)
Tel: 01689 888222

Return by Post: Calfordseaden, St Johns House, 1A Knoll Rise, Orpington, Kent, BR6 0JX

Appendix 3

Sample On Line Questionnaire from Dotmailer Used for the Research

Questionnaire for Design, Construction, Commissioning and Handover of Low Energy Homes

"Thank you for agreeing to complete this questionnaire, the results will really help my understanding of mass low energy homes for my Professional Doctorate". (Terry Keech)

It should not take longer than 15 - 20 minutes to complete.

There are 28 questions that require a click on the appropriate box to record a response. Please answer all questions (there are 'Don't Know' and Not Applicable 'N/A' boxes to be used where you either do not know or the question is not applicable) . Thank you, and remember a donation will be sent to Cancer Research UK on completion of the survey.

Terry Keech.

Role and Experience

Please complete **all questions** and give brief additional information wherever possible, as it will help to further interpret your responses.

1. What is your role in the construction process? ***Please click the boxes as appropriate below.***

- [ ] Architect
- [ ] Surveyor
- [ ] Structural Engineer
- [ ] Building Services Engineer
- [ ] Project Manager
- [ ] Employer's Agent
- [ ] Developer
- [ ] Housing Association
- [ ] Main Contractor
- [ ] Estimator
- [ ] Mechanical Contractor
- [ ] Electrical Contractor
- [ ] Building Contractor
- [ ] Commissioning Engineer
- [ ] Other

Other, please state your role in the construction process, if not above

2. What is your position within your organisation? ***Please click one of the boxes as appropriate below:***

- [ ] Trainee level
- [ ] Graduate level
- [ ] Junior level
- [ ] Intermediate level
- [ ] Senior Technical
- [ ] Site Management
- [ ] Senior Management
- [ ] Project Manager
- [ ] Director
- [ ] Junior Trades Person
- [ ] Senior Trades Person
- [ ] Foreman
- [ ] Other

Other, please state your position in the construction process, if not above

Next

Role and Experience

3. How many 'Low Energy Homes' projects have you directly worked on?

Please click on the scale for each subject below, where none please click on the None below:

	None	1-3	4-6	7-10	11 - 19	20+
EcoHomes (Very Good or above)	○	○	○	○	○	○
Codes for Sustainable homes Level 3	○	○	○	○	○	○
Codes for Sustainable homes Level 4	○	○	○	○	○	○
Codes for Sustainable homes Level 5	○	○	○	○	○	○
Codes for Sustainable homes Level 6	○	○	○	○	○	○
Passivhaus	○	○	○	○	○	○

Other, please state

4. Do you have any specific training in the field Low Energy Homes?

Please click the boxes for as many as are relevant to you, where you have no training please tick None .

- ☐ Seminars by product providers
- ☐ Seminars by technical providers
- ☐ 'In House' seminars by staff member
- ☐ CPD Courses with certificate
- ☐ Attended short course run by recognised body (such as CIBSE, RIBA, RICS etc.)
- ☐ Site Instruction
- ☐ Tool Box Talks
- ☐ None

Other please specify:

5. Do you have any recognised qualifications in the field of Low Energy Homes?

Please click the boxes for as many as are relevant to you.

- ☐ Diploma Level
- ☐ Degree Level
- ☐ Post Graduate Level
- ☐ BTEC
- ☐ None

Other, please state

Back Next

Role and Experience

6. What Low Energy systems have you been involved with and to what extent? ***Please click the relevant statement in the scale for each technology below:***

	Experienced	Limited Experience	No Experience
Solar Photovoltaic	○	○	○
Solar Thermal	○	○	○
Ground Source Heat Pump	○	○	○
Air Source Heat Pump	○	○	○
Wind Turbine	○	○	○
Communal Heating/CHP	○	○	○
MVHR (1)	○	○	○
Passive Building Design (2)	○	○	○
Biomass	○	○	○

Other, please state

[1] Mechanical Ventilation with Heat Recovery

[2] Work with building fabric for air tightness, U Values, solar shading etc.

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Role and Experience

7. In your opinion has the Code for Sustainable Homes made a difference to your approach to low energy homes. *Please click the relevant statement in the scale for each technology below:*

	Substantial Difference	Some Difference	Limited Difference	No Difference	Don't Know	N/A
Installation Method	○	○	○	○	○	○
Design Method	○	○	○	○	○	○
Materials Used	○	○	○	○	○	○
Building Design	○	○	○	○	○	○
Building Cost	○	○	○	○	○	○
Environmental Impact	○	○	○	○	○	○

Other, please state:

8. In your opinion how effective would you rate the Low Energy systems you have been involved with? ***Please click the relevant scale for each technology below:***

	Very Effective	Effective	Little Effect	Not Effective	Don't Know
Solar Photovoltaic	○	○	○	○	○
Solar Thermal	○	○	○	○	○
Ground Source Heat Pump	○	○	○	○	○
Air Source Heat Pump	○	○	○	○	○
Wind Turbine	○	○	○	○	○
Communal Heating/CHP	○	○	○	○	○
Passive Building Design (Fabric First Design)	○	○	○	○	○
MVHR Ventilation	○	○	○	○	○

Please give brief reason for your response:

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Design and installation Stage

9. At the design, planning and construction stages do you have experience of the following documents and assessments?

Please click the relevant scale for each statement below:

	Experienced	Little Experience	No Experience	Don't Know	N/A
Building Regulations Part L	○	○	○	○	○
The London Plan	○	○	○	○	○
Code for Sustainable Homes	○	○	○	○	○
SAP Assessment	○	○	○	○	○
Local Planning Guidance for Low Energy Design	○	○	○	○	○
Zero Carbon Hub Information	○	○	○	○	○

10. How do you find the regulation and guidance for low energy homes when reviewing a new project? ***Please click on the appropriate scale for each statement below:***

	Strongly Disagree	Disagree	Agree	Strongly Agree	Don't Know	N/A
Clear and easy to follow	○	○	○	○	○	○
Co-ordinated with planning requirements for Low Energy Homes	○	○	○	○	○	○
Costly to provide for the construction industry	○	○	○	○	○	○
Will deliver mass affordable zero carbon homes	○	○	○	○	○	○
Will deliver mass affordable low energy homes	○	○	○	○	○	○
Needs to be more proscriptive to drive effective low energy homes	○	○	○	○	○	○

If possible please give a brief response on your opinion of the regulation, assessment and guidance in the planning stages of a new project below:

11. Do you have your own design/installation/ manangement guides for low energy homes? ***Please click the boxes for as many as are relevant to you.***

- [ ] Your own organisation guidance document
- [ ] Your own team guidance document approved by your organisation
- [ ] Your own personal guidance without approval of your organisation
- [ ] Not applicable
- [ ] No
- [ ] Other

If Other, please state:

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Design and Installation Stage

12. If you answered question 11. How is the information gathered for use?
Please click the scale for each statement below:

	Mostly Used	Little Used	Not Used	Don't Know	N/A
Manufactures information	○	○	○	○	○
Practical information gathered within the organisation	○	○	○	○	○
Information from technical organisations	○	○	○	○	○
Information from professional institutions	○	○	○	○	○
Information gathered from your site exprience	○	○	○	○	○

Other, please state:

13. Of the following statements which best reflects your opinion/s of the planning process for low energy homes. *Please click the scale below for each statements:*

	Strongly Disagree	Disagree	Agree	Strongly Agree	Don't Know	N/A
The planning process is effective in its approach to deliver low energy homes	○	○	○	○	○	○
The planning process gives a clear message to the construction industry on what is expected to achieve low energy homes	○	○	○	○	○	○
The planning process is flexible and allows interaction on how the low energy homes are provided	○	○	○	○	○	○
Planning process does not give adequate consideration to the additional cost of construction	○	○	○	○	○	○
The planning process is fundamentally wrong on the provision of low energy homes	○	○	○	○	○	○

Other, please state:

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Design and Installation Stages

14. Of the following statements, which best reflects your opinions of the effect communal heating and CHP are having on low energy homes you are involved in?

Please click the scale for each of the statements below:

	Strongly Disagree	Disagree	Agree	Strongly Agree	Don't Know	N/A
An effective way of contributing to low energy homes	○	○	○	○	○	○
Only effective on large scale domestic projects.	○	○	○	○	○	○
Creates high costs for the development	○	○	○	○	○	○
Creates high heating bills for the residents	○	○	○	○	○	○
Effective at reducing CO2	○	○	○	○	○	○
Combined with air tight buildings has created long term overheating issues	○	○	○	○	○	○
Not effective due to incorrect design	○	○	○	○	○	○
Not effective due to poor installation	○	○	○	○	○	○

Other, please state:

15. Briefly what main change would you make to the planning process for low energy homes? ***Please answer briefly below if known:***

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Design and Installation

If your main role is in design or installation please go to question 16 below. If your main role is in estimating, site managment, management, project management and Housing Association management please go to question 17

- [ ] Main role in estimating site managment, Management,project management or Housing Association managment go to question 17

16. Where your role is as designer or installer, how are you employed during the construction process on site? To answer *Please click the relevant scale for each statement below: please click N/A for all roles that are not applicable*

	Never	Sometimes	Often	Very often	Always	Don't Know	N/A
Performance Design only	○	○	○	○	○	○	○
Full Design Only	○	○	○	○	○	○	○
Performance Design with review of contractor design	○	○	○	○	○	○	○
Full design with limited commissioning inspections	○	○	○	○	○	○	○
Full Design with site inspections and commissioning	○	○	○	○	○	○	○
Site installation with no design	○	○	○	○	○	○	○
Site installation with part design	○	○	○	○	○	○	○
Site installation with full design	○	○	○	○	○	○	○

Other, please state below:

17. Where you have been involved on construction projects for Design and Build contracts, how often is a value engineering exercise undertaken on the agreed tendered design? ***Please click scale number as appropriate below.***

	Always	sometimes	Never	Don't Know	N/A
Value Engineering	○	○	○	○	○

18. In your opinion, what have been the main reasons for the Value Engineering exercise? ***To answer Please click the relevant scale for each statement below:***

	Strongly disagree	disagree	agree	Strongly agree	Don't Know	N/A
Cut costs for contractor using alternative materials	○	○	○	○	○	○
Cut costs using alternative design	○	○	○	○	○	○
Reduce costs by using contractor procurement route for tendered design	○	○	○	○	○	○
Improvement to design at no additional cost	○	○	○	○	○	○
Improvement to design with additional material cost but saving in programme	○	○	○	○	○	○

Other, please state below:

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Completion and Handover

19. Where you have been involved on low energy projects, what is your opinion of the contractor approach to low energy homes during construction?

To answer Please click the scale for each statement below:

	Very Common	Common	Uncommon	Very Uncommon	Don't Know	N/A
Practical experience of low energy homes	○	○	○	○	○	○
Designs reviewed before commencing on site	○	○	○	○	○	○
Co-ordinated approach to the installation	○	○	○	○	○	○
Contractor manages individual self employed personnel	○	○	○	○	○	○
Sub-contractor team from another EU member country	○	○	○	○	○	○
Design is installed with no alteration	○	○	○	○	○	○
Contractor has regular meetings to monitor low energy installation	○	○	○	○	○	○
Installer/designer meetings to review installation	○	○	○	○	○	○

Please add any further brief comments if desired below:

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Completion and Handover

20. Where you have been involved on low energy projects, what is your opinion of the approach to Low Energy homes during commissioning? ***To answer Please click the relevant scale for each statement below:***

	Very uncommon	Uncommon	Common	Very Common	Don't Know	N/A
Subcontractor has a full commissioning program	○	○	○	○	○	○
No monitor of the commissioning programme on site	○	○	○	○	○	○
Regular updates of the commissioning programme	○	○	○	○	○	○
Specialist commissioning engineer employed	○	○	○	○	○	○
The commissioning programme is often disrupted.	○	○	○	○	○	○
Co-ordinated approach to commissioning	○	○	○	○	○	○
Little or no commissioning is carried out before handover	○	○	○	○	○	○
The designer is present at Commissioning	○	○	○	○	○	○

21. In your opinion do you believe commissioning is being carried out effectively on site for low energy homes? ***To answer please click on the scale below***

	Strongly Disagree	Disagree	Agree	Strongly Agree
Effective Commissioning on site	○	○	○	○

22. Where you have been involved on low energy projects what is the magnitude of Mechanical and Electrical defects / issues in the first year?
Please click the box as appropriate:

- ☐ More defects / issues on low energy projects
- ☐ Less defects / issues on low energy projects
- ☐ About the same amount of defects / issues
- ☐ Don't Know
- ☐ N/A

If you have additional comments on questions 21 and 22 please add below:

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Completion and Handover

23. In your experience where low energy technology defects/issues have been reported are they due to one or more of the following?

Please click as many boxes as are appropriate below:

- [ ] Issues with heat pump technology for heating and hot water
- [ ] Issues with district heating with CHP
- [ ] Issues with ventilation with heat recovery
- [ ] Issues with billing of heat energy used by residents in communal heating systems
- [ ] Issues with biomass boilers
- [ ] Issues with Photovoltaic panels
- [ ] Resident issues with heating controls in the dwelling
- [ ] Issues with overheating in dwellings
- [ ] Issues with communal heating system for overheating in communal areas
- [ ] Resident issues in using the low energy technologies in their home
- [ ] Don't Know
- [ ] No Issues experienced
- [ ] N/A

Other, please state:

24. Are the low energy defects / issues resolved?

Please click as many boxes as appropriate below:

	Always	Mostly	Sometimes	Never	Don't Know	N/A
Mostly quick to resolve as the defects / issues are minor	○	○	○	○	○	○
Take some additional time to resolve as repeated visits are required to resolve the defect /issue	○	○	○	○	○	○
Substantial time taken to resolve as the issues are considered complex and have repeated faults	○	○	○	○	○	○
Lack of maintenance of low energy technologies affect the defects process and increase the time for issues to be resolved	○	○	○	○	○	○
Not found to be defects, but issues found due to lack of understanding of using low energy technologies	○	○	○	○	○	○

Any additional information can be added here

25. In your opinion where low energy issues are experienced are they caused by one or more of the following?

Please click on the scale for each statement below:

	Very Often	Often	Seldom	Never	Don't Know	N/A
Resident use issues	○	○	○	○	○	○
Performance of technologies	○	○	○	○	○	○
Lack of commissioning	○	○	○	○	○	○
Poor installation	○	○	○	○	○	○
Poor design	○	○	○	○	○	○
Lack of maintenance	○	○	○	○	○	○
Lack of understanding how the technology operates	○	○	○	○	○	○
No issues have been experienced	○	○	○	○	○	○

Other, please state below:

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Completion and Handover

26. Where you have been involved in the defects period what has been the general resident response to the low energy home, where expressed. *Please click the relevant statement for each technology you have worked with below:*

	Very Positive	Positive	Negative	Very Negative	Don't Know	N/A
Solar Photovoltaic	○	○	○	○	○	○
Solar Thermal	○	○	○	○	○	○
Ground Source Heat Pump	○	○	○	○	○	○
Air Source Heat Pump	○	○	○	○	○	○
Wind Turbine	○	○	○	○	○	○
Communal Heating/CHP	○	○	○	○	○	○
Passive Building Design	○	○	○	○	○	○
Biomass Boiler	○	○	○	○	○	○
Metering and Bill control	○	○	○	○	○	○
Heating Controls	○	○	○	○	○	○
MVHR Ventilation	○	○	○	○	○	○

Other, please state below:

27. In your opinion, based on the projects you have worked on, are low energy homes delivering their intended outcomes? ***To answer Please click on the scale for each section as appropriate below:***

	Not Achieved	Partially achieved	Fully achieved	Don't Know
For residents moving into a new low energy home	○	○	○	○
For landlords managing a low energy development	○	○	○	○
For developers of low energy developments	○	○	○	○
For design of low energy projects	○	○	○	○
For maintenance of low energy homes	○	○	○	○
Reduce fuel poverty for residents	○	○	○	○
Reduce CO2 emissions on the development	○	○	○	○
Achieve an increased level of satisfaction from residents	○	○	○	○

Please give any further brief points below:

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Personal Information

28. To understand a little of your own personal opinion on energy use outside your professional working environment, please give your opinion on the following statements? ***Please click as appropriate for each statement.***

	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't Know
Saving energy is not important	○	○	○	○	○
Climate change is happening now	○	○	○	○	○
I can directly make a change to the climate through energy saving	○	○	○	○	○
Saving money is more important than saving energy	○	○	○	○	○
Renewable energy is just a Gimmick	○	○	○	○	○
Saving energy means reducing comfort levels in the home	○	○	○	○	○
Saving energy is easy to do in the home	○	○	○	○	○

Any other comments please feel free to add below:

Your Age:

	16 - 21	22 - 30	31 - 40	41 - 50	51 - 60	61 - 70
Age	○	○	○	○	○	○

Nationality:

- ☐ UK
- ☐ Other EU Member State
- ☐ Non EU Member State

Thank you for your time to complete this questionnaire it is very much appreciated. If you were approached to take part in a one to one interview session to gain further information on low energy homes, would you be interested. It is envisage that the interview will take approximately 30minutes (either in person or by telephone) and all information used will be completely in confidence. No names or project details will be used in the data collected. Please click as appropriate below:

- ☐ **Yes.** I would like to take part in a follow up interview. My contact details are below and I'm assured that these details will not be made available to anyone, and not used in the data study or final dissertation.
- ☐ **No.** I would not like to take part in a follow up interview.

If you clicked YES. Please enter your contact details below - (e-mail / contact telephone number):
These details will be kept **strictly confidential** and not used in the study or made avaliable at any time now or in the future. All details are recorded seperately and not linked to the questionnaire completed; this is to maintain confidentiality for questions answered and for follow up interview data.

Thank you again for your time, it really appriciated.

Terry Keech
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Appendix 4

Interview Questions (used for Interview Sessions)

Case Study Ref:	Respondent Ref:

Interview Questions for Design, Construction, Commissioning and Handover of Low Energy Homes

Thank you for agreeing to an interview, the results will really help my understanding of the construction process for mass low energy homes.

The interview is planned to last approximately 40 minutes, and has a semi structured format consisting of set pre-arranged questions, based on the recent questionnaire completed. There are 10 set questions in total, and these will be the same for all interviews to allow the responses to be compared. The interviews will be taped throughout to allow me to accurately transcribe all responses, and all text will be forwarded to you for review. All information used from the interviews will be anonymous, and references to names and locations will be removed to protect all parties.

The interview questions are sent in advance to allow you to review the structure and, wherever possible, compose your thoughts prior to the session. It is hoped that this will give time for you to reflect on your experiences, so that your answers can be as considered as possible. If you would like to add notes into the text boxes provided prior to the interview please feel free, as all information will be gratefully received.

Thanks again for your time and help it is really appreciated.

Terry Keech

Information for Interview

Each question will be asked in turn and your responses will be recorded in full (for comparison purposes only). Supplementary questions ***(marked in blue and italic),*** maybe asked just to pick up on additional detail where relevant to the set question.

A meeting room is required for confidentiality and to assist with the recording. It would be good if this can be booked for 1 hour so that I have 10 minutes to set up before and to complete after the interview.

A full transcript of the interview will be sent to you for review, and to ensure accuracy. When sent all names and location details will be blanked out (as these are not required, and to maintain anonymity for the interviewee).

The final copy of the qualitative data to be used from the interview will also be forwarded when the analysis is completed. Thank you.

About You

- **What is your role and position in the construction process?**
- **Do you have low energy technologies in your own home?**

Interview Questions

Questions:

1. What low energy systems have you been involved with and to what extent? ***(Types of system or construction method, length of time involved and how you were involved etc.)***

2. What are your opinions of the Code for Sustainable Homes, and its method of delivering low energy homes? ***(Such areas as ease of use, relevance, how it has informed choice, cost and understanding etc.)***

3. What are your opinions of the current Planning process for low energy homes? ***(Is the mechanism enabling the delivery of low energy homes?)***

4. What are your opinions of the approach of communal heating in achieving low energy homes, and what have been your experiences? ***(Areas such as installation, operation, metering and billing, comfort levels etc.?)***

5. With the Design and Build contract being the main method of procurement for housing projects, is the process the most effective way of delivering low energy homes? ***(What are your experiences throughout the process including Set up, tendering and VE etc.?)***

6. What are your opinions of the actual construction process for delivering low energy homes? ***(What are your experiences of the building process including site experiences, the installation of low energy homes, and the methods used to monitor progress of the low energy technologies?)***

7. What is your opinion of the commissioning process for low energy homes? ***(Areas such as commissioning period, understanding of commissioning, time required, holistic approach, programming etc.)***

8. What are your opinions on the handover and defects period with low energy homes? ***(Is the handover different, are there more or less defects, are there more or less equipment use issues etc.?)***

9. Reflecting on the whole process for delivering low energy homes from inception to completion, are the current low energy homes you have been involved with delivering as anticipated? ***(Areas such as use for residents, fuel poverty reduction, comfort levels and energy bills etc.)***

10. What have been your learning experiences from your involvement with low energy homes construction?

11. With reference to Case study…… Do you think the areas we have discussed have been prevalent on this scheme?

Thank you for your time to review these questions prior to the interview, if you would like to make any notes beforehand please feel free to include on the sheet attached. I can then use this as supplementary information as part of the review.

Notes here if you wish:

Notes here if you wish:

Thank you.
Terry Keech. **E-mail: tkeech@calfordseaden.co.uk**
Tel: 01689 888222

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Appendix 5

Interview Transcript Sample

Interview 5
Conducted 5th September 2014 – C-01

Terry: Thanks for coming along. The interview is going to last approximately 40 minutes, it's roughly 10 questions and it's in a semi-structured environment whereby I'm asking the same questions of everybody so that I can then analyse those questions against all of the replies that I've got. However because I'm asking different people from different backgrounds within the construction industry there will be supplementary questions which I will use or not use depending upon the information that comes out. I will send you a full copy of the transcript for you to review and just to let you know every element that relates to a name, a site, your company or anything that you wouldn't like us to refer to we will remove from the transcript. The transcripts will be eventually coded and the coding is the element we use not the transcript. Are you comfortable with that.

C-01: Yes no problems.

Terry: Thank you C-01. Right to start off then just a little about yourself. What is your role and position in the construction process.

C-01: I'm a director of a large mechanical and electrical subcontractor really that carries out an awful lot of district heating systems, schools, colleges, and an awful lot of I suppose housing that sort of thing, shared ownership, some high rise developments that are worth a lot of money.

Terry: Thank you. Do you have any low energy technology in your own home?

C-01: I have about 26kw of solar thermal, I have a full PV array, I have a log boiler and low energy lighting throughout really.

Terry: So you're quite an advocate of low energy?

C-01: And I'm fully qualified to install all of it, yes.

Terry: Thank you C-01. Moving on to our interview questions. What low energy systems have you been involved with and to what extent, so that's the types of systems, method of construction, that kind of thing?

C-01: I think we would start with the biomass boilers on a scale from domestic right up to 250kw installs from schools and colleges to housing schemes where the biomass used to go in. Those have changed on the planning applications now to CHP units and now we do an awful lot of CHPs and quite a bit of PV. I think the Housing Associations have realised that PV is possibly the way because there is no maintenance, it's installed and it will pay itself back in 7 years and it's probably the best one of all to use really.

Terry: And why do you think they're moved away from the biomass to the CHP?

C-01: In truth the biomass, whilst it's probably at the same sort of expense to service and maintain, somebody's got to deliver an awful lot of pellets and storage of pellets is of huge concern, you can't just pour them into a bunker and that's the end of it and they'll be there for 6 weeks until you want the next lot. You have some pretty onerous responsibilities with gas build up, there's been several deaths across Europe, it's not an ideal technology to use, especially where nobody is maintaining it. If you've got a full time maintenance guy it's fine, but if you're just pouring it in and expecting it to work it doesn't work that way, somebody has to clean the ash pans out and everything else, it's not ideal.

Terry: And as a supplementary question of all of those technologies you've mentioned which did you think are the most effective?

C-01: PV and solar thermal, really good.

Terry: Could you just expand a little bit on that?

C-01: The cost of installing PV has now come down a long way. It's up there, it's guaranteed, you get a very good revenue from installing it and it doesn't need any maintenance. The worst that can go wrong is an inverter can blow – they take a couple of hours to change and they're not expensive. So it's a no-brainer really other than the space you need to deal with it. The solar thermal is a fantastic way to combine with any of the heating systems and hot water. If you use it during the summer you know an oversize cylinder it supplements everything. It's a very good way, unfortunately it's expensive and there is no easy way to make a claim under the RHI or any of the grant schemes because they've only ever looked at it as a hot water back up not as anything more, but it is probably the most cost effective, certainly for me at home it's out of this world.

Terry: C-01 thank you. What are your opinions of Code for Sustainable Homes and it's method of delivering low energy homes, such as ease of use, it's relevance?

C-01: It's one of those things, we don't get that involved in early doors and then when we all sit down and think how did we get to this position, who's ticked these boxes to make us put these technologies in. It's almost as if it's at the wrong stage that that happens. Our issues then come with trying to actually get a building to work with the restraints that the Code has put on the building, not just financially but on spatial requirements and that is probably the biggest issue. We don't get involved day 1, but we have to sort of deal with what comes out of somebody ticking boxes. That's the biggest issue. The understanding of it is, yes, there had to be a method, whether that Code for Sustainable Homes was the best possible method I don't know but we've been using it for a few years and I suppose we've all evolved with it. It's difficult.

Terry: What is your opinion of the current planning process for delivering low energy homes.

C-01: We don't get that involved in planning but I've got 2 properties myself that have just gone through planning and the restraints put on us and the financial implications of what you've got to use to actually get planning permission to tick all your code boxes and everything else and I think Code Level 4 are both the ones I'm doing at home. It is a pain in the backside and the Local Authority have no understanding really and truthfully what they need to do, all they're doing is ticking boxes, they don't know they don't understand that perhaps a high efficiency gas boiler would be by far the best way to go combined with some solar thermal, they're just not interested, they have to tick a box.

Terry: Do you feel that the Code could actually impede what you would like to do, or do you think it's the lack of understanding or an understanding by the planners themselves?

C-01: I don't think the planners understand it and I would love to see a way where we could demonstrate a simplistic way back to them that this is the most efficient way to heat and run our house, whether it be part and parcel of the Code or not, if that meant I want to put a log burning stove in and some solar thermal totally off the cuff then they would go oh why would you do that because it doesn't tick any boxes, but I know the way the build how it would work and we could demonstrate that.

Terry: So do you think something that was linked to a calculation or post-occupancy monitoring would be more flexible or is there another option

C-01: It would be nice if it was more flexible. If you go up to BRE at Watford where they've got dozens and dozens of different houses all set up and they monitor them for energy efficiencies and everything else, they've done it, but the only reason they've done it is because the big companies, the likes of Dimplex and Mitsubishi have done all the air source and they're the ones that are funding it, why is that fair? Where is the alternatives that the small guy can actually come up with rather than someone who has invested half a million in proving that their bit of kit works and then we're all stuck with their bit of kit, is that right, probably not.

Terry: What are your opinions of the approach of communal heating in achieving low energy homes and what's been your experience, so you know does the installation achieve low energy homes, issues like metering and billing and comfort levels?

C-01: Efficiency wise probably not, but ease of use I would say it had to be done, you could no longer keep going with 200, 300 domestic gas boilers. There's always a problem having a gas in a building let alone having flue gases in every dwelling where nobody looks after anything. That had to be done away with. I still feel that we're missing a trick that with buildings don't have any heat loss as such just having some lighting on heats the rooms up, so why are we not all looking at electrical heating and finding a cheaper way of generating electricity? That is probably the easiest way to push forward, but you never see it do you, you never see a block of flats heated by Dimplex heaters and an electric water cylinder anymore because they can't get away with it, why? It's bizarre.

Terry: You mentioned on the district heating efficiencies is that a fact of design or other issues with the heating system before it's installed or as part of the installation itself?

C-01: I would blame fully the early installation on our governing body the likes of CIBSE where they sit with their heads in the sand and have no concept of looking at the Europeans and how the Europeans have done it and the diversities we should have been using, the pipe sizing we should have been using, the boiler capacities we should have been using, they are so archaic that everybody hides behind that's what we've got to do that's how it works, and they are wrong. It should never have got to where it is, giving our industry an awful name and it's really sad, you know we can prove time and time again that we could do it with a third of a capacity, a third of the pipe sizing and still be overheating the building. I have to look back at the historics of what's caused this problem and it's given the mechanical side of our industry an awful name it really has.

Terry: Thank you C-01. With the design & build contract being the main method of procurement for housing projects, is this process the most effective way of delivering low energy homes?

C-01: It's certainly the financial driver, I would say that yes, the way they've done it and the D&B and to get to a figure is the only way it would work. But unfortunately there are so many corners you can cut when you get some, perhaps people that aren't experienced in doing district systems, perhaps people that aren't experienced in doing proper housing that needs to be that way, the first thing you've got to do someone's going to cut a corner. Someone's not going to do it properly should the guidelines not have been written before that was allowed to happen – yes, probably, you would have to look at how they measure the performance of the properties afterwards. It's easy to build a block of flats and it's easy to walk away from it, but does it really work? Well, who cares, that's what they say isn't it, it's just done they walk away and we're all left to pick the pieces up for the next 2 or 3 years trying to put it right. So, yes, I can't knock D&B it's how I earn my living. And it's probably how you earn your living, that's what it is.

Terry: But if we looked purely at delivering low energy homes and maybe the holistic approach that's required from delivering a low energy home, is there a more effective method or do you think the method that's there can be managed?

C-01: I think possibly it could be managed but with a few more guidelines. I would love to see low energy homes inasmuch as they do like in Europe or Denmark or Sweden where their insulation levels far exceed anything that we could every do here but they are prepared to put all their time and effort and money into it and then they don't need any heating. It's so minimal on what they do and they live in a lot colder climate than we do. They certainly expend a lot more money on that side of the card than we do. All we're about is cutting corners and all they're about is make sure it works first time and that's where we're wrong.

Terry: Thank you. What are your opinions of the actual construction process for delivering low energy homes, so how we go about delivering, you know what is the experience of the build process, including site experience, insulation of low energy homes?

C-01: Do you know what it's simple, if you looked at the process of right we're going to build 200 houses or a block of flats with 300 dwellings in it, however you do it, you get an architect that comes up with a concept and design and the one we're looking at the moment is a prime example of that. They come up with a concept, they put it all together, the M&E boys design up and work alongside them, the structural guys the same. The builder or the developer sits in on it half way through the process with his technical guys, and the first thing they're trying to do is remove all the concepts that have been started in the first place to reduce the cost of the build.

I can't see how that works, but how do you restrain an architect or consultant from running away with everybody's money because they want it look lovely, they want to do this they want it to do that. That I think is where it falls apart. The standards are so open across the entire industry isn't it, I mean it could be anything from a boiler to a type of radiator to - as we're looking up there - a triple glazed unit made in China 2 years imported to clad on the side of this building. Well how do we know that actually performs because where are they going to test it, will they ever test it, probably not. We look at that all that up there will eventually perform or not and we won't know, it will only be probably me that's get called back oh I can't keep the building cool because it won't work. I don't know, it's all about the original concept and the man who then has to make it pay and the first thing he's going to do he's going cut out the luxuries and the bits that really would have mattered. He's never going to cut out the bits that look lovely he's going to cut out the bits behind the scenes that kept it sealed, insulated, or the glazing on the windows.

Terry: When the low energy homes are being constructed, the monitoring process on site from the main contractor to the subcontractor, is that effective or does it need to be more effective, or are there other things we can be doing or not?

C-01: Do they really monitor it? Does anybody monitor it? I don't think they do, I think they just, we get a concept the design is there it all gets thrown in and we'll bumble out the other end of the building with no time to spare. Does anybody actually check it's installed as it should be installed, does anybody check is it working as it should. On housing no, on a commercial scheme you wouldn't dream of walking out of the building the day it's handed over, you would have a 3 months running, commissioning, we would have hours with you boys, we would spend so much money on commissioning, proving figures, writing it off, handing it over. You tell me that's going to happen there, that will never happen in a million years. As a builder you wouldn't have the time to allow it to happen. We'll be thrown out and we're outside going is that right, yes that will be alright and it will get signed off.

Terry: So do you think that is an experience across the industry?

C-01: On residential absolutely. Not so much on commercial buildings. Because historically commercial has been so much more disciplined. Residential it's a bunch of house builders that think they know how to build a proper building. We should have combined the two disciplines and you would never have, I mean all the years we've built the universities and the colleges and all the schools, they would never have allowed a house builder to do that, they would have built the structure and said well if you want to put some houses inside feel free, but this is the building this is what it is, this is the concept, and by the way it works, whereas that – nope just left, done and dusted, unfortunately.

Terry: Moving on, what is your opinion of the commissioning process for low energy homes?

C-01: I spend half my life arguing about handover process and having to go back and set things up. Every time we go back it's never there as it was set up if it was set up in the first place. I would say 90% of the dwellings that we leave have never been commissioned properly and that's us as a company. I mean it grates a little bit that my guys don't see it, that if the builders don't give them a chance we get, a typical one we've got a job with Bellways and the end of the month I'm to hand over 60 dwellings. Well I get a week to commission 60 dwellings and that's heat recovery units, HRUs, all the blending valves everything. How do you do that? You can only do that if you had 60 blokes. But I've got 4. It doesn't work, so I get an hour a dwelling. How does that work? The guy runs round turns it on hot yep yep done and out, chuck a bit of tissue paper on it, oh that's alright that's switched on. And you'll be called back in in 6 months time to do a survey on the ventilation systems because they're not working and you'll say but they've still got tape on this, yes well that's how it happens.

Terry: Do you think that has a direct consequence on how residents use their low energy technologies?

C-01: A typical example is we've got some houses at …….. They're £1.2m each these houses and on the roof of each one they've got a state of the art solar thermal array from Baxi, cobbled together with a 300 litre megaflow cylinder down in a cupboard. I can't remember how many houses there are but we got called up there because we've had so many call outs and everything on these so I went up to have a look at them and out of all the houses only one of them was actually operational and we went into 3 or 4 of them where they had overheated, the design was horrendous there was not enough expansion, there was, in truth the people that had designed it, the people that had installed it, the people that had commissioned it, had no real

concept of what was going to happen. These places, £1.2m, they've got 5 bathrooms, 5 bedrooms, but they had 2 people living in them, young families that get up in the morning at 5am, go to work and come home at 9pm at night. The hot water usage is negligible. But I've still got these huge solar systems pumping into them all day long. What does it do, it overheats, over pressures, blows out into the drains and stinks the house out every time. None of them are working bar one. That one's working because the guy whose house it, the solar thermal array sits behind a wall, so it never gets any sun. But he's ever so happy. We install all this stuff, nobody knows what it does, nobody sets it up and unfortunately the people that live in these dwellings are oblivious unless there's a flashing light telling them it's not working. And that's it, and then they phone up and complain. They've never looked at it, they've never read any literature, they've got no idea exactly what it does. And whether that be solar thermal, whether that be heat recovery, it could be anything, absolutely anything and they have not got a clue. You tell me the likes of these small houses we do where it's a requirement to put PV on there to tick their Code, or solar thermal to tick the Code. Their roof might be facing north, but I've still got to put it on the roof to tick the box. It will never get the sun, it will never work and somebody has spent £3,000 or £10,000 to put it up there. But the old dear in the house says oh I've got PV that's lovely. But it's never ever going to work, because the man with the codes gone oh you need that to get the box, he's never even looked at the site layout. How is that right? The residents, they haven't got a clue and I don't think they're even bothered anyway, they all say they would rather have just a combi boiler back, so, madness.

Terry: And what are your opinions of the handover and defects period for low energy homes, I know you've answered to a certain extent already, but is there anything else you want to add to that?

C-01: We get called to defects and we've got a permanent team of 4 doing defects, I mean we do £30 million a year so you know a large part of our business is covering the defects, not just on our developments, we cover an awful lot of other people's defects because they don't have that facility. In truth if every defect was reported I would probably need 100 engineers. But 9 times out of 10 the people that move into these dwellings don't understand it's not working, don't have a clue what they really should be getting out of everything, and they accept a dribble at a tap or they accept lukewarm water or they accept, gosh we've got some that have been in for a year and they've got no water, or people that go in and they've got no lights in half the flat, but where they've come from it's a luxury to have a light bulb, it's a luxury to have cold water, it is just completely bizarre when you finally get into some of these dwellings, if everybody complained and the defects were there then yes I don't think we would ever finish a job.

Terry: Do you think there is a case then for greater education with low energy homes or do you think it's something else?

C-01: I don't think the majority of the residents are capable of being educated in any way shape or form. I think we need to simplify what we do, if that means we tick the Code box by producing a lot more solar energy on the roof that goes back into the grid and it doesn't affect the flats that is probably the easiest way to do it. If we do it with district systems and HIUs and CHPs as the way that we tick the box even better. The less we put in and the less technologies we put anywhere near a resident or a dwelling, the better. It's beyond their comprehension.

Terry: And what about education for the construction process. You've said you know there are difficulties or possible difficulties with commissioning, possible difficulties with design and with install, does there need to be more education or a new way of looking at that?

C-01: I think all the time that the house builders are building these dwellings and they are well they've got no real concept that what you need to do and how long you need to spend to commission to get it to work properly. We've just done a development with …….. and when it came to the next phase I withdrew our tender and …….. went absolutely mad and said why have you done that and I said what we've done we've handed you over a job that is s**t, we're going to be spending so much time, effort and money putting it right because we never had the time to commission it. We never had the time to set it up, I said it's awful, it's cost us a fortune, I've got 5 years warranty on this and it's going to cost me even more money for the next 5 years and I'm really not interested in working for you. So they came back and said no we've got to get you to do it, you're doing the whole estate, so we revised our quotation but more importantly we had 5 days written in to our order by them would be our allowance to commission and set up a dwelling. So I had 5 days from having gas, electric and water, the moment they were on they could not throw us out of that dwelling for 5 days. I don't get any defects. They don't get any call outs, and they've suddenly realised maybe there's a bit of sense in doing this, but it's taken us what nearly 3 years we were on that job and that's how long it's taken us to get to that position, and the Site Manager or the Project Manager there now adamant. OK we still need to get over the line, but I know we're not letting Sales have that until you've been finished and you've handed me those keys back.

Terry: So reflecting on the whole process for delivery of low energy homes from the inception to the completion, are the current low energy homes you've been involved with delivering as anticipated, so as we originally anticipated back in the ticking of the boxes are they delivering?

C-01: Every single one of them has the ability to deliver as designed. The construction process and the commissioning process and the customer awareness process is what's letting it down. You and I if we were given the time to install it put it together and sort it and hand it over and witness it and sign it off, we would comfortably walk away knowing that the kit works, the building works exactly as it should do, everything's right and works well, but it falls down in about three places and it only needs to fall down in one and that's the end of it isn't it, so no is the answer to that. Very rarely does that happen.

Terry: And do you think that low energy homes are now directly affecting fuel poverty or not?

C-01: I think we've come a long way with what we build now to what I was involved in 20 years ago inasmuch the technologies we put in now, the way they seal the buildings, the insulation levels and everything else is a great benefit. What we're doing helps, I don't think it's detrimental and every time we do one if its 50% better than it should be, or than the original concept, then I think you're fine. I think, fuel poverty, well if we got them all right 100% we would have a lot more fuel to go around, but you and know that on a scale of, well if you said 100% right I would say each one we're doing is probably 40% of what we have put in is actually working, which is a bit worrying.

Terry: What has been your learning experience from your involvement with low energy homes from construction, apart from all of the wealth that you've given me, any other learning experiences?

C-01: I don't leave things to chance and obviously from the list of what's in my house I wouldn't go and let my lads install anything that I haven't done, experienced and spent hours playing with, to see what actually works, what problems we're going to have, what's going to go wrong and everything else. I truly believe that we're going the right way, we're just not carrying it out in the build process. I would love it to be simplified, you know that way down

the line, but I think the only thing we lack is time and the understanding on the build process it has to be done properly. And that's where we go wrong.

Terry: A last question where we're both working on a scheme which is going to be called Case Study 4 which is…….. and again as I've said before everything will be removed with regards that name, with reference to that Case Study 4 do you think the areas we have discussed have been prevalent on that scheme?

C-01: I think ……..is one of the typical examples of us as a company, obviously it's not one I'm personally involved in but I will be on the next phases where we'll change how we do it. I looked at the commissioning sheets yesterday from my guys and what they've done on site and they are just typical of someone not doing their job properly, not ticking the box properly. Maybe a criticism is that your side of the fence, you've not insisted and come over and spent time commissioning it properly. All credit to …….. who's reviewed every commissioning sheet that we've done and has pulled us up on so many where we've had to go back and redo it, re-check it and everything else, but I still don't think his understanding is as good as he'd like to think it is. No, I think …….. we've let that slip appallingly from the day we allowed Hoare Lea? to design that energy centre 5, 6 years ago, to what we're doing now. I believe that we will get better over there and I believe that whatever we do from here on in is only going to enhance that scheme. I think we all know that we got a bucket of c**p in the corner and we've just got to try and get the best we can over it and cover it over and keep going forward. It is a hell of a job but I think this last phase we've done ourselves any favours at all. But it's nothing given to what we do everywhere else.

Terry: But if you had it from the start, knowing what you know, what would be two or three points that you would make sure would be included?

C-01: I would have pushed very very hard for the early doors of changing the whole energy centre strategy the whole billing strategy, the HIU's are probably one of the worst efficient bits of kit out there. We could have improved the system efficiency tenfold and possibly got the client some monetary gain back from negotiating some proper tariffs at early doors and designing it so that the whole estate actually operated properly. I just think it's been done in bits and you can't do a job that big in bits. You have to start and you have to look at the whole strategy, what's it going to cost when you've got 700 units running? How do you get over that, how do you actually mitigate the costs of it? And I think all they've done is thrown poorly at it early doors, massive system, everybody interfered, the system even got bigger and we're just bearing the brunt of a grossly inefficient system with a very dissatisfied client. It's proved such a shame because it is a transformation of a housing estate that was, where you wouldn't want to go there after dark when we first got involved in it, whereas now you walk down there and it is a lovely place to be, it is a shame. But as I say, we can only get better. Two or three points, reduce the size of the energy centre massively, reduce the size of the energy usage coming from there put in early doors a big CHP unit that would have just ticked over and been ticking over there forever, need never even worried about it and they could have made a fortune on their energy before everybody else was selling it they could have been the first out there made a killing we probably let them down in not advising that early doors.

Terry: C-01 they're the end of my questions and I would just like to say thank you for your honesty and thank you for going through and answering those. As I said at the beginning we will send you the transcript with all names and other references removed. Thank you for your time.

C-01: Pleasure.

END OF TAPE

Interview 3
Conducted 1st September 2014 – HA-01

Terry: Thanks for agreeing to the interview. The interview is going to be around about 40 minutes. It's going to consist of a set of semi-structured questions, so I'll ask you each one of the questions, and if you can reply in your own time. A full set of the transcript from the tape will be made available to you for you to critique and look at and then from that we'll break it down into a coded matrices for use in my Phd study. Is that OK?

HA-01: Yes that's fine.

Terry: Brilliant. We'll dive straight in. What is your role and position in the construction process?:

HA-01: So my role is Sustainability Manager for the Development Department of ..... and I guess that my role is really to review the design proposals and sort of construction and other processes to try and make sure that we are mitigating the risks of sustainability and enhancing the benefits as far as possible for ..... in the long term and for our customers.

Terry: Brilliant, that's absolutely fine. And do you have any low energy technologies in your own home?

HA-01: No.

Terry: Do you use metering or do you look at your energy consumption?

HA-01: Yes, I do check up on gas, electricity and water actual usage so when I get my bill each month I'll check the usage and I'll compare to my usage the previous year and check up whether it lines up with national averages and things like that and I do have plans to get PV panels at some point, but just haven't done yet, only just moved into our house so, nothing yet.

Terry: Is that the main reason because of only just moving in, or is it being a long process of cost?

HA-01: To be honest I haven't even looked into it at the moment, it's something for the future for us PV panels and also possibly solid wall insulation of some kind, but currently we don't have support so you know .....

Terry: Thank you for that. And part of that is just to get an understanding of what your own feelings are for sustainability. So we'll move on to the questions. What low energy systems have you been involved with and to what extent?

HA-01: So mainly my involvement at ..... has been, most of what I do is to do with communal heating in different forms, but also fabric, high performance fabric – I say high, it's all relative. We haven't done any Passivhaus stuff so I don't know much about that. And photovoltaic panels those are the main technologies and systems. In terms of type of my involvement, I've been in this role for 2 years and prior to that I was Housing Officer, prior to that I studied architecture, so my knowledge of actually working in the industry and really understanding sustainability is only the last 2 years which means I don't have that sort of understanding of oh 5 or 10 years we did it like this, so I'm coming into it quite afresh. And the involvement that I have is quite secondary so I don't have defined knowledge I'm not out there

on site, I should be more to be honest but there is so much to do. It's a lot of getting feedback from other people and working with the people who are front line.

Terry: Of those technologies that you mentioned what ones have you found the best or the ones that are most easily dealt with, or the ones that come back from the front line so to speak as being the ones with least issues?

HA-01: The photovoltaic panels are always a good one because even though they do have their issues, you kind of can't, it's one of those things where you can benefit from them but you're not likely to make a loss from them in the sense that once you put them up there if you don't do anything with them they're not going to cause you any problems they'll just sit there, they may not give you many gains but the problem that we have with some of the other technologies is that they actually create problems for you and create financial losses so, I think photovoltaics are the only thing that we don't really have any issue with. I should mention also things like mechanical ventilation heat recovery, everything else we have problems with.

Terry: We'll go on and have a look at those in a minute. Thank you for that. What are your opinions of the Code for Sustainable Homes and its method of delivering low energy homes?

HA-01: With the Code I think there's, because I've only been in this part of the industry for 2 years I think I haven't been aware really of what its predecessors were like and what life was like before the Code and I can really appreciate that it brought in a lot of important awareness and pushed innovation in the industry, but I also think it's a bit too checklist based, too point scoring. It's difficult because with tools like the Code if you've got a good designer or a good contractor who cares about what they're doing then they'll produce a good product and it will just happen to comply with the Code. But if you've got someone that's doing it poorly then they'll do it to comply and not really think about it in any other way, so you can obviously come out with some really bad solutions where the contractor's just gone through and looked at what the cheapest credits are and I don't know whether it's possible to get more of a system that's less fallible to those problems, or whether that's just life. But I do think that's a key problem, because it's quite easy to manipulate and to just go for the easy win credits.

Terry: So if I can understand, is it that you feel that the Code doesn't control the quality or designers that's working to the Code that guarantees the quality?

HA-01: Yes, yes. I think you can create a really poor building which complies with the Code but it's not actually performing well in practice and there's not really a good set of technologies for a resident to use or whatever it may be. It's like any tool it needs to be used with expertise and consideration really.

Terry: Do you think the Code has changed the way constructors construct or not?

HA-01: My perception is that it has and that it's helped to bring things really to the forefront sustainability, but I do still feel like contractors and a lot of people generally in the industry just feel that it's more a burden than anything else, it's just kind of extra rent? paying for extra box ticking that they have to do. So I, yes I think it's that perception of people who care about delivery and just want to get it over the line on time and on budget so that includes project managers internally as well. It's seen more as a burden than anything else.

Terry: Would you say that that's a more prevalent experience in the construction industry, or not?

HA-01: I would say that's pretty much throughout yes.

Terry: Thank you. What are your opinions of the current planning process for low energy homes, for delivering low energy homes?

HA-01: I don't think it's very helpful the planning process as it is, I think main problems are so it's quite easy to manipulate or to come up with poor designs so SAP scores and also like overheating analysis, overheating analysis for example you can come out and say OK in your energy strategy for planning you can say well it's medium risk, but there's nobody who will actually go in and check what parameters that they need to come out with that outcome, so they might have assumed that the windows are open all the time yet there's also shutters in place all the time, you know things like that. And as a result I don't think that those results are just taken they're manipulated in the process in a lot of cases, or they can be manipulated, and then outcomes are not really interrogated by the planning officers and so I think there's a lot of things that are getting through planning just on more again of a lip service basis rather than because things have been properly considered in the spirit of what the planning requirements are all about. So you don't necessarily get good design through planning and also I think the other problems are the planners themselves not having enough knowledge of the sustainability stuff and the different solutions that you can use, not really understanding them holistically as well. So from the point of view of the customer and the client as well as the Planning Authority and of course the standard problem that different Local Authorities will have their own special requirements, there's inconsistencies, even the individual officers will have their own different opinions and they'll often have their pet solutions that they want to try and push, so I think planning as a part of the process is probably the best. I agree with the thing the new way of doing things that planning and Building Regulations are the way to control building performance, but I think there are a lot of problems with the planning process that make it more difficult to ensure the performance of low energy projects.

Terry: Have you had a particular experience whereby you've wanted to deliver one thing but planning decide another option?

HA-01: Again I've not had personal direct experience but the planning managers that we have here sort of there's often stories, communal heating is one where some Planning Authorities will just want you to put it in regardless of whether it's a sensible solution or not, so that's the main one. But also we've had ones where the planner's said to us oh well why aren't you doing air source heat pumps, I did a project the other month and it worked great there so of course it's an ideal solution for everywhere. Yes, that kind of thing.

Terry: Do you feel that the level of understanding from the planners that are taking control of that particular area is not sufficient or is sufficient?

HA-01: My perception is that generally it's not sufficient, then I think that the knowledge is not sufficient across a lot of people within the industry including myself because it's not possible for any one person to be a full expert on all of this stuff and you can't view any issue in isolation there's always all the other contexts to it that you have to consider as well. So I do think there is a training issue generally but part of it I think is just a consequence of more and more complex buildings and complex legislative structures and all the rest that it's almost impossible for anyone to have the level that's required to make good decisions.

Terry: What are your opinions of the approach of communal heating to achieving low energy homes and have you had any experience of dealing with that?

HA-01: So communal heating, I think district heating and combined heat and power are really good technologies and really good concepts for how to diversify the energy supply in urban areas and make use of sources of waste heat and generate power more efficiently and use waste products, I really understand that and I think it's a great idea. I think the applications have been wrong in a lot of cases and we have definitely been on the receiving end of some projects, many projects, where communal heating has been put in where it doesn't make any sense, aside from the fact that there is a policy a planning policy to promote communal heating, if you look at it in the wider more holistic sense of what is this strategically going to achieve for London, it's not by application it's too small a site, it's not economical, those kind of problems, and as a client I think we are struggling a lot with communal heating so we, it's not a technology that we favour because residents don't tend to like it, they don't understand it, we do have a lot of overheating problems and the cost of heat is higher than if they had their own gas boiler, that's kind of something that the industry just accepts there's no two ways about it. So as a client it's not something that we would choose by our own, if we had the option, but we get forced down that route and it's very onerous to manage and it's not so much the maintenance, it is maintenance but it's all of the administrative layers that build up once you take on the role of being a heat provider so if you're putting in a gas boiler into someone's home as a landlord you're making sure that the boiler is running and the heating system is circulating, but the resident's gas supply that's all them, sort of issue with communal heating the landlord has to get involved and I think there's a lot of problems in that area, more so probably than the installation side of things.

Terry: So do you feel that communal heating within a residential block can achieve a low energy environment, or can't achieve a low energy environment?

HA-01: I think it can, but it has to be operated and maintained in a careful Managed by people who know what they're doing. Like the CHP being operated for particular periods of time, but in a lot of cases the reality is that's it's not efficient in the slightest and we've found from consultants and agents and also actually case studies done by RSL's we've found that the annual efficiencies of communal heating can be anything from sort of 25% to 55% and you're going to want it to be at least 60% efficient to rival to get comparable with the cost of the individual gas boiler. So in reality they are very inefficient and I think part of the problem with that they are being left to non-specialists to operate and maintain, so if when you have your electricity transition network I'm making an assumption that it's all electricity specialist companies that are doing that, whereas heat networks are often operated by people like well organisations like Housing Associations that don't really know what they're doing and it's a lot of energy that's been wasted.

Terry: Would you say the same is the case for the designers and the constructors;what is the level of understanding of the technology in your own opinion at the moment?

HA-01: Yes I definitely would agree with that. I think it's a really specialist area and a lot of these things is about experience and feedback cycles and we haven't had many feedback cycles and a lot of the people who are specifying the equipment are specifying based on theory rather than what they know from previous experience.

Terry: With that in mind with the design & build contract being the main method of procurement for housing projects, is the process the most effective way of delivering low energy homes, the design & build procurement method? Does that procurement method give you the process to deliver what you require from a low energy home?

HA-01: I think design & build is one of those things where it's kind of the best of a bad bunch overall when you consider everything so if you take different procurement routes then you're obviously opening yourself up to other types of risk, but with design & build it's not working for production for good quality outcomes on the energy side of things. We're having a lot of problems with products and poor installation as well because it doesn't seem that there's a huge amount of checks going on for commissioning. All of those problems I think if the client was more involved then we would be able to mitigate those and I do think that it's possible to use design & build for its benefits without, and mitigating the poor side effects as it were I think you can build in checks and balances it depends how the organisation how strict they want to be at the adherence to the design & build philosophy because you can't leave things to the contractor that's the bottom line you can't leave it to them.

Terry: Do you feel that the process of the Employer's Requirement document is sufficient within the design & build process to deliver what you require, or is there another way or is there something else that you would like to see?

HA-01: I think that the Employer's Requirements need to be much tighter. There is another developer that we've been working with actually who they say, I can't remember what stage they take their designs to before they go out to tender, they take it much more advanced than ..... does. They basically produce the full package of designs and specifications and then put it out to the contractor so it's kind of getting away from a design & build, but I think they do still use the design & build route. But I think that way would create a much better outcome on the energy performance side of things, but it will have its risks in other areas of the development process.

Terry: What is your opinion of the actual construction process for delivering low energy homes, looking at the process itself from the tendering to the actual works on site and delivery?

HA-01: This is probably an area where I'm less knowledgeable in terms of the construction and also the commissioning on site. I don't tend to go on site and see what's happening. But from the secondary feedback that I get it it doesn't seem like quality is sufficient and we have stories of our Clerks of Works going out and not taking drawings with them so they're not checking against the drawings against what's being built, they're waiting until the weekly or monthly project meetings to raise any issues rather than raise it then and there with the Site Manager. They're missing things that our project managers are picking up so I think there's an issue with the quality of the Clerk of Works and the work that they're doing and we've also when we have had a specific M&E Clerk of Works audit they've picked up on a lot of problems with the installations so it definitely seems like the build is not proceeding like it should.

Terry: And is that specifically for low energy homes where low energy technologies are used, or is that across the board?

HA-01: I think it's across the board, in particular, well that's across the board and my perception is just within the industry as a whole, is there obviously seems to be an issue with fabric performance and the airtightness especially that kind of thing, achieving the designed levels of performance and I can well understand why that would be. But I think the main thing with low energy homes as opposed to any other is that generally they have more M&E kit and M&E kit is often the part we have problems with the installation and commissioning.

Terry: Why do you think that is?

HA-01: I think there's just more to go wrong, there's more stuff therefore there's more things that can happen and also the technologies are relatively new and unfamiliar to a lot of people and the knowledge isn't there yet. I have seen on some sites how unfamiliar it is for the installers, and if they can't get it right what hope do the residents have if they don't know its working as it should.

Terry: What is your opinion of the commissioning process in low energy homes, so maybe you can reflect that on some other experiences that you have of the buildings you are working on?

HA-01: What I'm seeing is that definitely our asset management team find poor commissioning prior to handover is making things difficult for them. Admittedly they would have picked those issues up quicker if they had been a bit more on the ball about maintaining and servicing and there's always historically had a bit of an issue with the gap between handover and when asset management actually start maintaining equipment, but given that the proportion of M&E equipment that's going into the buildings is increasingly about low energy, I think it's very much true about those technologies the solar thermal panels, your communal heating client, your ventilation systems, there is definitely an issue with commissioning not being done properly and nobody picking up on it.

Terry: Do you feel that there is an understanding of an holistic approach to dealing with low energy homes or do you feel low energy homes are being dealt with as all homes in the past, just with something added to them, or do you feel they're dealing with it in a different way?

HA-01: I think it's just carry on with the same, I don't think that a different approach is really being taken, it's just additional pieces of kit to maintain or commission or install and my perception is that it's not really looked at holistically. To be honest I feel there is a great lack of understanding of the installation and commissioning and that is one area that is then reall having an effect on the resident. I say this because most times when we look at a fault during defects you can see it was never right from the installation, so how much energy has been lost, and its then difficult to get the resident to like or use the technology.

Terry: Taking what you have said what are your opinions of the handover and defects process for low energy homes?

HA-01: In terms of the handover of a low energy home versus a non-low energy home, I think all of our homes now would be classified as low energy homes as our handover processes have also been evolving over a number of years so it's not like we can say that the handover process for a low energy home is different to that non low energy home. Although that said if you think that a lettings or a sale of an older property like a Victorian street property or something could be seen as a handover to a resident, there is a lot more that we need to educate residents on now than then well, with the newer homes than if they were moving into an older property because they're familiar with the technologies in the older property and they're familiar with the way of operating their home in terms of when you open windows where you leave things to dry those kind of issues. Whereas now there's a lot of the ways of operating the home is counter-intuitive for some people, so I think there is definitely more communication and guidance needed for residents. I don't think that as an organisation we're doing that very well yet, there is a lot more that we can do and also the same goes for the communication and the guidance for the staff that are going to maintain because a lot of our housing officers and frontline staff don't understand the homes either so educating those personnel and the residents is very important but I don't think it's something that's being done as well as it could.

Terry: Do you feel that commissioning does go towards hindering residents in moving in, or do you feel that doesn't play a part in how a resident sees and uses thier home for using it for low energy?

HA-01: I think there will be some issues with the handover so whether systems are commissioned or set up to function under certain default settings that's something which could be helped a lot or could help a lot if the contractor was to do it better. Making sure that things like that filters and ventilation systems are clean at the point of handover. I think there are lots of things that a contractor can do to make that transition easier and I think in terms of the contractor's role the information that they provide we often rely on the information they provide as the guidance for our staff and residents and it's just jargon really it's not suitable for consumption of lay people it's technical manuals and things. So that could be improved.

Terry: So how do you monitor defects and how are they analysed?

HA-01: We don't have analysis of the defects that are reported to us which would be really good if we did start doing that. I think it's a real mixture by the feedback we get. Again it's difficult to distinguish whether we get more defects at better performing homes than not because all of our homes perform to a very similar standard now. I don't know that we have an increasing rate of defects over the years, however, when we do see issues with some of the low carbon technologies more often than not the installation is poor and that hasn't help the resident in using it.

Terry: Reflecting on the whole process for delivering low energy homes, right from the inception to the completion, are the current low energy homes you've been involved in delivering what was anticipated. Are low energy homes that you're involved in are they actually functioning as low energy homes?

HA-01: I think they're delivering as anticipated because our view of what's anticipated has changed, we no longer think they are going to do any better than a normal home. But in terms of the original aspirations definitely not because I mean communal heating is one area which is a real problem because the cost of the heat, the way that the calculations are done at design stage suggests that the system will run at a certain efficiency and in reality it doesn't, therefore the cost of the heat to the resident is always much more. So we are finding often that their bills are quite low in terms of the amount of energy they're using but the cost per unit of energy is very high, so it kind of balances itself out really, and a lot of residents, we do get a lot of complaints or expressions of dissatisfaction from residents about their bills when they've got communal heating, because they perceive that they are high, even some residents at a couple of sites residents who have moved into these homes which are touted as being low energy, you know save on your bills, they've moved there from a much older property that should be much more expensive to run and they are finding that their bills are higher in the new property they've moved into, well that could be for a range of factors, but yes I think definitely with communal heating it's a problem. I think my concern the building performing as they were supposed to is more a long term concern, so I think a lot of the technologies that are being used to theoretical performance levels are only as good as the people who are installing them and operating them, and if you have somebody who doesn't know what they're doing at the helm then it will not perform as it was supposed to. There's also the issue of long term maintenance and operation costs and I really think these buildings are going to become very uneconomical to run and to replace their end of life replacements and everything in a couple of decades and quite possibly be demolished and rebuilt because in the same way that 1960's buildings are no longer economical to run. I think the same will happen which to me is another element of the low energy homes that you are defeating the object that there's no point in creating a building that

operationally uses very little energy if you're just going to demolish and use a load of energy to build a new one.

Terry: And with other technologies such as air source heat pumps and ground source heat pumps, what has been your experience from inception and aspiration to final delivery on those kinds of technologies?

HA-01: We haven't had any heat pumps which has been good for me.

Terry: Could you qualify that?

HA-01: Well my perception from the industry and from the experience of others is that they are no good. I know that other Housing Associations love ground source love air source heat pumps in rural locations where the alternative is electric energy, in urban locations nothing currently can rival gas for efficiency and cost so, no we haven't done any heat pumps.

Terry: And then with the PV and where it's a PV and a gas boiler home the inception to the anticipated outcome of that, have they been better or worse?

HA-01: For a home like a house where the resident is receiving the direct benefit from the PV I would say it's a good thing however, it's really not something that we're monitoring. I hate to say it but we are not actually monitoring or even checking that these photovoltaic panels are working. Even though we've got something to gain from them, we've got nothing to lose if we don't do it ,so I think it's been poorly managed, so we don't have any data on that.

Terry: What has been your learning experience from your involvement with low energy homes and construction?

HA-01: What I wrote down was that law of intended consequences ?, because it really does feel like there is no perfect solution and part of me wonders whether with trying too hard to push it too far with low energy homes and the idea that you can push the performance of a building up and up and up. I wonder whether it's just not possible to get it above a certain point because once you get a building to a certain point in terms of thermal efficiency you start introducing other problems with ventilation and the over-heating. I do wonder whether there's sort of an equilibrium that gets reached and therefore we should from a policy perspective just sit tight where we are for a while, get good at it and focus our energies on retro-fitting of older homes rather than continually pushing this lower and lower energy ……?

I think a lack of consistency and stability is a real problem for any industry and the fact that as soon as you learn one thing it moves on and you've got to learn another way of doing things does mean that you have to invest of time and energy in learning the new way of doing things rather than learning how to do the existing thing well. I think that's an issue for the contractors in particular because the installation and commissioning needs to constantly change, and I don't think they have learnt the basics yet.

Terry: Just a last question, has involvement with low energy homes affected fuel poverty either positively or negatively do you feel as a whole?

HA-01: I'm reluctant to say too much because I don't have any statistics or data to back anything up. My perception is that generally it has been beneficial for residents from a build perspective, but I think there's been a lot of dissatisfaction along the way and I think in some cases fuel poverty issue has not been an improvement with low energy homes. The example I

gave before where some sites with communal heating residents are actually paying more than they used to for heating their old property, that can't be right for low energy homes, can it?.

Terry: Thank you

END OF TAPE

Appendix 6

Permission Request and Participation Form for Observations

Date *[Add Text]*

Address
[TEXT]
[TEXT]

Dear *[NAME]*

Request for Permission to Undertake Observations as Part of a Professional Doctorate Research – *[Project Name]*

We are currently working with you at *[Project Name]* as building services consultants. As you are aware I am currently engaged in a professional doctorate at Anglia Ruskin University researching low carbon homes from the perspective of the construction process.

I would like to request permission to undertake observations of the construction process for my research. The observations will involve the following activities:

- An initial meeting with the construction team to outline the observation process
- Regular observations of the installation and commissioning processes
- Note taking during the observation process to use in the research
- Photographs of equipment and installation and commissioning activities

As part of the research process no names, contractor details or project locations will be required or taken. All information given will be in strictest confidence and will only be used in the professional doctorate research. A copy of all information will be given for review before being used.

To give permission please complete the form on the next page and return in the pre-paid envelope or to my email address tkeech@calfordseaden.co.uk.

Thank you

Yours sincerely

Terry Keech
Equity Partner
B Eng (Hons) C Eng MCIBSE MIE MIET FRICS
for and on behalf of calfordseaden LLP

Email: tkeech@calfordseaden.co.uk
Direct Tel: 01689 888281
Direct Fax: 01689 888296

NAME OF PARTICIPANT:

Title of the project: THE EFFECTIVENESS OF INSTALLATION AND COMMISSIONING PROCESSES IN DELIVERING NEW MASS LOW CARBON SOCIAL HOUSING

Researchers contact details: Terry Keech. I can be contacted by email: tkeech@calfordseaden.co.uk , Tel: 01689 888281 – 07872 033327

Members of the research team at Anglia Ruskin University: Supervisors: Dr Ian Frame and Dr Carlos Jimenez-Bescos.

1. I agree to take part in the above research. I have read the Participant Information Sheet which is attached to this form. I understand what my role will be in this research, and all my questions have been answered to my satisfaction.

2. I understand that I am free to withdraw from the research at any time, for any reason and without prejudice.

3. I have been informed that the confidentiality of the information I provide will be safeguarded.

4. I am free to ask any questions at any time before and during the study.

5. I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data which I have supplied anonymously. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of participant (print).....Signed.....Date.....

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP

If you wish to withdraw from the research at any time, please complete contact me and withdrawal will be recorded immediately and all information returned to you, with no information used in the research:

I WISH TO WITHDRAW FROM THIS STUDY

Contact: Tel: 01689 888821
Mob: 07872 033327
E mail: tkeech@calfordseaden.co.uk

Appendix 7

Initial meeting Minutes

Minutes of Site Meeting - Observations/Interventions

Prof Doc – Site Meeting

Held on at 3:00pm October 9th 2014 – Site Office – Location……

For and on behalf of:
……

Minutes issued (by hand) on 16th October 2014

Name Removed – Site manager	✓
Name Removed – M&E Site Manager	✓
Name Removed - Client	✓
Name Removed – PM	✓
Name Removed – Site Block Lead	✓
Name Removed – M&E subcontractor Supervisor	✓
Name Removed – M&E subcontractor	✓
Name Removed – M&E subcontractor	✓
Terry Keech – Researcher	✓

Apologies for Absence

Name Removed - M&E Site Manager
Name Removed – Client Sustainability Team member

ITEM	SUBJECT	ACTION
1.	Introductions for all site members. It was noted that the main M&E Site manager was not available for the meeting, but would attend at the next 'on site' session. Site manager apologised for lack of attendance and asked for all minutes and information to be passed onto..... for his review before the next review.	**Note**
2.	TK gave an overview of the intended research for the observations and how the information would be recorded. The following process was agreed by all: 1. Site to be given a code number with location given by region only. 2. All observations to be coded with no information given on site specific location, name or company names of the construction and client teams. 3. Where commissioning data is used the location and site identifying information is to be removed from the photocopy or tabulated information 4. Site staff will be approached for participation; however there will be no compulsion to engage with the research. 5. No staff details will be identified and staff information given will only be used in the research in a code form (identification information removed and texted coded). No staff information will be kept on the site and any information taken will be discussed with the staff member before using within the research. 6. All electronic information will be stored on a separate hard drive by the researcher (TK) and will not be stored on the company computers or server. 7. All research items are not connected with the day to day activities on the site and will not be reported as part of the construction works. 8. If there is a health and safety issue or a safety notifiable issue during the research the session will be stopped, records closed and agreement to report incident to the site manager (as with the agreed health and safety policy on the site). 9. Confidentiality maintained throughout the process M&E site Supervisor asked for a copy of the research when completed and this was agreed by TK.	**Note**

ITEM	SUBJECT	ACTION
3.	Recording for the observations was agreed as follows: 1. Installation or commissioning contractor's names not to be recorded. 2. No location specific details recorded on the observation or intervention sheets. 3. Where photographs are taken, these are to be of the issues observed and not include location specific information or staff photographs. 4. Any notes taken during the observation shown to the participant in full. 5. No audio tape or video recording are to undertaken on the construction site. 6. Standard contractual site inspection reports, where undertaken to have all identification information removed before using in the research. 7. Any e-mail communication used in the research to have all identification information removed before using in the research. Client and site manager requested that any contractual site inspections are reviewed and agreed with them before using in the research. The PM stated that this is not to change the information, but to ensure that no contractual issues are affected by the research. TK to have all contractual report agreed for use before including in the research.	**Noted**
4.	Discussion on the low carbon technologies on the site was conducted at the end of the meeting. It was noted that there was much scepticism around the table on the value and input of the EASHP. M&E supervisor raised the issues of 'bad press' around the use of the units. There appear to be a general 'feeling' that these were individual units like a domestic boiler and this was common to the installer. The M&E supervisor noted that staff had been on the one day training course and that they would be able to manage the installation. Site manager made the point 'there are 300 to install so we should get it right by the end'. TK suggested that the observations would identify any responses from the staff and that this would be an interesting part of the research. The site manager agreed that this was a good point and hope that the information obtained would be useful.	**Noted**

ITEM	SUBJECT	ACTION
5.	M&E engineer attending ask about time scales and involvement during the installation and commissioning. TK responded that the observation would be approximately 30 minutes and would not involve any additional input from the staff. These were observations only to record actual installation and commissioning activities to gain a better understanding of the process. TK confirmed that where intervention were to be suggested these would be fully agreed with the site team before carrying out. It was also stipulated that if the interventions were not acceptable they would be stopped. Site manager and Client confirmed to all that the observations and suggested interventions were not a contractual obligation and the process was to help with the research, but not to affect the programme or works currently under construction. TK confirmed that it was not the intention to interfere with the contractual process, but to observe record and, where agreed, trial simple interventions to observe the outcomes. This was agreed by all.	**Noted**
6.	TK thanked all for their participation and suggested that a regular update with the site manager would be carried out to make sure that he was fully informed of the process. This was agreed Meeting finished 4:15pm	

ITEM	SUBJECT	ACTION

7. **DATE OF NEXT MEETING**

6.1 It was agreed that future meetings would be arranged as required. The main drive was to get out on site and review the process. Site manager and Client requested that TK be given every assistance during the review. Time scales for the observations and interventions was to be agreed with the M&E site manager and Supervisor. **All to note**

7. **DISTRIBUTION**

7.1 As per front sheet. **(note names to be removed before use on research)**

Signed: .....

Terry Keech
for and on behalf of calfordseaden LLP

Date: 16th October 2014

Appendix 8

Sample Observation Records S1

Observation 1 – First Fix - S1		
Location and stakeholder	**Theme**	**Observation note**
Site Office • Site Manager • Subcontractor • Researcher	Understanding the process	• Site manager not used EASHP before and states he doesn't understand how they work – 'renewables it's a bit of a mystery to me' • Site manager unsure of mechanical installation. Discussion on responsibilities follows before subcontractor arrives. Same contractor responsible for M&E installation • Install already to first fix stage EASHP units delivered and positioned in each dwelling before any walls installed, as the units did not fit through the dwelling entrance door. • Heating floor pipe work installed, but some areas covered before inspection. Duct work installed at high level in ceiling • Subcontractor arrives late and is not the subcontractor manager as organised – 'he's on another site so I'm standing in, I know a little bit about the units, but we can have a look when we get to the flats' • Site Manager cannot accompany the inspection and suggests initial inspection with subcontractor and inspector/researcher. Subcontractor manager to be contacted for the next meeting • Agree to inspect floor pipe work where visible, duct work and EASHP units
Dwelling • Subcontractor • Researcher	Technical knowledge	• Subcontractor unsure of units. Asked by researcher 'what types are to be reviewed' and he is not sure – 'I've not used these units before (…….) knows how they work but he's off today. I will make sure he's around for the next meeting' • Researcher witnessed that the front panels of the unit were missing. • Subcontractor suggested that this was typical across the site.' Some are missing because they are damaged, and some are just taken, you know if its not nailed down they take it'
Dwelling • Subcontractor • Researcher	Management of the process	• Researcher asks if this was the process for the installtion going forward • Subcontractor stated that ' once we all get use to the technology we will then do the inspections and testing for our own flats'

Dwelling • Subcontractor • Researcher	Communicartion of Change	• Researcher ask how any changes to the process would be communicated • Subcontractor stated that each block is managed differently therefore he would need to find out from the block manager • Subcontractor stated ‘ a few of us talk to each other so we will make sure that our units are all the same, some other just do what they like, its not my responsibility’
Dwelling • Subcontractor • Researcher	Relationship and trust	• Subcontractor suggested that if you get ‘too good at anything’ you get more work and ‘not more money’ • Subcontractor suggested that as a self employed person he gets paid for the works agreed and ‘not any more’. Also need to be careful of the main contractor as any works caused by other trades often get put down the the last person in the flat, typically M&E.

Observation 4 – First Fix - S1		
Location and stakeholder	**Theme**	**Observation note**
Dwelling • Subcontractor • Researcher	Technical knowledge	• Duct work connections had extended flexible sections for terminal positions. Asked subcontractors opinion. • Subcontractor cut all flexible sections the same and connected and would cut shorter in the second fix. • Researcher asked what happened if the flexible was pushed back into the ceiling void. • Subcontractor left the flexible at the same length as this would not greatly affect the air flow rates, and if it did you can turn up the fan speed to compenstate for the required flow rate. • Researcher asked about the additional energy use. • Subcontractor responded ' that's not my job' its got to work how the manufacture tests state and if I achieve that I've got 'sign off'.
Dwelling • Subcontractor • Researcher	Design and design responsibility	• Researcher ask if this was as the design intended • Subcontractor replied that the design has the flow rates to be achieved and that's what he was doing. 'I wouldn't know how to measure the energy off the fan and if the manufacturer has designed to have variable fan speeds then that's ok for me' • Noted that all ductwork for the EASHP was installed sepeartely to the connections to the unit. As the unit has to be installed at a very early stage (due to size) the ductwork connection did not match the routes locations due to ductwork route changes. Additional flexible ducts used to connect to new locations.
Dwelling • Subcontractor • Researcher	Knowledge and Understanding	• Researcher asks how the units worked at the lowest energy level • Subcontractor responded that it was 'agreed' that all flow pumps in the units were to be set of 3 (highest setting). This was because there are several underfloor heating circuits for each of the flat types and it takes too long to set up each flat. 'Setting 3 works for all. So that's what we are all using' • Researcher asked about set up for hot water and heating. • Subcontractor responded that baths needed to be at 48^{o}C and the blending valves needed a 10^{o}C difference, therefore all EASHP were set to 58^{o}C. When asked if this was high for the unit, the contractor responded that the manufacturer data shows it can go upto 60^{o}C so that's ok. 'The residents can turn it down if they want to later if they want'.

Site Office • Site manager • Researcher • M&E Site manager	Communicartion of Change	• Researcher ask how the installation was progressing from their perspective • Site manager stated that he had not been out on site lately as theres ' lots going on, it's a bit manic' • M&E site manager stated that the supervisor was monitoring but had not been on any of the observations as it was a busy period • M&E manager stated that they were on programme, but there had been some architect and client changes that affected the start of 2nd fix close up works. • It was noted that the EASHP was not seen as a big issue and there were other issues that were taking the attention of the site management staff. Installation was left to continue at the pace of the individual installers. No coordination of installation was evident. • M&E designers have not attended site for the first fix inspections and it was noted that the 'push to close up' would be very soon.
Dwelling • Subcontractor • Researcher	Relationship and trust	• Subcontractor suggested that if you get 'too good at anything' you get more work and 'not more money' • Subcontractor suggested that as a self employed person he gets paid for the works agreed and 'not any more'. Also need to be careful of the main contractor as any works caused by other trades often get put down the the last person in the flat, typically M&E.
Dwelling • Subcontractor • M&E Supervisor • Researcher	Communication of change	• Review of a 1st fix installation as part of the research review. Covers not included on the unit. Lifting straps still on the unit, flexible connections are damaged in several places, but the supervisor stated that these will be replaced as part of the second fix. • Subcontractor stated that the connections to the EASHP were taking longer than intended, but they had found some easy fixes to the installation
Dwelling • Subcontractor • M&E Supervisor • Researcher	Management of the Process	• Supervisor stated that standard connections for the pumps and duct connections are ok. 'We will check with the manufacturer and come back to you'. • Research asked if these would be energy efficient • Supervisor suggested that agreement with the manufacturer was was he had to do the energy was for someone else. 'If it can be done and it's allowed by the manufacturer then that's the way we will do it. That's what the contract requires and that's what we will be working to'. • Researcher noted that installation and programme were key and the energy performance was not really considered. If it will work and that's ' allowed' then that's it.

Observation 9 – Second Fix - S1		
Location and stakeholder	**Theme**	**Observation note**
Dwelling • Subcontractor • Researcher	Knowledge and Understanding	• Note ceilings have been fitted and walls completed. Many of the terminal positions are different to the flexible points. Flexible ducts have been extended into the space and indicate damage to the PVC coveres • Subcontractor cannot get access to the duct connection point so has therefore cut the flexible section back as far as possible and made repairs. • Researcher asked if this would affect the energy operation of the EASHP. • Subcontractor stated that the fan speed could be adjusted to mange the correct flow rates 'fan settings are from 1% - 100% therefore I have got room to play'
Dwelling • Designer • Researcher • Subcontractor	Design and design responsibility	• Researcher asked about the installation in comparison to the design. • Designer stated that there had been several VE (value Engineering) changes that he was not involved in. the responsibility for the changes was with the installers designer ' if there is one' and the main contractor. • Researcher asked if this had affected the energy performance of the unit. • Designer suggested that the EASHP manufacturer carried out the design and there was a current dispute. The dispute was between the EASHP unit and the underfloor heating design which was by others. Each had stated that their design was ciorrect but the temperatures required from the unit had not been agreed. • Underfloor heating temperatures have not been coordinated with the floor finishes (wood finish on concrete screed). Temperature required to achieve 21^{o}C in living room requires 49^{o}C which is 10^{o}C above the suggested energy efficient temperature for the heat pump (35 40^{o}C) • Note energy efficiency is not being considered the main drive is to get the system to work and give the room temperature. • Subcontractor stated that he will install what he is told to. ' this isn't about energy its about get the system working which is much more inmportant'
Dwelling • Subcontractor • Researcher	Knowledge and Understanding	• Unit is set up to a standard for the 'worst case' and is to be run throughout the development to keep time down in each flat and keep the PC (practical completion) date. • Pumps are noted as set at setting 3 and fan speeds are at 45 – 60%. • Room temperatures are under test and thermal imaging is to be carried out as part of a simple intervention to see if temepratures and pump speeds can be reduced and reduce energy

Site Office • Site manager • Researcher • M&E Site manager	Management of the Process	• Site manager does not want to lose the PC date and therefore the standard settings have been agreed. Where small interventions can be achieved this can be carried out but no more time should be spent on the EASHP issues. • M&E site manager stated that he had a commitment to making them work and they would work for handover • Site manager stated ‘ carry on the testing but don’t let it get in the way’ • Researcher suggested that the energy performance was important to the unit operation. • Site manager stated ‘ if oit’s not in the specification its not part of the contract, and its not getting done’.
Site Office • Site manager • Researcher • M&E Site manager	Relationship and trust	• Noted there was a strained relationship between the M&E site manager and Site manager. The key was the ‘job needed to be done’. Any review of energy performance beyond requirement was not to be carried out.
Site Office • Site manager • Researcher • M&E Site manager	Communication of change	• Communication beyond getting the units working was not discussed. The site manager stated ‘ if the manufacturer agrees it can work at the temperatures required, that ok for me’ • Researcher asked again about energy performance, however this was not considered as the crtical issue. M&E site manager stated ‘ we can work on the performance later lets just get them in and ‘over the line’ • Communication to the installation staff was to carry on with the agreed standard arrangement and review after PC • It is noted that the intent to complete after PC is not a confirmed action.

Appendix 9

Post Intervention Test Samples – 'On Site' Review

Site Review Notes from Intervention Session

VENTILATION	**UNIT - 205**	**PLOT – U1 00 04**	**SN - 08989111189013**
Exhaust duct / Extract duct installed and insulated (If Visible)	Installed. Extract insulation needs finishing (Insulation)		
Flexi duct	Connected from rigid duct to unit. Needs cutting to length.		
No. Exhaust air grilles	2		
No / Type of Fresh air grilles	2x Domus , 1 x Acoustic 1 x Exhaust Type Grille		
UNIT			
Positioning	In cupboard, can access side panels		
Levelled	Yes		
Straps / packaging	Straps removed, Packaging will be removed at commissioning		
Pipe work Connected	Connected, Not under pressure		
Condensate pipe work connected	Connected, has a fall on drain		
Condensate fitting	McAlpine		
T Stat fitted	# Yes, Acting as master T Stat, Sited in Living room		
Bypass fitted	Yes		
Expansion Vessel fitted	Yes, in next cupboard, can access it for future maintenance		
MCB	Either B16 or B20 – MCBs not labelled at this stage		
Outdoor sensor	NA		
Indoor Sensor	NA		
OTHER			

Exhaust vents fitted, are able to remove from ceiling (to enable to lock vent once airflow is set). Recommend grilles are not sealed onto ceiling.
T Stat – extra cables (2 Cores) need to be wired into stat and at unit. The cable is installed so just needs connecting. Otherwise pump will not run.
Exhaust flexi duct needs cutting to length to avoid duct collapsing on itself.
Extract duct insulation needs finishing touch to ensure it is air tight
Recommend units are covered to stop any ingress of moisture / water in to unit to stop any damage to electrical components.

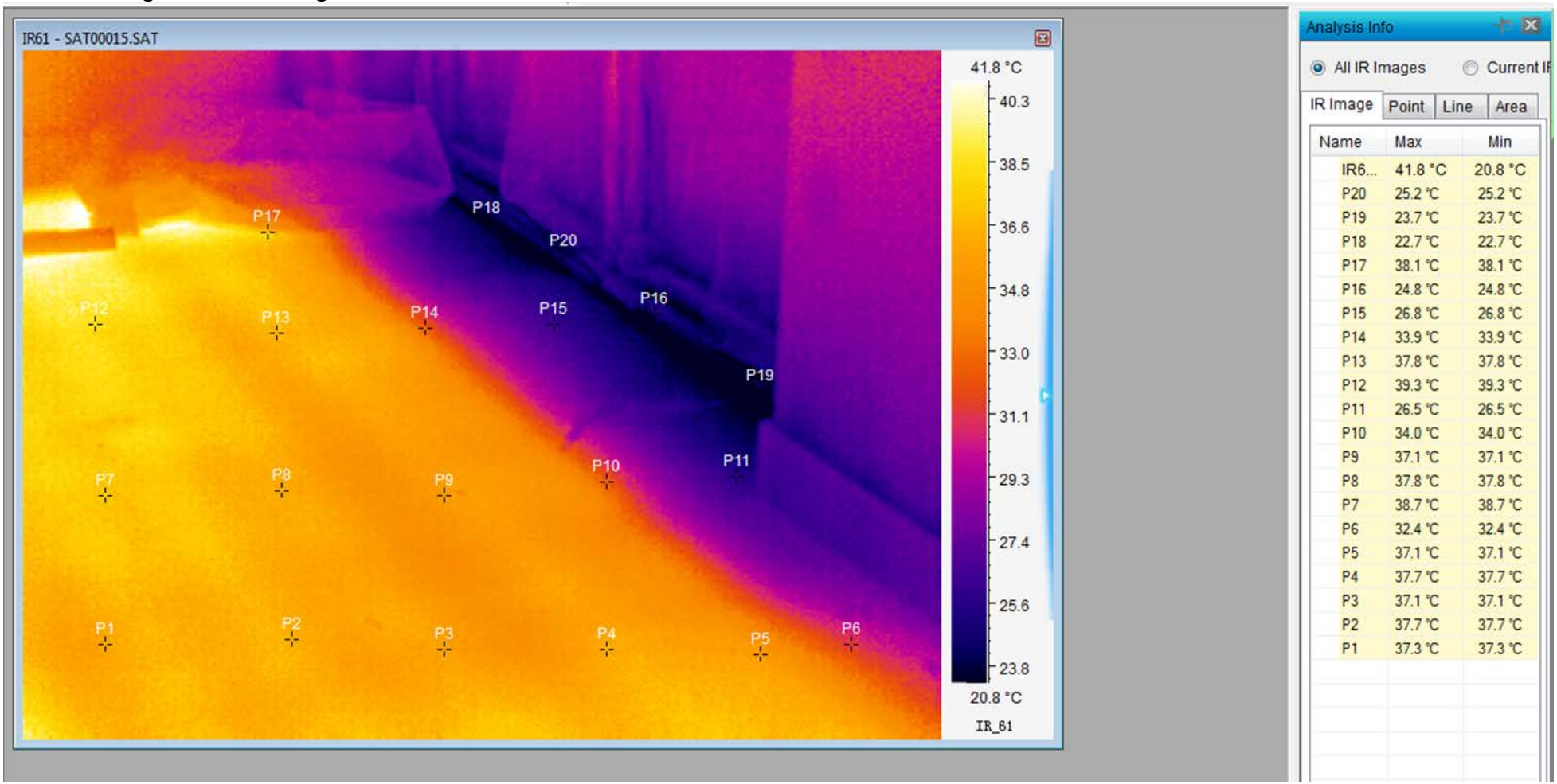
Sample Monitoring Sheet from the 'On Site Intervention

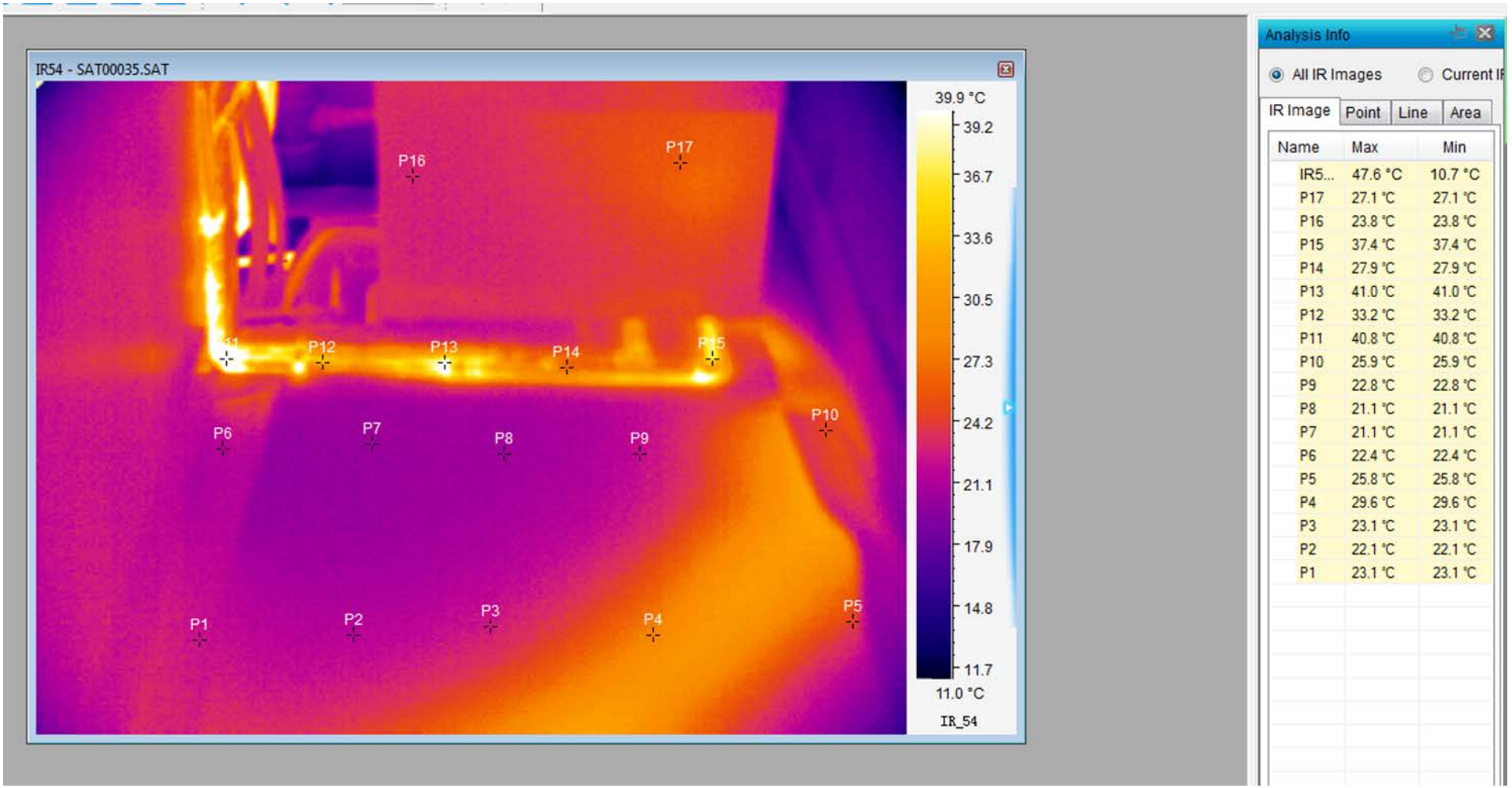
DATE	SITE	STATUS	REPORT	NOTES/RECOMENDATIONS
01/03/2015	Removed	Commisioning	Plots	
	Removed	Checks		
	Removed		FW1 02 01	LP ALARM - Requires pressure testing to find leak. It has been
			205 S/N = 08989111140012	leak tested once before.
			FW1 03 01	MONITOR TO SEE IF FAULT RETURNS
			205 S/N = 0898911110008	(top light flashing / Temp gauge reading high - replaced)
			FW2 01 01	Fan speeds set wrong way round. Corrected. Airflows in each
			205 S/N = 08989111140018	room and overall too low. Corrected
				Removed air from unit.
				Blending valve checked, and adjusted pump on speed 3, now
				on speed 2 after checking differential
				Hot water temp checked at the tap - ok.
				T Stat wired ok
			FW2 01 03	Airflows in each room and overall too low. Corrected.
			205 S/N = 08989111110007	(Checked with NIBE airflow meter and the installers)
				Removed air from unit.
				Blending valve checked, and adjusted pump on speed 3, now
				on speed 2 after checking differential
				Hot water temp checked at the tap - ok.
				T Stat wired ok
			FSS	Removed a lot of air from unit. Pump on speed 3, now 2 after
			370 S/N = 06604111186056	checked differential.
				Airflow in each room overall ok but very slightly under
				building regs in one room.
				Hot water start = 49°C stop = 50 °C
				HW settings as instructed by Terry Keech
			FSS 00 04	Removed a lot of air from unit. Pump on speed 3, now 2 after
			370 S/N = 06604111181054	checked differential.
				Airflow in each room ok but overall total slightly high
				(airflow achieved with a good fan speed)
				Hot water start = 49°C stop = 50 °C
				HW settings as instructed by Terry Keech
				Indoor and outdoor sensor wired incorrectly - need
				swapping over.
				Other notes:
				There were several plots where the extract grille is very close
				to the cooker hood. The NIBE recommendation of 1 metre min
				distance was discussed, it was stated clarification be sought
				from the office.

Sample Monitoring Sheet for EASHP Checking Process

Plot No.	Plot Type	Postal Address	NIBE Size	(i) = iBox (B) =Blending	Kitchen Domestic Water Temp	Bath Domestic Water Temp	Total Air Volume l/s	NIBE Flow Set Temp 205 Units Only	Pressure By-Pass Valve Setting	Under Floor Heating Control Checked	NIBE unit Control Settings Checked 370 unit only	NIBE Internal Externall Sensor Calibration 370 unit only	Comments
FSS.00.01	31		205	(B)	50.1°c	44.5°c	29.6 l/s	47.5°c			N/A	N/A	
FSS.00.02	46b		370	(B)	50.6°c	44.7°c	29.4 l/s	N/A			Checked	Within 1°c	
FSS.00.03	33		370	(B)	50.4°c	44.5°c	28.6 l/s	N/A			Checked	Within 1°c	NIBE in fult. Outside door sensor not fitted
FSS.00.04	33		370	(B)	50.1°c	45.5°c	29.6 l/s	N/A			Checked	Within 1°c	
FSS.00.05	33		370	(B)	50.2°c	44.7°c	32.1 l/s	N/A			Checked	Within 1°c	
FSS.00.06	34a		370	(i)	50.2°c	47.2°c	31.2 l/s	N/A			Checked	Within 1°c	
FSS.00.07	35		205	(i)	52.3°c	47.0°c	29.1 l/s	45.3°c			N/A	N/A	
FSS.00.08	36		205	(i)	51.0°c	46.0°c	29.3 l/s	45.6°c			N/A	N/A	
FS1.01.01													
FS1.01.02													
FS2.01.01	34b		370	(B)	51.6°c	44.6°c	31.7 l/s	N/A			Checked	Within 1°c	
FS2.01.02	40		205	(B)	50.0°c	45.1°c	29.0 l/s	46.0°c			N/A	N/A	
FS2.01.03													
FS2.01.04	41		370	(B)	51.0°c	45.3°c	32.4 l/s	N/A			Checked	Within 1°c	
FS1.02.01	34b		370	(B)	50.4°c	44.4°c	32.3 l/s	N/A			Checked	Within 1°c	
FS1.02.02													
FS1.02.03	4e		205	(B)	50.0°c	44.9°c	29.5 l/s	45.3°c			N/A	N/A	
FS1.02.04	4e		205	(B)	50.1°c	45.9°c	28.9 l/s	45.4°c			N/A	N/A	
FS1.02.05													
FS2.02.01													
FS2.02.02													
FS2.02.03	34c		205	(B)	50.0°c	47.4°c	29.7 l/s	45.8°c			N/A	N/A	
FS2.02.04	41		370	(B)	51.2°c	45.8°c	32.5 l/s	N/A			Checked	Within 1°c	
FS1.03.01													
FS1.03.02	37		205	(B)	50.5°c	45.5°c	29.6 l/s	45.0k°c			N/A	N/A	
FS1.03.03	4e		205	(B)	51.7°c	44.7°c	29.3 l/s	45.3°c			N/A	N/A	
FS1.03.04	4e		205	(B)	50.3°c	44.4°c	29.8 l/s	45.5°c			N/A	N/A	
FS1.03.05													
FS2.03.01													
FS2.03.02	40		205	(B)	51.0°c	45.4°c	28.8 l/s	45.7°c			N/A	N/A	
FS2.03.03	34c												No power B&C to Check
FS2.03.04	41		370	(B)	50.0°c	44.6°c	31.4 l/s	N/A			Checked	Within 1°c	
FS1.04.01													
FS1.04.02	37		205	(B)	52.0°c	46.0°c	28.8 l/s	45.3°c			N/A	N/A	
FS1.04.03													
FS1.04.04	4e		205	(B)	50.0°c	44.8°c	28.3 l/s	45.1°c			N/A	N/A	
FS1.04.05													
FS2.04.01													
FS2.04.02	40		205	(B)	50.0°c	45.2°c	29.5 l/s	45.3°c			N/A	N/A	
FS2.04.03	34c		205	(B)	50.0°c	44.4°c	29.0 l/s	45.1°c			N/A	N/A	
FS2.04.04	41		370	(B)		44.7°c	31.6 l/s	N/A			Checked	Within 1°c	
FS1.05.01	34b		370	(B)	49.8°c	44.6°c	30.0 l/s	N/A			Checked	Within 1°c	
FS1.05.02													
FS1.05.03	4e		205	(B)	50.0°c	44.9°c	29.4 l/s	46.0°c			N/A	N/A	
FS1.05.04	4e		205	(B)	50.3°c	45.6°c	28.6 l/s	45.7°c			N/A	N/A	
FS1.05.05													
FS1.05.06	38		205	(B)	50.6°c	44.6°c	29.9 l/s	45.4°c			N/A	N/A	
FS2.05.01													
FS2.05.02	40		205	(B)	52.6°c	45.0°c	28.4 l/s	45.7°c			N/A	N/A	
FS2.05.03	34c		205	(B)	50.0°c	44.6°c	29.8 l/s	45.3°c			N/A	N/A	
FS2.05.04	41		370	(B)	50.4°c	46.0°c	31.3 l/s	N/A			Checked	Within 1°c	
FS1.06.01	42		370	(B)	49.7°c	46.0°c	31.5 l/s	N/A			Checked	Within 1°c	
FS1.06.02													
FS1.06.03	4e		205	(B)	50.0°c	45.6°c	28.1 l/s	45.3°c			N/A	N/A	
FS1.06.04	38		205	(B)	50.0°c	45.2°c	28.7 l/s	45.3°c			N/A	N/A	
FS2.06.01	39		205	(B)	50.2°c	44.6°c	28.5 l/s	45.6°c			N/A	N/A	
FS2.06.02	40		205	(B)	50.4°c	45.0°c	28.7 l/s	45.9°c			N/A	N/A	
FS2.06.03													
FS2.06.04	41		370	(B)	50.7°c	44.0°c	31.9 l/s	N/A			Checked	Within ½°c	

Thermal Images taken during ‘On Site’ Observation and Intervention

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P17
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P13
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P15
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P8
P9
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P2
P3
P4
P5
39.9 °C
39.2
36.7
33.6
30.5
27.3
24.2
21.1
17.9
14.8
11.7
11.0 °C
IR_54
Analysis Info
All IR Images
Current IR
IR Image
Point
Line
Area
Name
Max
Min
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P15 37.4 °C 37.4 °C
P14 27.9 °C 27.9 °C
P13 41.0 °C 41.0 °C
P12 33.2 °C 33.2 °C
P11 40.8 °C 40.8 °C
P10 25.9 °C 25.9 °C
P9 22.8 °C 22.8 °C
P8 21.1 °C 21.1 °C
P7 21.1 °C 21.1 °C
P6 22.4 °C 22.4 °C
P5 25.8 °C 25.8 °C
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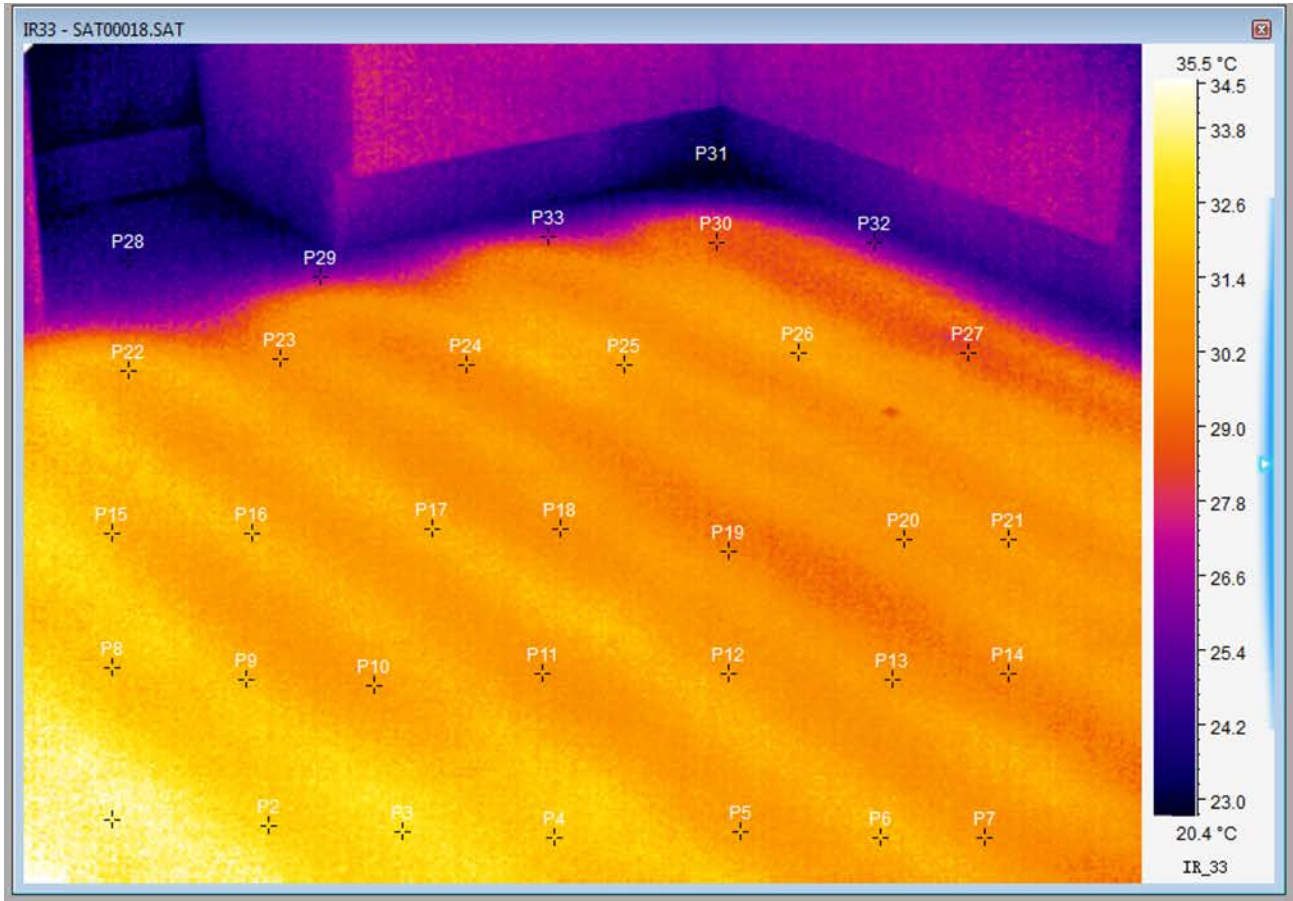
P2 22.1 °C 22.1 °C
P1 23.1 °C 23.1 °C

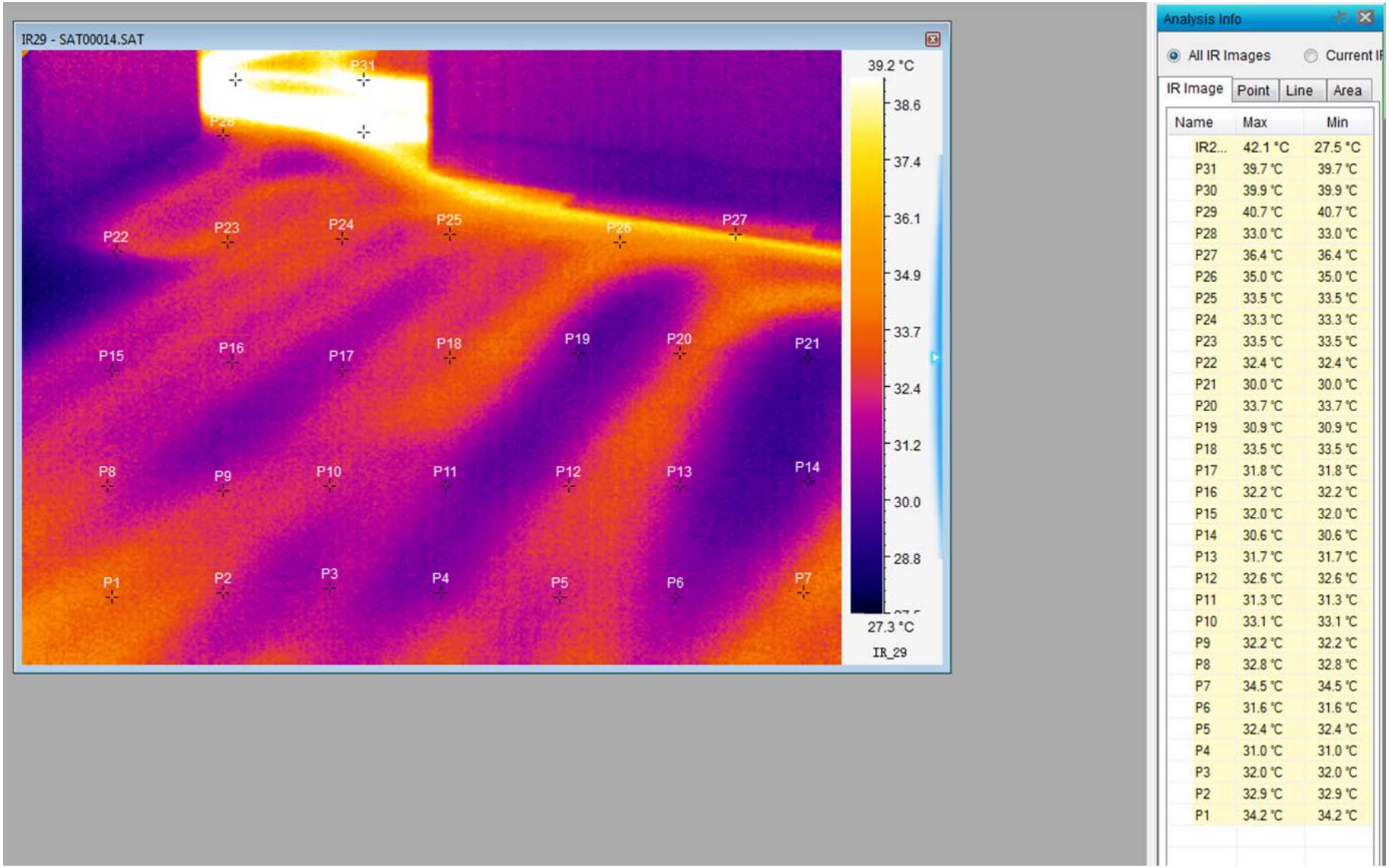


Analysis Info

All IR Images Current IR

IR Image | Point | Line | Area

Name	Max	Min
IR3...	35.5 °C	20.4 °C
P33	27.3 °C	27.3 °C
P32	25.9 °C	25.9 °C
P31	22.4 °C	22.4 °C
P30	29.0 °C	29.0 °C
P29	26.6 °C	26.6 °C
P28	24.4 °C	24.4 °C
P27	29.0 °C	29.0 °C
P26	31.5 °C	31.5 °C
P25	31.1 °C	31.1 °C
P24	30.1 °C	30.1 °C
P23	30.4 °C	30.4 °C
P22	31.4 °C	31.4 °C
P21	30.6 °C	30.6 °C
P20	30.5 °C	30.5 °C
P19	29.8 °C	29.8 °C
P18	30.6 °C	30.6 °C
P17	31.9 °C	31.9 °C
P16	31.9 °C	31.9 °C
P15	31.8 °C	31.8 °C
P14	29.6 °C	29.6 °C
P13	30.8 °C	30.8 °C
P12	30.9 °C	30.9 °C
P11	30.8 °C	30.8 °C
P10	31.3 °C	31.3 °C
P9	31.8 °C	31.8 °C
P8	32.4 °C	32.4 °C
P7	30.4 °C	30.4 °C
P6	31.9 °C	31.9 °C
P5	31.9 °C	31.9 °C
P4	32.1 °C	32.1 °C
P3	33.2 °C	33.2 °C
P2	32.7 °C	32.7 °C
P1	33.9 °C	33.9 °C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39.2 °C
38.6
37.4
36.1
34.9
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30.0
28.8
27.3 °C
IR_29
P31
P26
P22
P23
P24
P25
P26
P27
P15
P16
P17
P18
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Analysis Info
All IR Images
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IR2... 42.1 °C 27.5 °C
P31 39.7 °C 39.7 °C
P30 39.9 °C 39.9 °C
P29 40.7 °C 40.7 °C
P28 33.0 °C 33.0 °C
P27 36.4 °C 36.4 °C
P26 35.0 °C 35.0 °C
P25 33.5 °C 33.5 °C
P24 33.3 °C 33.3 °C
P23 33.5 °C 33.5 °C
P22 32.4 °C 32.4 °C
P21 30.0 °C 30.0 °C
P20 33.7 °C 33.7 °C
P19 30.9 °C 30.9 °C
P18 33.5 °C 33.5 °C
P17 31.8 °C 31.8 °C
P16 32.2 °C 32.2 °C
P15 32.0 °C 32.0 °C
P14 30.6 °C 30.6 °C
P13 31.7 °C 31.7 °C
P12 32.6 °C 32.6 °C
P11 31.3 °C 31.3 °C
P10 33.1 °C 33.1 °C
P9 32.2 °C 32.2 °C
P8 32.8 °C 32.8 °C
P7 34.5 °C 34.5 °C
P6 31.6 °C 31.6 °C
P5 32.4 °C 32.4 °C
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P3 32.0 °C 32.0 °C
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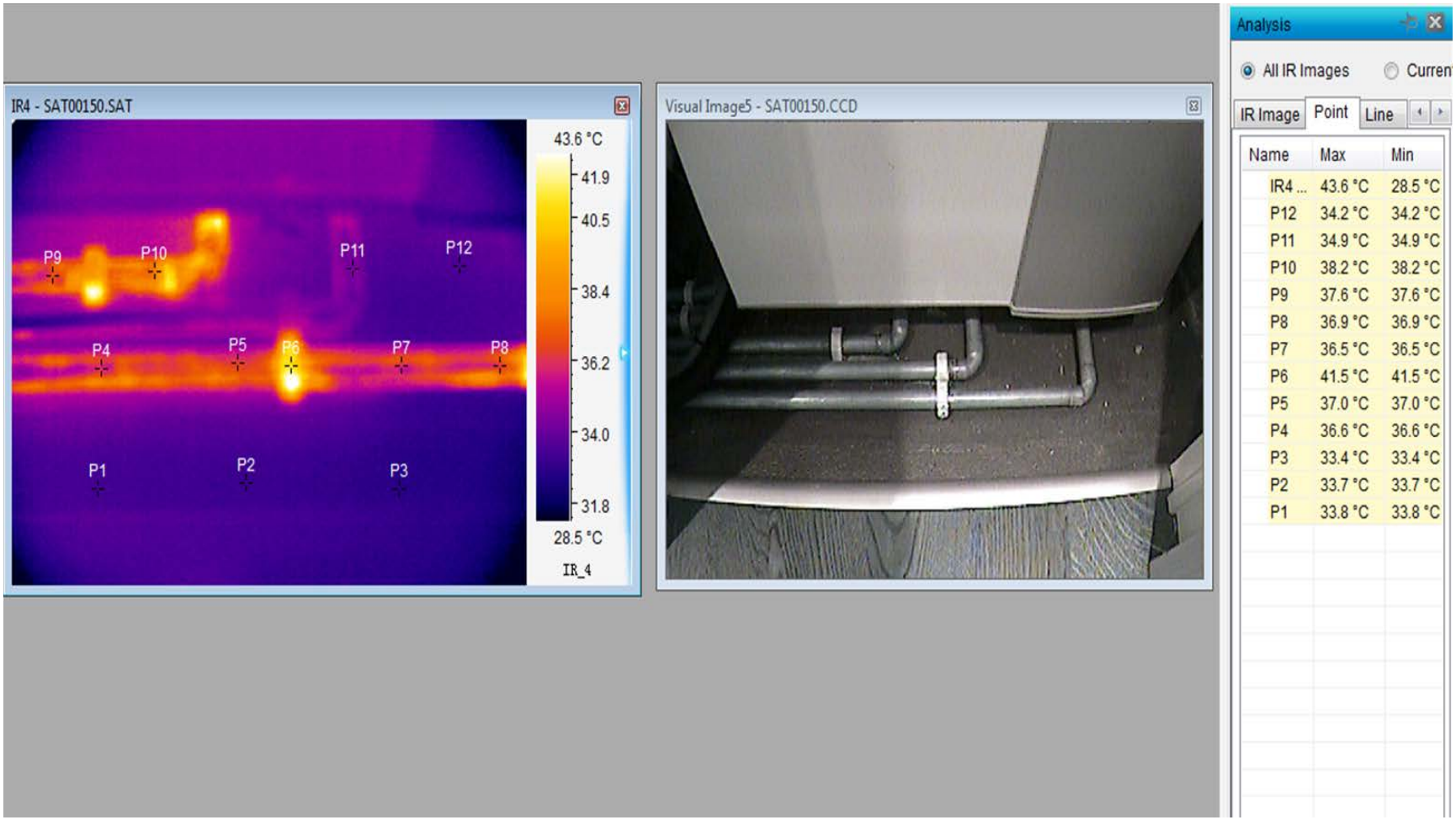
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41.9
40.5
38.4
36.2
34.0
31.8
28.5 °C
IR_4
P9
P10
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P4
36.6 °C
36.6 °C
P3
33.4 °C
33.4 °C
P2
33.7 °C
33.7 °C
P1
33.8 °C
33.8 °C

Appendix 10

Intervention Presentations

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M&E What to look for
Presentation

Terry Keech BEng (Hons) CEng MCIBSE MIET MIE FRICS

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Agenda

- Introduction
- Change
- The unintended consequence
- The Things to look out for
- The delivery
- Questions

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Change

"Make everything as simple as possible, but not simpler."

~Albert Einstein

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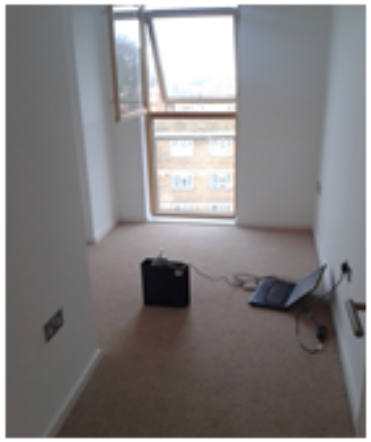
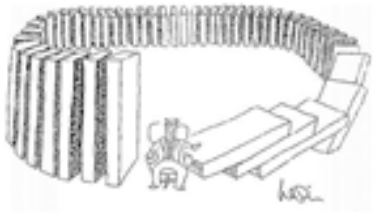
The Unintended Consequence

- 'Fabric First'
- Over Heating
  - Ventilate risers
  - Ventilate corridors
- Understanding and Use
- Long Term Maintenance





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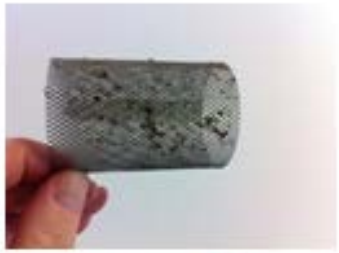
The things to look out for

- **Water Quality**
  - Storage
  - Cleaning
  - Treatment



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The things to look out for

- **Insulation**
  - Brackets
  - Continuous

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The things to look out for

- **Insulation**
  - Modifications
  - Damage and removal by other trades

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The things to look out for

- **Pipe work Installation**
  - Fixing

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The things to look out for

- **Pipe work Installation**
  - Fixing

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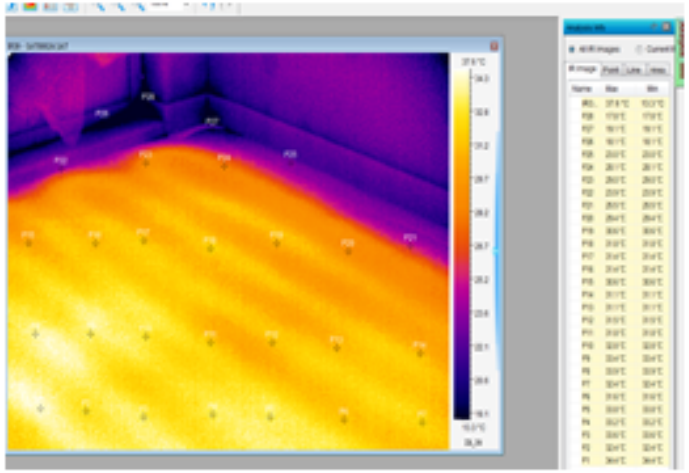
The things to look out for

- **Flow Rates and Heat Output**
  - Heat meters good way to look at basic information
  - Typical Temperature Flow 75oC Return 50oC
  - Flow Rate between 600 – 900l/Hour Primary Side
  - Too high Primary side suffers
  - Too slow and Secondary side too cold



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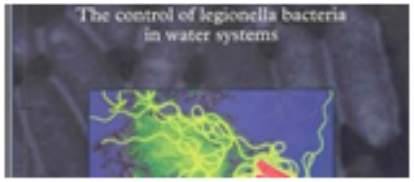
The things to look out for

- **Cold Water**
  - Cold Water- Tap Restrictors installed
  - L8 requires below 20oC at the cold tap in a maximum of 2 minutes (should not exceed 25oC in summer)
  - Heating pipework should be above cold water pipe work
  - Minimise length of run from meter to tap
  - If possible separate cold water distribution from heating distribution



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The things to look out for

- **Ventilation**
  - Filters
  - Noise
  - Flexible connection length 5 x Diameter (typically maximum 750mm)

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The Delivery

- Time
- Co-ordinated approach to commissioning
- Commissioning Program
- Commissioning Schedule
- Verified Results
- Client Approach

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Questions

Appendix 11

Commission 2 Perform Process Document

Commission2Perform©

Reporting for Installation and Commissioning Activities

Domestic Dwellings – [name]

Project title:	
Client name:	
Main Contractor:	
Sub-Contractor – Electrical:	
Sub-Contractor – Mechanical:	
Building Type (Flats / Houses):	
Number of Dwellings:	
Phasing (No of Phases):	

Revision No.	Revision Date:	Completed By:	Revision Notes

Guidance Note:

Commission2Perform© has been design to be a single point document for the recording and reporting of installation and commissioning activities on new build domestic projects.

The installation and commissioning process is to be recorded throughout the project to form a complete record of the construction activities.

The activities are divided into the following sections:

- Project Setup and Design
- Installation
- Commissioning
- Handover
- Defects

The aim is to have clear and concise set of information on activities throughout the construction process, which can complement and support the Operations and Maintenance (O&M) manual.

The following documents will be need for this process:

1. List of installation drawings/schematics with revision and date
2. Electronic issue of all 'As Installed' drawings
3. Copy of Commissioning Programme with revisions
4. Copy of Commissioning certificate list (original certificates to be kept within the O&M manuals)
5. Copy of Defects record for the defects period

It is important that the installation and commissioning activities are co-ordinated and structured. The commissioning programme must be co-ordinated with the construction programme and where changes are required, the programme takes account of this and is revised accordingly.

It is essential that test dwellings are set up as the model for the development. This will assist in setting the standard of installation and commissioning activities. This can be based on bedroom numbers or dwelling types and is for the team to decide.

Where there is a separate energy centre or other central control, the commissioning programme needs to allow for this and indicate how the central facility and individual dwelling are to be tested and commissioned.

It is recommended that the Contractor use the 'Tool Box Talk' sessions to add a 'Technical Tool Box' to allow communication of ideas, quality and compliance with the building services installation and commissioning activities.

Please complete all questions in each of the activity areas. The process will be allocated a section in the construction progress meetings so that a regular update on progress can be given against each activity.

Commission2Perform© is a team activity and must be kept up to date by all participants. The monthly 'Site Progress Meeting' agenda will have an reporting item for progress from each of the areas covered in the programme

Project Setup and Design	
Question:	**Response:**
Is there a separate designer or has the sub-contractor engaged their own designer	Name of Designer: Role:
Sub-contractor is not engaging a designer	Who has design responsibility: What information is used for the installation/commissioning:
Are the client's ER requirements defined and documented?	
Are there areas not covered by the ER documents, if so please list	
What stage was the design developed to prior to D&B contract	
Have installation/commissioning performance targets been set?	
Does the Contractor have performance targets in addition to the Contractual requirements?	

Project Setup and Design	
Question:	**Response:**
Does the client have a monitoring process for the design?	Give brief description:
Does the contractor have a monitoring process for the design?	Give brief description:

Installation	
Question:	**Response:**
Does the client have a monitoring process for the installation?	Very briefly what is the process:
Does the contractor have a monitoring process for the Installation?	Very briefly what is the process:
Is there a checking process for the installation drawings?	Very briefly what is the process:
Who carries out the checking process?	Please State:
Is there a test dwelling/s for the installation standard?	Please State:
Is there a sign off for 1st and 2nd fix	Very briefly what is the process:
What are the main requirements to be achieved from the test dwelling/s	Very briefly what are the requirements:

Installation	
Question:	**Response:**
What information is to be recorded for test dwelling/s?	• Photographs of standard • Room Data Sheet • Information sheet • Technical Tool Box Talk • Other, please state:

Commissioning	
Question:	**Response:**
Is there a commissioning Programme?	
Is the Programme updated to match the construction programme?	
Does the contractor have a monitoring process for the commissioning?	
Does the client have a monitoring process for the commissioning?	
Is there a checking process for the commissioning?	
Who carries out the checking commissioning?	
Is there a test dwelling/s for the commissioning process?	
Is there a sign off for the test dwelling/s?	

Commissioning	
Question:	**Response:**
Is there a specialist for the energy centre commissioning?	
Is the energy centre commissioning linked to the dwelling commissioning?	
Is there a commissioning demonstration to the client's team?	
Is there a commissioning review with the client's maintenance team?	
Are commissioning certificates reviewed against the design and 'AS Built' drawings and specification	
Is the 'As Built' information reviewed to reflect the final agreed commissioning?	
Is seasonal Commissioning to be carried out	

Handover	
Question:	**Response:**
Are the O&M manuals completed before handover?	
Are the O&M manuals checked before handover to the client?	
Is there a demonstration and handover to the client's housing team?	
Is a training session/s arranged with the clients housing team?	
Will a maintenance contract be set up for the first year	
Will there be a handover to the maintenance contractor?	

Defects Period	
Question:	**Response:**
What will be the defects process?	Please state:
How will defects be recorded?	Please state:
Will there be defects meetings	If so; at what intervals?
Will there be an end of defects project review?	If so: will this include contractor, subcontractor client and consultant?
Will there be a review of the monitoring (if carried out)	Please state:
Briefly describe want the review will be and what information is included:	Please state:

Appendices

1. List of installation drawings and revisions

2. Photos for test dwelling/s at first and second fix

3. Agreed Commissioning Parameters

4. Commissioning programme with list of updates

5. List of commissioning certificates

6. Copy of training session's log

7. Copy of Technical Tool Box talks log

8. Copy of Defects list/s

9. Monitoring Review and Result