CIBSE Technical Symposium, London,
UK, 12-13 April 2018'.

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

Dr Terry Keech BEng Hons PrD CEng MCIBSE MIE MIEE. And
Calfordseaden, St Johns House, 1a Knoll Rise, Orpington, Kent, BR6 0JX
tkeech@calfordseaden.com
Dr Carlos Jimenez-Bescos
Anglia Ruskin University, Bishop Hall Lane, Chelmsford, Essex, CM1 1SQ
Carlos.JimenezBescos@anglia.ac.uk

Abstract

This research explores the installation and commissioning performance issues within the social housing sector, with the goal to improve and develop new practice for low carbon homes. The research uses the exploration of the existing literature and practice to investigate installation and commissioning performance within mass low carbon housing. The approach is explored through stakeholder surveys and site observations and interventions utilising mixed methods with the action research methodology.

The research findings demonstrate that a structured and mutually agreed monitoring process within a 'real world' learning environment, can contribute to the reduction of energy and carbon emissions through the installation and commissioning process. The research has 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.

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

1.0 Introduction

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 is 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 domestic construction activities. The research highlights 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 paper aims to explore, through the practitioner experience, the 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.

2.0 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 training 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.

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, this paper 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.

3.0 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.

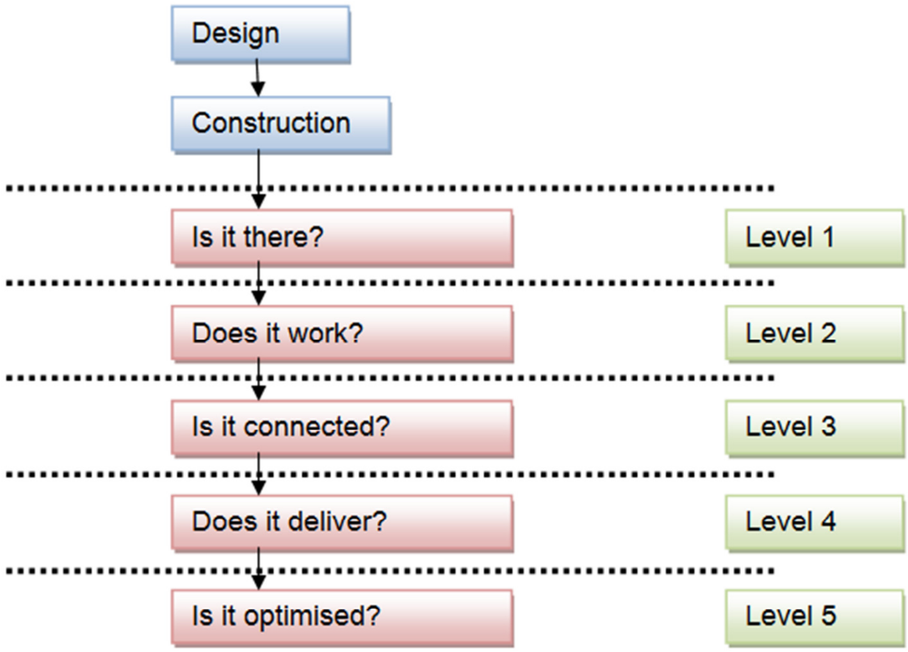

Figure 3.1 Five Primary Steps to the commissioning Process Adapted from (Noyne et al, 2013)

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. 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.

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, compound 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 centred 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 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 a 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.

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, subcontractors and main-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. 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.

4.0 Methodology

The research has adopted a mixed methods methodology using quantitative and qualitative research methods. Teddlie and Tashakkori (2009) 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). This approach has had benefits for the research within construction, as training and commissioning are, to an extent, collaborative processes.

Data gathering has been achieved from both questionnaires and in-depth interviews. The questionnaires were distributed to a wide and diverse cross section of the construction community via a survey software programme call 'Dot Mailer'. 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. The questionnaires were emailed to construction professionals including Developers, Construction Managers, Mechanical and Electrical Subcontractors, Housing Associations, Architects, Mechanical and Electrical designers and Project Managers. 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%. The findings of the questionnaire survey were enhanced by in-depth semi-structured interviews with a number of the construction professionals that had completed the survey.

5.0 Findings and Discussion

The findings from the questionnaire and follow up interviews have given a valuable insight into the training and commissioning process on past and current low carbon developments. A wide coverage of construction industry stakeholders was achieved for the survey, giving validity and depth to the data presented. Figure 5.1 below illustrates the response rate and the respondent categories within the construction sector.

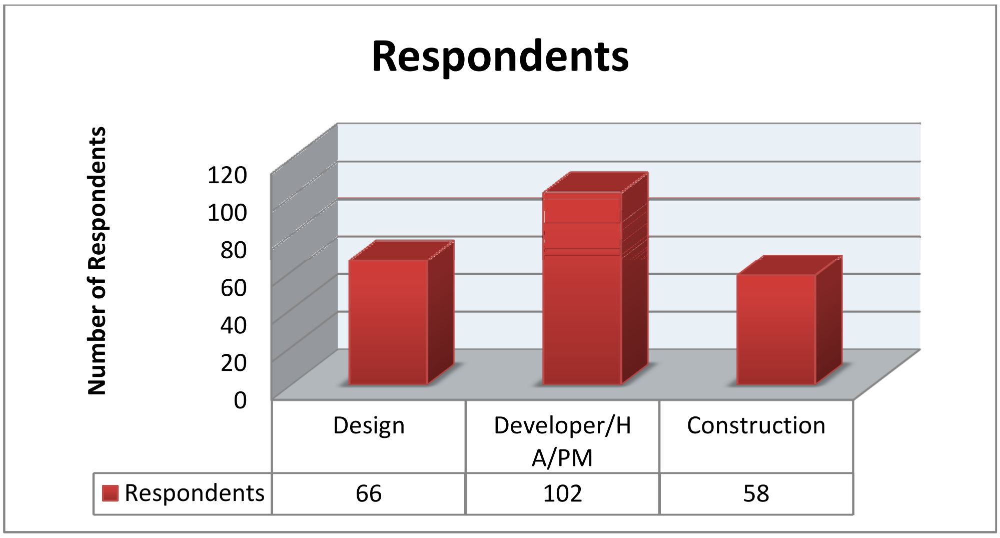

Figure 5.1 Numbers of Respondents

Figure 5.2 shows the responsibility level of the respondents, indicating a cross section of roles and responsibilities have been represented in the survey.

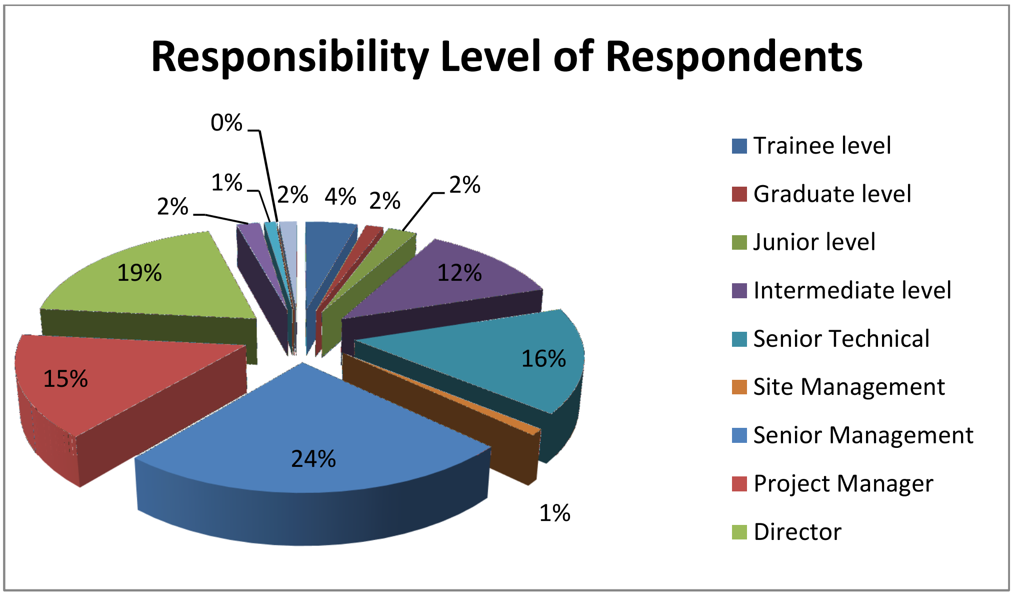

Figure 5.2 Responsibility Level for Respondents

What can be seen is that the survey distribution across professions and responsibility levels gives a representative view of the area under research.

The questionnaire identified key areas with regards training and education in low carbon technologies, Figures 5.3 and 5.4 indicate that there is a low level of formal qualification in the survey group, whilst the main form of knowledge transfer is short term courses and 'in house' seminars.

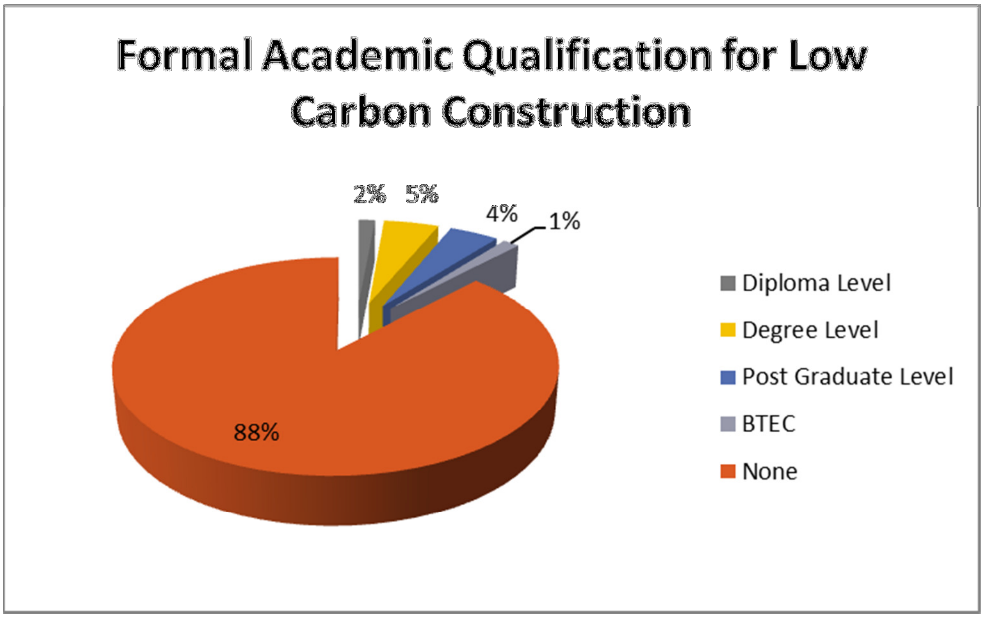

Figure 5.3 Respondent Attendances for Formal Academic Qualifications for Low Carbon Construction

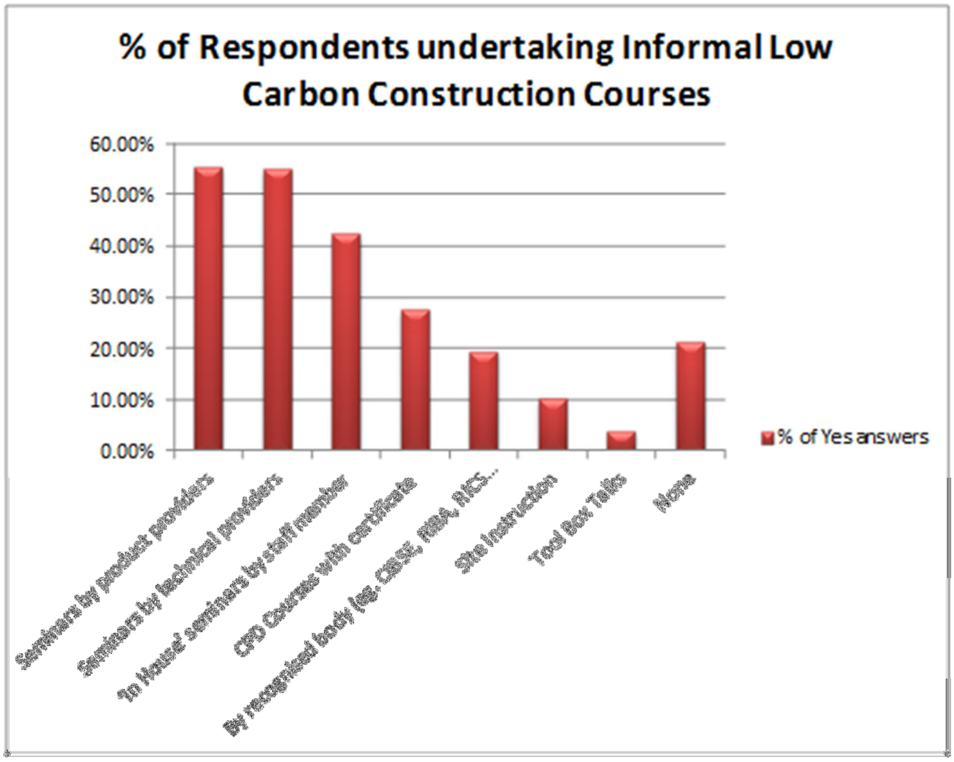

Figure 5.4 Respondent Attendances for Informal Courses for Low Carbon Construction

Figure 5.3 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 sector. 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 formal academic education in low carbon construction would have been seen in the survey.

Figure 5.4 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 sales 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.

Heffernan et al (2012) argue that skills gaps and lack of knowledge are primary barriers to advancing performance in low carbon homes. The survey indicated significant failings in commissioning activities based firmly within knowledge and skills deficiencies. Figure 5.5 indicates the perception of the approach to the commissioning for low carbon homes taken across all the stakeholder groups on current and past schemes. The chart suggests four key areas that stand out namely updates to commissioning, disruption to the commissioning process, co-ordination, and designer at commissioning.

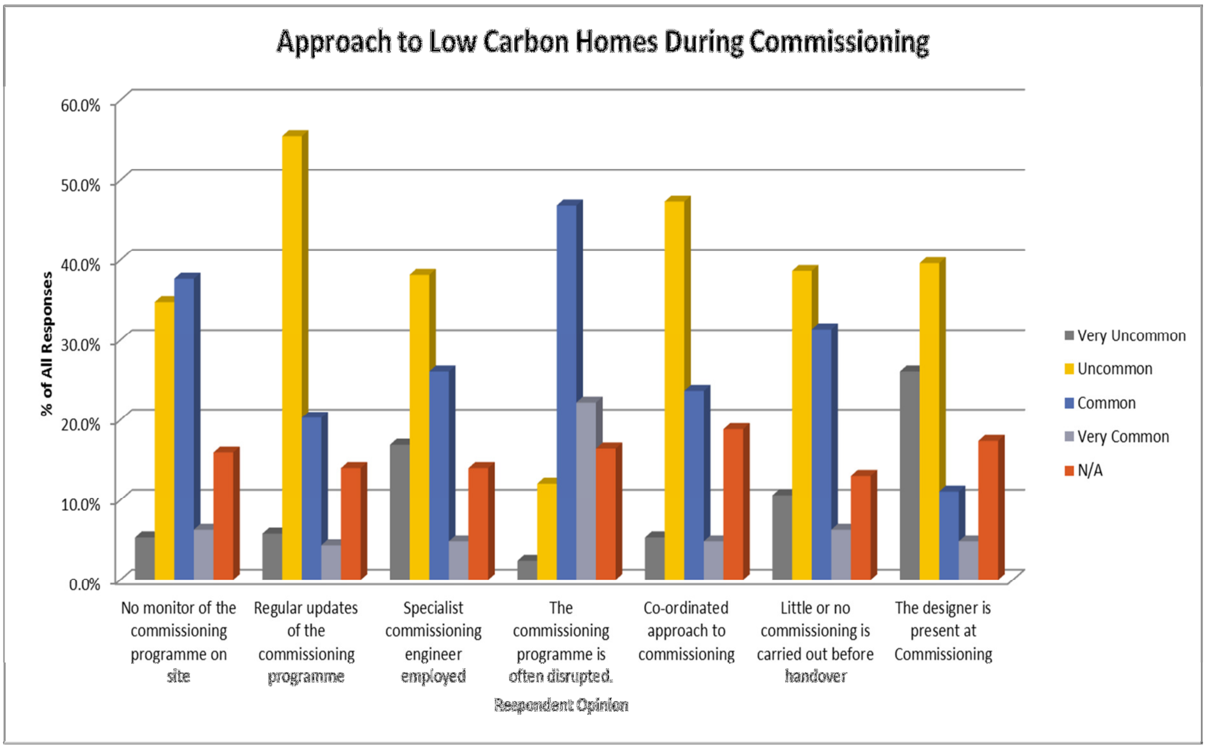

Figure 5.5 Respondent Opinion of the Approach to Low Energy Homes during Commissioning

These gaps highlighted in commissioning indicate that the process is considered disjointed and lacking co-ordination, with validation by the designer as the least engaged area of commissioning. Considering that most low carbon technologies require a higher degree of co-ordination with the building and other building services to operate effectively, the deficiencies observed indicate a serious concern for efficient performance of the technology.

This is further demonstrated in figures 5.6 and 5.7, where the survey asked questions on the effectives of the commissioning and the subsequent occurrence of defects during the defect period. There is a noticeable level of opinion that suggests its effectiveness is lower than should be expected for low carbon performance. When this is read in conjunction with the incidence of defects a distinct pattern is observed from failing commissioning processes through to the direct operation of the technology by residents.

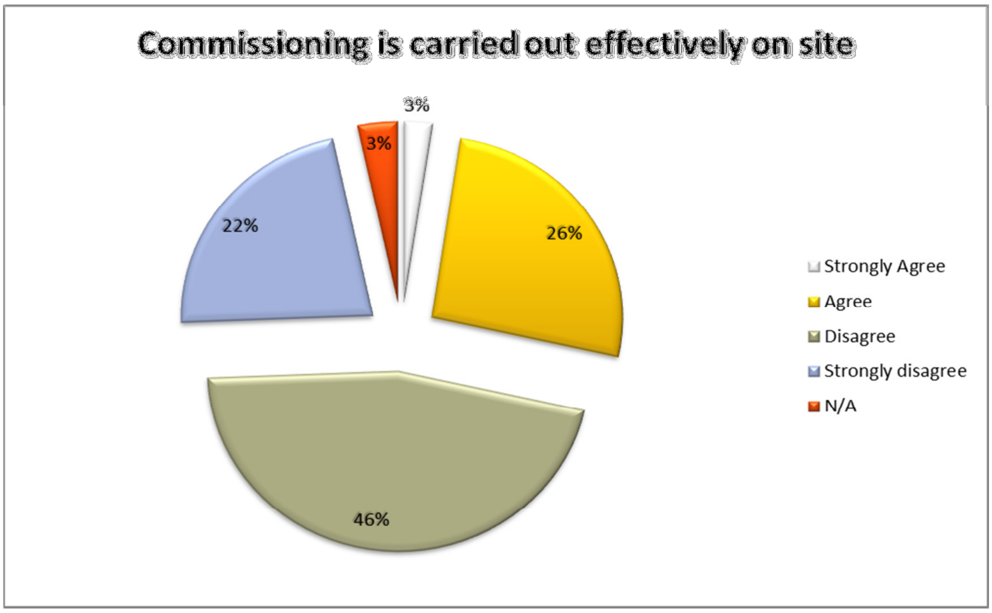

Figure 5.6 All Stakeholder Views on the Effectiveness of Commissioning

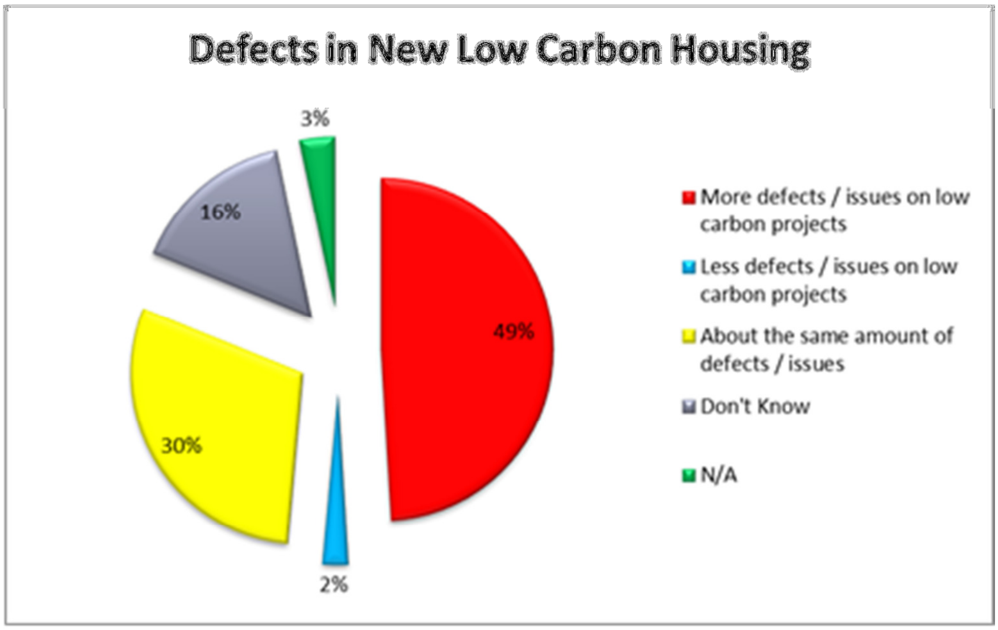

Figure 5.7 All stakeholder Views on Defects in New Low Carbon Housing

Where complex technologies are being used for low carbon housing, the higher rate of defects could be related to the extended 'undeclared post-handover' commissioning of the installed system. Therefore, commissioning is continuing, rightly or wrongly, long after the building is handed over hidden within defect rectification. Consequently uncoordinated commissioning 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 centred 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.

The interview process followed the completion of the survey. 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 – 11 Responses
Construction – 7 Responses

An emergent theme from the interviews was the types of technologies that were considered the most effective, and how that level of effectiveness was measured against ease and simplicity. It was observed from the interviews 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 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. 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.

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 are being missed. In not appreciating the often holistic nature of the combined technology, the individual process approach is delivering reduced efficiency. Therefore, the failing in the process is directly influencing the early stage use of the technology, and thereby potentially affecting long term use and perception of low carbon effectiveness.

This is illustrated by a respondent, 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.*

The emerging picture is 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),in figure 3.1 seen earlier. From the survey and interview data this would appear to be the same case on domestic developments. This is further illustrated by a respondent in the statement:

> *R - 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.*

As an additional point of interest a respondent made the observation:

> *R - 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*

Given these illustrative responses 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 5.6 and 5.7, where there was a strong opinion on the effectiveness of commissioning and on the level of defects.

Following the questionnaires and interviews, commissioning activities were observed on 3 sample developments with a view to testing interventions to the commissioning process to improve practice. Table 5.8 gives a summary of the research findings undertaken across the construction sites, where commissioning monitoring and knowledge sharing training was used to effect sustained change to practice.

Table 5.8– 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

The monitoring cycles were structure on direct observations by the researcher during each of the commissioning stages. The activity was structured to promote shared learning by the subcontractor team, engaging in a documented approach based on the actual design criteria and 'on site' input from the manufacture. The interventions demonstrate that the exchange of tacit and explicit knowledge, when dealing with low energy and carbon technologies, is limited. 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'.

However, engagement in knowledge sharing during monitoring and training sessions indicated the willingness to adopt change, however small the actual change achieved. Both the monitoring and training cycles demonstrate the effects of 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.

6.0 Conclusions

The research has identified the lack of training in low carbon technologies. The evidence recognises that there are several components contributing to this. Most evident amongst these components, is the disconnection 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 within the research. It can be seen, that training and the associated knowledge to critically evaluate optimum performance is lacking, and without compulsion, it remains a low priority in the construction process

Finally, monitoring and control of the installation and commissioning process is critical in achieving improvement in performance. It is clearly apparent, that monitoring and control commands little priority or attention in low carbon mass housing. 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, 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.

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 it's part to play in the overall short and long tern performance, and perception of the technology.

CIBSE Technical Symposium, London, UK, 12-13 April 2018'.

Acknowledgements

The Authors wish to thank Calfordseaden, Anglia Ruskin University and many members of the construction industry for their input and time in this research. The time and efforts given to the questionnaire and interviews is greatly appreciated

References

Bakker, R. M., Cambré, B., Korlaar, L., & Raab, J. (2011). Managing the project learning paradox: A set-theoretic approach toward project knowledge transfer. International journal of project management, 29(5), 494-503.

Barlow, J and Jashapara, A (1998). Organisational learning and inter-firm "partnering" in the UK construction industry. "The Learning Organization", 5(2), 86-98.

Berkhout, F Hertin, J and Gann, D (2006). Learning to adapt: organisational adaptation to climate change impacts. "Climatic Change", 78, 135-156.

BRE (2008) Egan: I'd Give Construction About Four Out of 10: Speech at Commons Reception Marking 10th Anniversary of Report. https://www.bre.co.uk/filelibrary/pdf/CLIP/SirJohnEgan21-05-08.pdf

Carbon Trust (2012). Making buildings Work. Lessons learned from commissioning low carbon buildings. Queen's Printer and Controller of HMSO. CTGH051.

DCLG (2006) The Code for Sustainable Homes:Setting the standard in sustainability for new homes. London. Her Majesty's Stationery Office, 2006

Djuric N., Novakovic V., (2007) Review of Possibilities and Necessities for Building Lifetime Commissioning, Renewable and Sustainable Energy Reviews, 2007, 13:486-492.

Gill, Z, Tierney, M, Pegg, I and Allan, N., (2010) Low-energy Dwellings: The Contribution of Behaviours to Actual Performance. "Building Res. and Info.", 38(5), 491-508.
Grey, D.E., 2011. 'Doing Research in the Real World'. 2nd edn. Sage Publications Ltd

Griffiths, G (1999) Construction Procurement Arrangements of Housing Associations in Liverpool. In:Hughes, W (Ed.), 15th Annual ACOM Conference, 15-17 September 1999, Liverpool John MooresUniversity. Association of Researchers in Construction Management, Vol. 2, 725-33.

Gann, D M and Salter, A J (2000) Innovation in Project-Based, Service-Enhanced Firms: the construction of complex products and systems. "Research Policy", 29(7-8), 955-972.

Heffernan E; Pan W and Liang, X., (2012). Delivering Zero Carbon Homes in the UK In: Smith, S.D (Ed) Procs 28th Annual ARCOM Conference, 3-5 September 2012, Edinburgh, UK, Association of Researchers in Construction Management, 1445-1454.

Homes and Communities Agency (2015) Annual Report and FinancialStatements 2014/15: Presented to Parliament pursuant to paragraphs11 and 12 of Schedule 1 to the Housing and Regeneration Act 2008. HC 220.HMSO.

CIBSE Technical Symposium, London,
UK, 12-13 April 2018'.

Hopkin, T, Lu, S-L, Rogers, P and Sexton, M (2015) Detecting Defects in the UK New-build Housing. A learning Perspective In: Raidén, A B and Aboagye-Nimo, E (Eds) Procs 31st Annual ARCOM Conference, 7-9 September 2015, Lincoln, UK, Association of Researchers in Construction Management, 1073-1082.

Ivankova, N.V (2015) 'Mixed Methods Applications in Action Research', Sage

Lofthouse, V.A., and Lilley, D. (2006) What They Really, Really Want: User Centered Research Methods for Design. International Design Conference - design 2006 Dubrovnik - Croatia, May 15 - 18, 2006.

Lohne, J., Shirkavand, I.,Firing, M., Schneider, K., and Ola Lædre (2015) Ethics in Commissioning in Construction. Published by Elsevier B.V. 256 – 263

Mills E., (2009) Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions, California Energy Commission Public Interest Energy Research (PIER).

NHBC Foundation (2012). Low and Zero Carbon Homes: Understanding the Performance Challenge. NHBC Foundation NF41. ISBN 978-1-84806-255-9

NHBC Foundation (2012). A Survey of Low and Zero Carbon Technologies in New Housing. NHBC Foundation NF39. ISBN 978-1-84806-254-2

Noye,S., Fisk,D., and North, R., (2013). Smart Systems Commissioning for Energy Efficient Buildings. CIBSE Technical Symposium, Liverpool John Moores University, Liverpool, UK, 11-12 April 2013

Office for National Statistics, (2015). Construction Statistics Annual. http://www.
ons.gov.uk/ons/search/index.html?newquery=Construction+Statistics+Annual+
London).

Ozorhon, B (2013), 'Response of Construction Clients to Low-Carbon Building Regulations', Journal Of Construction Engineering & Management, 139, 12, p. -1, Business Source Premier, EBSCOhost.

Taylor, C., (2004) Modern Social Imaginaries. Duke University Press, Durham, North Carolina.

Teddlie, C., and Tashakkori, A. (2009) Foundations of Mixed Methods Research: Integrating Quantitative and Qaulitative Approaches in the Social and Behavioral Sciences. Thousand Oaks, CA:Sage

Wray,C.P., Piette, M.A., Sherman, M.H., Levinson, R.M., Matson, N.E.,
Driscoll, D.A., McWilliams, J.A., Xu, T.T., and Delp, W.W. (2000) Residential Commissioning: A Review of Related Literature. Energy Performance of Building Group Environmental Energy Technologies Division, Lawrence Berkley national Laboratory , Berkley CA 94720.

Zero Carbon Hub, Sweett Group, (2014). Cost Analysis: Meeting the Zero Carbon Standard. Zero Carbon Hub, London.

CIBSE Technical Symposium, London, UK, 12-13 April 2018'.

Zero Carbon Hub (2011). Allowable Solutions for Tomorrows New Homes. Towards a Workable Framework. Zero Carbon Hub, London.