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Article

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Investigating the influence of quality management on building thermal performance

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Abstract

Purpose – Despite the number of quality management procedures being currently applied, construction defects in the domestic sector are acknowledged to contribute to the energy performance gap of buildings. This paper investigates the limitations and challenges to the implementation of Project Quality Plans (PQP) and their impact on the achievement of expected thermal performance in the UK social housing projects.

Design/methodology/approach – A qualitative approach, guided by grounded theory, was used in this research. This methodology provided the structure for systematic data analysis iterations, enabling cross-case analysis. An analytic induction process was designed to seek the explanation of the targeted phenomenon and required data collection until no new ideas and concepts emerged from the research iterations. This study collected data from five social housing projects through interviews, site observations and project documentation.

Findings – Multiple limitations and challenges were identified in the implementation of PQP to deliver thermal efficient social housing. Generally, there is the need for more objective quality compliance procedures based on required evidence. When investigating the root of the challenges, it was concluded that the adoption of statutory approval as the main quality compliance procedure led to the dilution of the responsibility for prevention and appraisal of defects, that compromised the effectiveness of PQP devised by housing associations and contractors.

Originality/value - This study identifies the shortcomings of PQP in addressing quality issues with potential to undermine the thermal performance of social housing projects. The findings could be used by housing associations, contractors and policymakers as steppingstones to improve the energy efficiency in the domestic sector.

Key words - Construction defects, quality management, social housing, thermal performance.

Paper type – Research paper

1. Introduction

Housing associations (HA) are independent non-profit organisations who play an important role in the UK housing sector. They are also an essential part of the country's social security net, providing affordable letting to a substantial part the population with low incomes. In 2018-19, the social rented sector accounted for 17% (4 million) of households in England (MHLG, 2020). Of these, 10% (2.4 million) rented from housing associations and 7% (1.6 million) from local authorities (MHLG, 2020).

In line with the Climate Change Act 2008 (HMG, 2008), the UK social housing sector has engaged in a large-scale effort to reduce carbon emissions, mitigate fuel poverty and increase the comfort level of their tenants (NEF, 2016; Pretlove and Kade, 2016) mostly by means of upgrading heating systems in existing dwellings and improving thermal insulation of building fabric in new homes (MHLG, 2020). In 2018 the social housing sector achieved higher average SAP ratings (68 points) than the housing sector average (63 points) in England (MHLG, 2018). Standard Assessment Procedure (SAP) is a UK Government assessment methodology (expressed on a scale from 1-100 points, where 1 means highly energy inefficient and 100 equals to highly energy efficient) and has been used as proof of statutory compliance at the design stage (BRE, 2014). Unfortunately, despite the efforts made to improve the energy performance of the social housing building stock, the intended energy saving targets are not being met (Alencastro et al., 2018; NEF, 2016). This mismatch between the predicted energy performance at design stage and the measured performance once the building is in operation is known as the building energy performance gap (Zero Carbon Hub, 2014; Zou and Alam, 2020).

Amongst other factors, defects and inefficient quality management systems (QMS) used in construction projects have been acknowledged as contributors to the energy performance gap (Alencastro et al., 2018; NEF, 2016; Zero Carbon Hub, 2014). According to Zero Carbon Hub (2014), QMS commonly used in the construction industry prioritise other project aspects (such as budget and programme) above energy performance.

This paper explores the relationship between quality management and the thermal performance of buildings. This study firstly establishes the challenges in the development and implementation of Project Quality Plans (PQP) in ensuring thermal performance of social housing new-build construction projects through the reduction of defects. Secondly, it proposes evidence-based recommendations to support HA, policymakers and the construction industry in general to improve the thermal performance of the UK social housing stock by means of robust quality management systems. Whilst some studies focus on quantifying the increment of energy use or heat loss due to occurrence of defects, this paper explores the qualitative aspects of quality management practices and their ability to mitigate thermal related defects.

2. Literature Review

Construction defects have a negative impact on the industry reputation as well as on project performance indicators such as client satisfaction, budget, programme and thermal performance targets (Alencastro et al., 2018; Forcada et al., 2014). Over the past decades, construction organisations have widely adopted standardised QMS such as ISO9001 (BSI, 2015; ISO, 2020), aimed to improve the management processes and to achieve the desired quality standards of their products and services. However, the adoption of these standards has not necessarily translated in a significant reduction of construction defects (HBF, 2020).

Hopkin et al. (2019), Alencastro et al. (2018), Tofield (2012) and Auchterlounie (2009), amongst others, suggest that the problem lies on companies concentrating efforts on the remediation of non-conformances, rather than focusing on the prevention of defect occurrences. This has resulted in companies mostly focusing on mitigating visible defects, which are those more likely to raise warranty claims and cause clients and occupants' dissatisfaction in the short term.

Whilst the correction of visible defects has limited impact on the building thermal performance, problems with the buildings' fabric can be less obvious and can remain hidden and unremedied. Unfortunately, these are the defects that can lead to undesired air permeability, thermal bridging, decrease of thermal resistivity, and consequently excessive heat loss (Johnston et al., 2015; Bell et al., 2005). The limitations of QMS in construction projects to prevent hidden defects that affect buildings' energy performance have been briefly investigated (NEF, 2016; Johnston et al., 2015; Wingfield et al., 2011; Bell et al., 2010). For instance, Johnston et al. (Johnston et al., 2015) measured the thermal properties of 25 new dwellings in the UK and concluded that the whole fabric U-value was 1.6 greater than predicted in the design stage, caused by discontinuity of the insulation panels, due to poor workmanship management. Similarly, Bell et al. (Bell et al., 2010) found that the overall heat loss in 6 new-build dwellings in the UK was 54% higher than predicted, even though high levels of insulation were used to minimize the space heating demand. Both studies claimed that poor quality during the buildings fabric installation was the main reason for the thermal bridging, thermal bypass and air permeability causing unexpected heat loss rates.

Implementing QMS to prevent these defects has often proved challenging, mainly due to the nature of the construction industry (Lu et al., 2019; Willumsen et al., 2019; Tofield, 2012). Previous studies suggest that the key success factors of QMS are related to their ability to deal with the uniqueness of construction projects, and the fragmented and adversarial nature of the construction industry (Manata et al., 2020; Willumsen et al., 2019; Hoonakker et al., 2010). Project Quality Plans (PQP) deal with the uniqueness of the projects, as they are developed for an individual project, and they are highly dependent on the requirements of the client, the adopted procurement route and the nature of the project (Harris et al., 2013; Landin, 2000), whilst still complying with the quality policy and the QMS framework adopted. They enable the incorporation of not only the technical characteristics of the project but also provide the opportunity to include other stakeholders' input such as the client, consultants and the supply chain (Willumsen et al., 2019; Landin, 2000; Chan et al., 2004). Therefore, PQP have the potential to incorporate thermal performance specific requirements (i.e. targeted fabric U-values and air tightness levels) and ensure that they are delivered in order to achieve the energy efficiency levels desired by the client. It is suggested that an effective PQP conceptual framework should contain the following categories (Harris et al., 2013; Kanji, 1996; Juran, 1993): (i) Quality requirements; (ii) Quality risk assessment; (iii) Quality resources assessment; (iv) Quality metrics and control; and (v) Quality compliance.

The definition of quality requirements involves the definition of the quality objectives in line with the client's aspirations and statutory requirements (Harris et al., 2013; Deming, 2000; Crosby, 1996), the quality compliance methods to assess the achievement of the quality objectives (Jraisat et al., 2016; Harris et al., 2013), and the communication approaches to be used within the project team (Gorse et al., 2012; Karim et al., 2005). Quality risk assessment aims at identifying the project issues that could undermine the achievement of the quality objectives (Koo and O'Connor, 2021; Willumsen et al., 2019; BSI, 2015), as well as the managerial and technical risks involved in the development and implementation of the PQP (Greenwood et al., 2017). This stage requires information from project participants' previous experiences and knowledge, and data recorded from similar projects (Battikha, 2008; Briscoe et al., 2004; Atkinson, 2002). Quality resources assessment involves the establishment of quality assurance procedures, including the definition of roles, responsibilities and authority of each project participant, and the appointment of external support when considered necessary

(Harris et al., 2013; Kanji and Wong, 1998; Juran, 1993). It also includes the assessment of the resources necessary to undertake quality control and workforce empowerment activities, such as training and awareness development (Brooks and Spillane, 2016; Tofield, 2012; Atkinson, 2002). Definition of quality metrics and control involves the definition of the attributes to be measured and their acceptability values for the quality requirements initially established (BSI, 2015). This stage also involves the planning of the quality control and appraisal procedures, including the timing, frequency, sampling of quality inspections, and necessary tools (Heravi and Jafari, 2014; Auchterlounie, 2009; Sommerville and McCosh, 2006; Atkinson, 2002). In the quality compliance stage, the quality control procedures are reported, assessed and analysed, and corrective measures are defined within a project duration (Gorse et al., 2012; Crosby, 1996). It also involves a learning process within the project, enabling continuous improvement based on the lessons learned in previous projects (Jraisat et al., 2016; Tofield, 2012; Bordass et al., 2001). Therefore, quality data (e.g. defects) needs to be recorded, stored and analysed during the project duration, so it can be used in future projects.

In summary, the existing knowledge establishes a comprehensive theoretical basis for the development of quality management frameworks in construction projects, highlighting the importance of recognising quality objectives, compliance procedures and making available the necessary resources for the implementation of PQP. However, there is a shortage of studies and sufficient information to provide a full understanding on the fact that despite the number of quality assurance procedures put in place in UK HA's projects, defects affecting the thermal performance of dwellings are still a widespread occurrence.

3. Methodology

A qualitative approach was used for this research. An analytic induction process was used to seek the explanation of the targeted phenomenon, and it required data collection from case studies until no new ideas and concepts emerged from the research iterations (Bryman, 2012; Corbin and Strauss, 2008). The research process consisted of: (I) define, design and prepare; (II), collect and analyse; and (III) analyse and conclude (Figure 1).

Stage I encompassed the identification of the research problem and definition of the research strategies. The PQP conceptual framework, as explained in the literature review, was used as the theoretical basis for the grouping and analysis of the case studies' key findings in Stage II. Reliability and validity of the findings was ensured by designing a triangulated data collection protocol from multiple sources to avoid biased information or unsubstantiated conclusions.

Stage II entailed the collection and analysis of data emerging from the case studies through several data analysis iterations (Bryman, 2012). Each iteration was informed by previous data analysis, as suggested by Grounded Theory (Bryman, 2012, Corbin and Strauss, 2008). Data was collected during the design, pre-construction and construction stages of the case studies. Data was then analysed and distilled into concepts, which in turn were grouped within the categories of PQP conceptual framework.

Stage III consisted of the cross-analysis between the concepts emerging from multiple sources of data. As a result, the empirical model was defined, establishing the challenges in the development and implementation of PQP in social housing projects in the UK. Finally, recommendations to address the limitations of PQP were proposed.

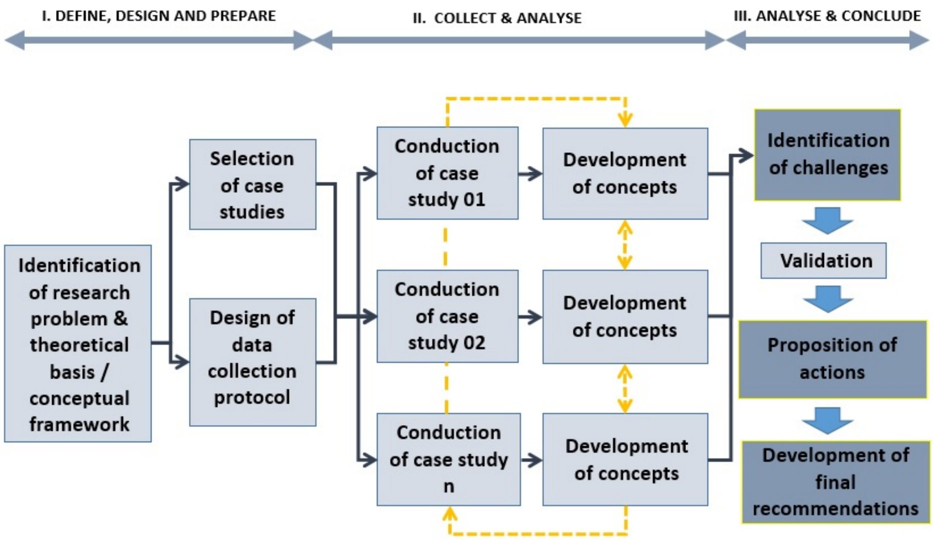

Figure 1 Overview of the research process (Source: Author's own creation)

The primary data was collected from original interviews. For each case study, semi-structured interviews were undertaken with the stakeholders representing the housing association, the main contractor, and the quality officer appointed by the main contractor. They were aimed at obtaining different perspectives on how the PQP were developed and implemented in each case study and the challenges encountered. In total 15 face-to-face interviews were undertaken; 3 interviews for each case study. They were designed to take between 30-45 minutes, and they were voice-recorded and transcribed for later analysis. Interview questions were defined around the five categories of the PQP conceptual framework. These categories were briefly described to the participants in order to minimise any ambiguity or misinterpretation (Bryman, 2012).

Additional data was used in each case study to confront or confirm the findings emerging from the semi-structured interviews, thus improving the reliability and validity of the research findings. Other sources of information included: (i) quality management documentation (quality policy, quality plan, quality checklists, quality reports and compliance information); (ii) observations during project team meetings and construction site visits attended by representatives of the housing association (development manager (DM), project manager (PM) and quality officer (QO)), consultants, and contractor (project manager, site manager (SM)); and (iii) on-site construction defects surveys undertaken using a specifically designed defects taxonomy. Other project documentation, such as design drawings, materials specifications, and construction phase plan, were also available for the purpose of the study. Some examples are included in Figures 2 to 6.

The interviews transcripts were analysed using an iterative and systematic conceptual coding system recommended by the Grounded Theory methodology (Bryman, 2012; Corbin and Strauss, 2008). First, an initial list of 39 codes was extracted from the literature review. The transcripts were coded using the initial list resulting from the literature review, and clustered using the five categories of the PQP conceptual framework. The process of coding entailed the use of five colours, one for each of the aforementioned categories. The relevant sections of the interview transcripts were highlighted with the specific colour and coded to enable further data analysis iterations and clustering of converging data. Further iterations of coding analysis were conducted to merge similar codes into key concepts, as well as establishing causal relationships between them (Stall-Meadows and Hyle, 2010; Charmaz, 2006). In total, 12 concepts emerged from the data analysis (See Tables 2 to 6).

The same data analysis process was used with the secondary data sources previously mentioned. A crossed analysis between the concepts emerging from the interviews and the additional sources of data, helped to establish the challenges in the development and implementation of PQP with focus on the building thermal performance in social housing projects.

In total, five case studies of new-built social housing developments were analysed. The case studies were selected based on the project characteristics (purposive sampling) that are representative of the social housing sector. They differed in location (Cornwall, Devon and Wiltshire), construction method used (timber frame, brick and block construction); energy performance standards targeted (CSH4, Part L1a, Passivhaus); contract value (£3.1M - £10M); and number of housing units per development (28 - 121 units). The HA and contractors involved in the case studies were all ISO9001 certified. See details in Table 1.

Table 1: Summary of the case studies (Source: Author's own creation)

	Case study 1 (CS1)	Case study 2 (CS2)	Case study 3 (CS3)	Case study 4 (CS4)	Case study 5 (CS5)
Project information					
Location	Cornwall	Cornwall	Devon	Devon	Wiltshire
Number of units	28	39	67	72	40 (121)*
Contract value (£M)	3.1	4.0	8.3	10.0	5.0
Type of contract	Traditional	Design and build	Design and build	Design and build	Acquired from the market
Energy performance target	CSH4**/ Building regulations Part L1a***	Building regulations Part L1a	Building regulations Part L1a	Passivhaus standard****	Building regulations Part L1a

Project team characteristics					
HA number of assets	4500	4500	16000	16000	55000
HA geographical area	Cornwall	Cornwall	Plymouth local authority	Plymouth local authority	South and Southwest
Main contractor number of employees	60	60	5696	450	800
Main contractor geographical area	Cornwall	Cornwall	Whole UK	Southwest and South of UK	Southwest, South and Southeast of UK

* Developer led project of 121 housing units where 40 dwellings were acquired by the housing association.

** CSH4: Code for Sustainable Homes Level 4 - voluntary standard for energy efficiency in buildings that was discontinued in 2015 (McManus et al., 2010; Pretlove and Kade, 2016)

*** Part L1a: The Approved Document Part L1a – Conservation of fuel and power in new dwellings – UK building regulations (HM Government, 2013)

**** Passivhaus: Voluntary energy performance standard for buildings (BRE, 2016)

The validity of the methods and results from this study was ensured by undertaking a chain of evidence (Stall-Meadows and Hyle, 2010), beginning with the findings of an in-depth literature review, followed by the multiple case studies analysis and constant comparison method between the findings of each case study. This approach allowed the triangulation of data within case studies individually and amongst them. To ensure the reliability of the research procedures, a data collection protocol was devised for each of the data sources providing repeatability and rigour (Creswell, 2013, Bryman, 2012, Yin, 2009).

4. Results

The results are presented according to the five categories of the PQP conceptual framework. They illustrate the limitations on the development and implementation of the PQP to deliver energy efficient social housing.

4.1 Definition of quality requirements

Table 2 summarises the PQP framework concepts and the challenges related to the Definition of quality requirements. These were observed in 4 of the 5 case studies.

Table 2 List of concepts and challenges related to the Definition of quality requirements (Source: Author's own creation)

PQP Framework Concepts	Challenges related to the Definition of quality requirements	Case studies				
		1	2	3	4	5
Quality objectives and compliance	Quality compliance assigned to third parties (i.e. building control bodies), diluting the responsibility for providing evidence of compliance	✓	✓	✓		✓
Formal procedures	Lack of formal PQP from HA and contractors guiding quality control and assurance	✓	✓	✓		✓

4.1.1 Quality objectives and compliance: The Quality Policies of the housing associations had acknowledged the improvement of the energy efficiency levels of their new assets as a way to improve the occupants' living standards and reduce their energy bills and fuel poverty. For example, the PM of CS4 stated "the reason why we are interested in that (more energy efficient homes), in principle, is because we're interested in our tenants and having as low energy bills as possible, so because we're housing people on limited means and also it helps on pay the rent.". However, when looking specifically to the projects' quality requirements and compliance, it was observed that most of them were only aiming to achieve the minimum thermal performance levels defined by the UK building regulations Part L1a (HM Government, 2013), through Building Control Bodies (BCB) award, as the main compliance procedure. The only exception was CS4, where the requirement was to go beyond minimum standards and achieve higher energy performance levels defined by the Passivhaus standard (BRE, 2016). The lack of ambitious thermal performance targets was questioned during the interviews, and most of the respondents mentioned financial constraints led by cuts in social renting values and limited funding as the main reasons. For instance, the PM of CS3 mentioned that "They (HA's quality policies) were originally aiming at higher energy performances […] but in the intervening period we had the rent cuts which cost us over £20 million."

4.1.2 Formal procedures: Except for the contractor of CS5, all other housing associations and contractors had ISO9001 accredited QMS. However, four out of five projects did not have a formal PQP as expected. Instead, they had other forms of quality frameworks, falling short of meeting the five categories of the conceptual framework. The only exception was CS4, where a full PQP was devised in order to ensure Passivhaus accreditation. The SM in CS2 and the QO of CS5 stated, respectively: "I'm not aware of a quality plan, etc. but it is knowing that our aim generally is zero defects." and "We have our own (quality management procedures) but it's not formalised, if you know what I mean. It's down to the individual surveyor's experience." Interviewees were also asked whether they knew what QMS accreditation their companies held. However, nine out of fifteen could not give an objective answer. For example, QO of CS5 stated "We do (have an accredited QMS) as a company, but it's not specifically related to this site.", and PM of CS3 mentioned "I think we do, but I'd need to find out that for you because I'm not sure it's specifically for our department […]."

Overall, the lack of a formal PQP used in the case studies and the interviewees' lack of knowledge on standard QMS adopted by their companies suggested that having a standard QMS at corporate level does not necessarily translate into formal quality management procedures being implemented at project level.

4.2 Quality risk assessment

Table 3 summarises the PQP framework concepts and challenges related to Quality risk assessment. Each of them were observed in more than one case study.

Table 3 List of concepts and challenges related to Quality risk assessment (Source: Author's own creation)

PQP Framework Concepts	Challenges related to Quality risk assessment	Case studies				
		1	2	3	4	5
Stakeholders' participation	Lack of participation of important project stakeholders, limiting the input in the risk assessment.	✓				✓
Sources of information	HAs' defect records mostly contained defects not related to thermal performance.	✓	✓			✓
	Lack of use of previous defect records to inform the risk assessment.			✓	✓	

Technical and managerial issues	Difficulties in sustaining consistent communication.	✓	✓	✓	✓	✓
	Low general level of education and technical capabilities.	✓			✓	✓
	High level of staff turnover and discontinuity of projects' sequence.	✓				✓
	Tight programme and budget compromising the administration of quality control procedures.	✓		✓	✓	✓

4.2.1 Stakeholders' participation: The procurement route and business model adopted in two of the five case studies did not facilitate the involvement of all relevant project stakeholders in the quality risk assessment stage. CS1 adopted a traditional procurement method and therefore, the contractor was not appointed until after the design stage. Therefore, they had no input in the identification of the technical and managerial risks. In that respect, the SM of CS1 confirmed: "The housing association appoints designers and then the contractor just purely builds, so we've got no input in design as a builder." In CS5, the project was commissioned by the developer of the housing development, thus the HA was not involved in the risk assessment process.

4.2.2 Sources of information: Results suggested that the case studies used databases containing post-handover defects identified by the tenants to guide the projects' quality risk assessment. It was observed that none of the defects related to the thermal performance of the dwellings. Instead, they covered other issues, such as in CS3: leaks (under the bath, sinks, radiators, and gutters); operational problems (faulty doors, locks, and telecom); and lack of instructions (how heating and telecom system work). In most of the case studies (except for CS1 and CS5), technical forums attended by designers, contractors and HA representatives were also organised to identify potential technical risks affecting the thermal performance of the dwellings, such as air barrier gaps and discontinuity of insulation. These forums mostly relied on the professionals' knowledge and experience, and only CS4 used a structured approach based on a defect list from previous projects provided by the Passivhaus consultant.

4.2.3 Technical and managerial issues: Interviews highlighted risks to the implementation of PQP associated with inconsistent communication of the client's quality requirements to the site management and supply chain. The PM of CS3 stated: “So they've (contractors and subcontractors) signed up to the design and project toolkit. So, I think they also have an understanding of our requirements. But again, I don't think it's always… it's a bit like Chinese whispers where it gets relayed differently on site and people get the wrong end of the stick.” Interviewees also questioned the effectiveness of subcontractors’ managerial team when communicating the quality requirements to the operatives due to continuous staff turnover. Even when the HA and contractor had a long-term relationship, there was still the constraint posed by the constant inflow of new operatives unfamiliar with the projects’ quality objectives and procedures. For example, “[…] there’s a lot of churn in the industry, and that’s difficult to manage. The churn isn’t usually at management level issue, it’s usually at the operative level, so, we usually get the same supervisors, the same contracts’ managers, but different operatives and that’s the difficult one.” (SM, CS1). Interviewees also noted the insufficient level of technical knowledge and managerial capabilities of the subcontractors as a challenge to the achievement of the quality objectives in some instances. For example, “[…] the general education across the whole industry needs to be improved without doubt.” (SM, CS5), and “My biggest problem that we’ve had is the education process with the supply chain and actually getting them to cost the job allowing the time for quality checks and doing things methodically and correct, instead of just banging up the building as quick as possible.” (SM, CS4). Risks associated with unrealistic or demanding projects programme and budget was also highlighted by the research. In contracts where the budget was too tight and programme inadequate, subcontractors were hard-pressed to finish construction activities as soon as possible at the expense of quality standards.

4.3 Quality resources assessment

Table 4 summarises the PQP framework concepts and challenges related to Quality resources assessment. These were observed in 4 of the 5 case studies.

Table 4 List of concepts and challenges related to Quality resources assessment (Source: Author's own creation)

PQP Framework Concepts	**Challenges related to Quality resources assessment**	**Case studies**				
		1	**2**	**3**	**4**	**5**
Provision of resources	Lack of appropriate resources (time and staff) allocated by the contractor and building control bodies for quality control procedures.	✓	✓	✓		✓
Development of competences	Lack of specific training and upskilling activities with the purpose of increasing awareness of the quality objectives and potential risks, as well as technical capabilities.	✓	✓	✓		✓

4.3.1 Provision of resources: In four of the five case studies, the quality control procedures under the contractor's responsibility were undertaken by the on-site management team in addition to the other daily activities. In some occasions, the effectiveness of the quality control procedures were compromised due to the lack of appropriate human resources and time. For instance, the SM in CS1 stated: "I'm on my own until the timber frame goes up and then I get a site assistant who will be going out and do the QA checks. I wouldn't like to say that the company let me down […]. I did not have continuity with my assistant site manager. So, I get one for weeks, then he'd go and then I'll get somebody else and you can't run a site like that". In contrast, the contractor in CS4 had appointed a dedicated QO to support the on-site management team. His role was to monitor specific building elements and construction stages where defects were likely to occur, as highlighted in the risk assessment stage. "From a managerial point of view, we have employed an extra person which we wouldn't normally have on another scheme to specifically check the QA and work through the QA process […]" (SM, CS4).All five HAs had internally appointed QOs to undertake on-site inspections to check the quality and the programme progress of the construction works. The frequency of the site visits varied from case to case from daily visits (CS3), to two to three times per week (CS4), weekly site visits (CS1 and 2) and monthly site visits (CS5). The QO of CS1 described the main purpose of site visits as: "I'll put a report together […] just an overview and you'll see the number of operatives that are on site, it's a particular snapshot of the visited site. If there's any defects it will be on there […]. And then it's just a general update for the client to see how the program is going forward […]." Approved inspectors were commissioned by the contractor and/or developer in all case studies to undertake the on-site quality control procedures required to achieve UK Building Regulations approvals issued by the Building Control Bodies (BCB). Figure 2 shows the areas requested by the BCB to be inspected for each plot (i.e. dwelling): Foundations, drainage, superstructure, pre-plaster and pre-handover. Although this inspection protocol was used by the appointed inspectors, research demonstrated that some dwellings were left uninspected in certain key stages of construction process (See Figure 2). Interviewees suggested that this was due to insufficient resources and tight programmes, resulting in quality control hold points not being fully respected The SM in CS3 explained: “They are very busy. […]. I would say they are probably a little bit overstretched and obviously it does have a knock-on effect to our programme sometimes and it’s the responsibility of the builder to obviously not go forward with the build, and I think a lot of people, because the time constraints, are inclined to continue to the next stage before the building control officer has been to sign it off.”

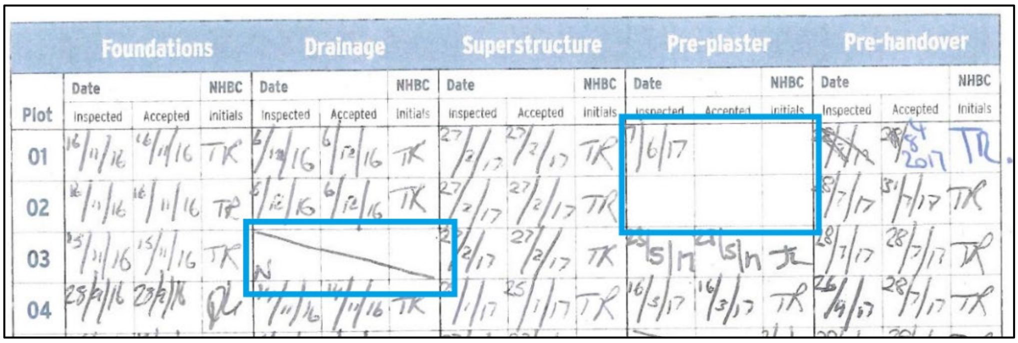

Figure 2 Section of BCB’s inspection record book showing missing quality control checks in certain key stages (Source: contractor CS5)

4.3.2 Development of competences: Quality resources also include those invested in improving the technical knowledge (e.g. to prevent defects) and the overall quality awareness of the workforce. The research could not identify any specific initiative in four of the five case studies. Daily site inductions took place, but the main focus was health and safety, as explained by the SM of CS5: “We use toolbox system mainly for health and safety. We don’t use that (to promote defects awareness) but it would be a good tool if we have the time”. Exceptionally, CS4 had allocated resources to upskill and train the workforce and management team on preventing, identifying and correcting defects affecting the thermal performance of the building.

4.4 Definition of quality metrics and control

Table 5 summarises the PQP framework concepts and challenges related to Definition of quality metrics and control. Each of them were observed in more than one case study.

Table 5 List of concepts and challenges related to the Definition of quality metrics and control (Source: Author's own creation)

PQP Framework Concepts	**Challenges related to the Definition of quality metrics and control**	**Case studies**				
		1	**2**	**3**	**4**	**5**
Quality attributes and criteria	Lack of objectivity in quality acceptance criteria used in quality control tools.	✓	✓	✓		✓
Quality control procedures	Quality checking hold points overly distant to each other and lengthy working packages affecting the identification of defects in certain building elements due to accumulated construction stages.	✓	✓			✓
	Lack of consistency of quality checklists due to being not site specific and generic in terms of construction method and sequencing.		✓			✓
	Quality checklists deployed did not encompassed at least the most recurrent quality issues affecting the thermal performance of the dwellings' fabric.	✓	✓	✓		✓
	Lack of consistency on the application of quality control procedures.	✓	✓	✓	✓	✓

4.4.1 Quality attributes and criteria: Results showed that air permeability was the only attribute used to assess the building thermal performance across all case studies. Partially, because it was a statutory requirement. In four of the five case studies, only one air permeability test (in all dwellings in CS1 and a percentage per housing type as statutory requirements in CS2, 3 and 5) was conducted to demonstrate compliance to the prescribed rate. This was done at practical completion, in accordance with statutory requirements. Differently, CS4 undertook three air permeability tests in each dwelling at different stages of the construction process as part of the process of obtaining Passivhaus certification. Other performance attributes, such as the thermal transmissivity of the overall building fabric or specific building elements, were verified using estimated values obtained by means of SAP calculations and Passivhaus Planning Package, both at the design stage. Therefore, the actual performance values were not tested, but verified in terms of the quality of the construction.

4.4.2 Quality control procedures: Quality control checklists were the most common tool used across case studies. PM in CS3 explained when quality checklists were mostly applied: “We have various of the checklist which we use on schemes which highlights particularly areas of defects but that is usually to do with the snagging stage”. Checklists normally included the quality risks identified at early stages of the project, but they failed to define quantitative metrics or objective acceptance criteria to ensure that quality attributes had been met. Instead, they used subjective or generic metrics, such as “complete” (See Figure 3). Therefore, it was down to the QO to interpret the acceptance criteria. Moreover, quality control tools used by contractors did not provide sufficient drive to identify defects affecting dwellings’ thermal performance, such as gaps in the vapour control layer; displacement of insulation layer due to pipework; or services penetration in the building’s fabric, which could lead to air permeability and heat loss. Differently, CS4 had mapped the potential defects thoroughly and the acceptance criteria were translated into measurable parameters in the checklists.

Carpentry/Insulation

#	Check Item	Status
1	06/25 Studwork set out correctly (300mm spacing to baths and showers)	Pass
2	06/26 Staircase installed per Standard detail and CQM and exposed soffit boxed for stepped drylining	Pass
3	06/27 Window boards fitted square with correct overhang for finishes	Pass
4	06/28 Door openings correctly set out with margins for full architraves etc.	Pass
5	06/29 Insulation to stud walls between bed rooms bathrooms etc. installed	Pass
6	06/30 Noggins and patresses for plasterboard, radiators, sanitaryware, boilers, kitchens, etc. installed	Pass
7	06/31 Shower cubicles formed using tray templates as per CQM.	Pass
8	06/32 Correct insulation board used at sloping ceilings or where required (refer to construction specification)	Pass
9	06/33 All insulation and sound proofing complete (partitions and SVPs)	Pass

Figure 3 Quality checklist used in CS5 (Source: contractor CS5)

It was also observed that quality checklists used in CS2 and CS5 had been developed by the contractors’ central management. Whilst CS1, CS3 and CS4 had been developed by the site management team and tailored to the specific project.

The same limitations were identified in the quality control tools used by the HA (See Figure 4). In this case, HA forms were mostly driven by the programme progress and offered little guidance to the identification of specific defects.

Inspection Date: 27/04/17 Time of visit: 09:30HRS COW: [redacted]

Weather: Sunny Temp:10ºc Wind: None

Site visit Number: 14 Contractor: [redacted]

Plots Completed (72 Plots in total)		
Rented	Shared Ownership	Total
0/49	0/23	0/72

Progress of Works

Plot Number	Observations	Overall Progress
Block A Plots 1-12 Block B Plots 13-16	Plot drainage complete. Slab insulation and membrane is in hand	6%
Block C Plots 17-23	Ground floor superstructure is 95%.	14%
Block D Plots 24-28	Slab reinforcement in hand. Concrete poured on 2 plots.	5%
Block E Plots 29-34	Plot drainage complete.	3%

H&S and Accidents	None	
Site Issues and defects		
Welfare on site	Site Office Toilets Canteen Meeting room	
Rectification notices issued/outstanding	Ref number	Status
	BOD01	**Signed Off**
Labour on site	Site Team MJL Balfour Beatty REB Utilities	
Material Issues	None	
L.A.B.C	Carrying out inspections – nothing to note.	
A.O.B	None	

Figure 4 Sections of site visit report template used by HA's quality officer. (Source: QO in CS3)

Results also suggested that contractors planned the inspections following the five key statutory construction stages requested by the BCB (See Figure 2) and upon the completion of subcontracting work packages. It was observed that this approach could result in long periods of time between inspections. For instance, Figure 2 shows that in Plot 1 there were more than three months between the Superstructure and Pre-plaster inspections. As a consequence, building defects, including those related to the building fabric thermal performance, could be hidden by the time of the inspection. Differently, in CS4 the working packages were broken down into much shorter sub-packages of about two-day build duration, allowing more frequent quality appraisals once they were completed.

4.5 Quality compliance procedures

Table 6 summarises the PQP framework concepts and challenges related to Quality compliance procedures. Each of them were observed in more than one case study.

Table 6 List of concepts and challenges related to Quality compliance procedures (Source: Author's own creation)

PQP Framework Concepts	Challenges related to Quality compliance procedures	Case studies				
		1	**2**	**3**	**4**	**5**
Quality results	Quality reports lacking focus on reporting quality issues related to the thermal performance of buildings as they are mostly developed upon checklists and site visit report templates.	✓	✓	✓		✓
Result analysis and actions	Failing to address defects affecting the thermal performance, which posed no apparent threat to programme and budget, and were not spotted by building control bodies.	✓	✓	✓		✓
	Ultimate compliance procedure assigned to building control bodies.	✓	✓	✓		✓
Continuous improvements	Lack of structure to feedback defects occurrences identified during the construction stage which could be used as a source in the risk assessment stages of future projects.	✓		✓	✓	✓

4.5.1 Quality results: On-site observations revealed that some defects had not been corrected. This was due to the fact that quality control tools (i.e. checklists and report templates) did not include those defects with potential to undermine the buildings' thermal performance. Figures 5 and 6 illustrate defects in housing units which had been considered satisfactory after being assessed for quality. These defects had not been spotted using the standard checklists. Apart from CS4, PQP did not provide a structured approach towards the prevention and correction of defects associated with the thermal performance of the dwellings.

Figures 5 and 6 Ill-fitted insulation layers and rupture of vapour control layer (Source: Author's own creation)

4.5.2 Result analysis and actions: In all case studies monthly project meetings were held and attended by the relevant stakeholders. The main purpose of these meetings was to assess programme progression and issues which had the potential to compromise the achievement of the project' milestones and budget. The quality issues raised in the quality officers' report, the quality checklist administered by the site management team, or "reportable items" from the BCB were also discussed. However, only outstanding quality defects which posed threats to programme progress or could potentially cause severe impact to the projects' budget, were addressed. The only exception were those cases where the defects spotted by BCB. In regard to defects affecting the thermal performance, the QO of CS5 mentioned "[…] we will have monthly meetings where we will lead and review all of those areas (building regulations and code for sustainable homes). So we can review any issues that (building control body), because they regularly inspect any issues, RI's (reportable items) that they flag up, we will query just to make sure if that there are some. If not, brilliant."

4.5.3 Continuous improvements: Results highlighted some limitations faced by the case study organisations when attempting to undertake a continuous process of quality improvement. In general, results showed an inconsistent recording of project quality data in the organisations' databases. Only in CS2, a defect logging system was being implemented. However, the only defects recorded were those identified in the snagging of the dwellings in practical completion and those reported by the actual tenants of the properties during the defects' liability period. At this stage, defects undermining the building's thermal performance were enclosed within the buildings' fabric, and therefore, they were not easily identifiable.

The research also identified that, in most case studies, the final construction stages were usually overlapped with the initial stages of a new project. This resulted in site management teams being rushed to the next project, not allowing enough time to fully discuss quality issues that could be avoided in future projects. These would not be discussed until the post-contract review, which relevant stakeholders such as SM would not normally attend. With this regard, the SM in CS5 reported: "There's always time as an issue at the end of the project […]. Having a full feedback meeting would go down very well but I got to do one in the last 10 years. […] We kind of finish one job and then we move into the next and they almost lap over."

4.6 Validation

The findings were validated by means of three focus groups attended by industry professionals and academics in the field. The focus groups were administered in two stages. The first stage sought to verify if the identified challenges were also experienced by the participants. A questionnaire was designed to check the likelihood and impact of the challenges, using a scale from 0 (not likely/no impact) to 10 (very likely/high impact). The average likelihood of occurrence was rated at 7.6, suggesting that the identified challenges were, on average, very common amongst the participants' projects. The average impact scored 8.1, suggesting that, according to the participants, the identified challenges had a significant impact on the delivery of energy performance of housing.

In the second stage, participants were invited to discuss their previous experiences regarded to the findings of this study. Participants also had the opportunity to report other challenges that had not been listed in this study. Through the open discussions, the participants unanimously agreed that the lack of definition of compliance procedures from HA pose a significant challenge to the achievement of thermal-related quality objectives. The over-reliance on BCB for quality control activities was also recognised as an additional challenge.

5. Discussion

5.1 Challenges of Project Quality Plans

The definition of quality compliance procedures was identified as the main driver to the implementation of the PQP, setting the authority for granting the achievement of quality objectives. The fact that most of the case studies (except for CS4) sought to exclusively achieve the statutory requirements in relation to thermal performance of dwellings contributed to undermine the implementation of PQP lead by the contractors. This study has identified the limitations of assigning the final quality control and compliance of quality objectives related to thermal performance to a third party, i.e. the building control bodies (BCB). Hackitt (2018) also highlights the inefficacy of BCB on assessing the achievement of quality requirements related to fire protection, even though granting statutory approval. This study points to similar trend in relation to the assessing the achievement of thermal performance related quality goals.

In line with previous research (Auchterlounie, 2009; Sommerville and McCosh, 2006), the study also revealed that the focus of PQP applied by the HA and the contractors was to reduce the occurrence of visible defects in the late stages of construction, being these more likely to become complaints by the tenants. On the other hand, defects affecting the thermal performance of buildings during the construction phase were mostly assessed by the BCB as the compliance awarding party. However, the study also highlighted that the shortage of resources deployed by the BCB impacted negatively in the identification of thermal defects and resulting in some not being addressed. Differently, CS4 adopted a more proactive and thorough approach, and appointed a dedicated quality officer to monitor quality issues, particularly during the building fabric construction. The use of an air pressure test once the building fabric was deemed weather-tight, but before internal lining installation, helped to effectively ensure airtightness and reduce heat loss, correcting defects with easy access and at low cost.

The impact of the procurement route on the ability to identify risks with the potential to undermine the achievement of the thermal related quality requirements was observed by the study. For instance, the traditional procurement method did not enable the early collaboration of important project participants, such as contractors, in relevant project milestones including the development of the design and technical detailing where buildability issues could have been avoided. Without the input of the referred stakeholders in the risk assessment, the potential thermal defects were not thoroughly identified and managed during the pre-construction phase. These findings were consistent with those from Lu et al. (2019), Gorse et al. (2012) and Karim et al. (2005), who also observed that the absence of key project stakeholders input in the definition of quality assurance procedures resulted in a greater number of defect occurrences. It was also identified that the risk assessment relied mostly on the experience and awareness of the project participants than the use of a structured approach based on logged thermal related construction defects from previous projects.

It was also identified that building quality could be affected by a high turnover of the subcontractors' workforce, added to the current skill shortages highlighted by the interviewees and existing literature (Greenwood et al., 2017; Tan et al., 2006; Love and Edwards, 2004). This contributed to a loss of quality standard awareness, undermining the final quality outcomes. Unremedied defects, such as the discontinuity of insulation and ruptures on the air and vapour barriers were often observed in the defect survey applied in this study. Tight programmes also impacted negatively on the application of quality control procedures, compromising the effectiveness and consistency of the quality control in key stages of construction relevant to the thermal performance.

Resources required to achieve quality standards are divided in three main categories: prevention, appraisal and correction (Josephson et al., 2002; Feigenbaum, 1991). Investing resources in prevention is an effective way to optimise resources required for appraisal and reduce correction costs. Although the quantification of resources dedicated to quality management was not part of the study, the research evidenced that most resources were allocated to the quality control and remediation activities in the late stages of the construction, such as the snagging process, and less resources were dedicated to the prevention of quality issues and upskilling of the workforce. This approach could had compromised the delivery of the expected quality as well as undermining the workforce's motivation and pride, as suggested by Atkinson (2002), Tofield (2012) and Brooks and Spillane (2016). A different approach was observed in CS4, where the workforce as well as the on-site management team were upskilled in the most adequate construction practices to mitigate the occurrence of thermal related defects identified in the risk assessment stage. In respect to statutory approval, in order to mitigate the identified conflict of interest and apparent lack of credibility of BCB, the current funding method should be reviewed. The direct appointment of the BCB by the contractors could negatively affect an independent and transparent quality appraisal.

The studies also investigated how quality metrics were defined and quality control tools, such as checklists, were implemented. Results suggested that in four of the five the case studies, the applied quality control tools did not provide a structured guidance and objective acceptance criteria to assess quality. In some occasions they were too generic and not adapted to the particular construction methods and sequencing of the projects. This could had contributed to recurrent occurrences of quality issues, as suggested by Sommerville and McCosh (2006), Johnston et al. (2014) and Enshassi et al. (2019). It is vital that quality control tools are designed to provide unequivocal interpretation of the acceptance criteria. The wording of the items embedded in the checklists should not leave room for interpretation or rely on common sense (Enshassi et al., 2019; Hoonakker et al., 2010).

Robust quality control procedures should also rely on appropriate frequency and timing of the implementation of quality control tools within the schedule of works. Results suggested that the inspection regime adopted by contractors in four out of five case studies, and by the BCB, were insufficient. Quality inspections were undertaken at a small number of key construction stages and were overly distant to each other. Due to the accumulated construction works completed between the inspections, building elements relevant to the thermal performance of the dwellings were already hidden by overlaying construction materials, thus undermining the visual appraisal of the desired quality standard. Although Atkinson (2002), suggests that overly distant quality control inspections can mask the identification of defects' sources and origins, studies providing a direct relationship between the frequency of quality control inspections and the identification of defects affecting the thermal performance of building fabric could not be found. Hackitt (2018), in a review of the UK Building Regulations, also identified the inadequacy of regulatory oversight and enforcement tools undermining the delivery of quality in construction projects. In order to overcome the referred challenges, it would be beneficial to commission smaller work packages where the subsequent quality appraisal would take place more frequently, therefore enabling a more effective quality control of building elements that are particularly important to the thermal performance of the dwellings.

Apart from CS4, the discussion of quality issues during the construction stage mostly occurred whenever they affected the achievement of the programme milestones or impacted on the project budget. Similarly, Jraisat et al. (2016) stated that contractors employ more effort on completing the works on time and on budget than focusing on achieving the defined quality standards. In most of the case studies, the detected defects were dealt within the projects, but no substantial procedures of sharing the learned lessons with other projects could be observed, impacting on potential continuous improvement. A standardised and robust quality assessment and reporting process would facilitate the benchmarking across different projects within and across companies of the sector contributing to continuous improvement towards achieving buildings' thermal performance.

5.2 Facilitating the achievement of building thermal performance

The following recommendations aim at improving the quality standards of the construction sector and the delivery of energy efficient buildings. They intend to help inform HA and contractors in commissioning and developing PQP with focus on thermal performance of dwellings, as well as potential UK policies, building regulations and standards.

The results suggested that the quality management approaches adopted in the majority of the case studies were not fully suited to address the quality issues undermining the thermal performance of the dwellings. The reliance on BCB to award quality compliance was perceived to be insufficient to ensure the achievement of quality objectives. It would be more beneficial if HA took the responsibility to procure quality by defining their own quality objectives and compliance protocol in addition to regulatory procedures. Contractors would then be encouraged to propose the allocation of resources and definition of the PQP tactics, such as the quality control procedures, to enable the achievement of the quality objectives, in line with the predetermined compliance protocol. It is believed that this flexibility on the application of quality management procedures is required to accommodate not only the managerial characteristics of contractors and subcontractors, but also to adapt to the project specific construction method and particularities. On one hand, HA's long-term strategic objectives related to thermal performance quality attributes and compliance procedures would be established and conveyed to contractors by means of the quality policy in the early stages of the procurement and tendering processes. On the other hand, the awarded contractor would be responsible to define the operational phases of the PQP with the contribution and collaboration of the other project participants, such as the design team, consultants, subcontractors, suppliers and HA's maintenance team.

In order to enable this shift of approach of the current quality management procedures, a significant change of culture must be undertaken, as also recognised by other studies (Tofield, 2012, Zero Carbon Hub, 2014). Another aspect to be taken into consideration is the impact of defects on the operational and maintenance costs, as well as the tenants' wellbeing and quality of life. This provides an additional incentive for HA to embrace this change of culture and increase the focus on quality, since social housing providers own the assets and consequently are responsible for their maintenance costs. Moreover, HA have a particular interest in the well-being of their tenants due to their long-term relationship, who would benefit from reducing their energy bills, improve their comfort and reduce fuel poverty.

This research also revealed different approaches amongst case studies to on-site training of the workforce and project stakeholders with the aim to improve quality. Upskilling project participants in thermal performance technical issues, such as the impact of discontinuity of insulation layers and ruptures on air and vapour barriers, would help to increase the technical knowledge, competences and awareness of quality objectives and associated risks. This could result in a more effective design and implementation of quality management procedures. Additionally, it would also indirectly contribute to people's motivation and a sense of pride to the successful completion of the assigned tasks, thus reinforcing the shift to a quality culture (Manata et al., 2020, Brooks and Spillane, 2016; Holt et al., 2000).

6. Conclusions

This study sought to investigate the reasons why quality defects affecting the thermal performance of dwellings still occur during construction despite the number of quality assurance procedures put in place by Housing Associations (HA) and contractors.

Results suggested that the adoption of statutory approval as the ultimate quality compliance related to thermal performance goals had a negative impact on the development and implementation of the PQP. This is due to the fact that the quality control and compliance roles had been shifted to third parties, i.e. building control bodies, diluting responsibility. It was evident that the PQP employed by HA and contractors were mostly used to mitigate visible quality defects that could be later identified by tenants. Equally, most quality appraisal efforts were concentrated in the final stages of the construction process, when the identification of defects affecting the thermal performance were already enclosed within the building fabric, therefore no longer visible.

The study also highlighted the shortage of skills across the industry, the lack of resources for upskilling the workforce in terms of their technical knowledge and awareness of quality procedures. In addition, the construction sector's high levels of staff turnover contributed to barriers to the delivery of the expected quality levels, undermining communication and retention of technical information.

Other challenges included the apparent minor importance given to the thermal performance related defects in project managerial meetings, as they were perceived as not affecting programme and budget, and the lack of a structured defect recording system for future analysis, learning from errors and benchmarking, thus undermining the development of systemic solutions.

6.1 Applications for the research

The research reported in this paper should be of interest to a number of key groups, including, social housing associations, housing developers, contractors, local authority (particularly the building control departments), and government policy makers.

Findings of this research demonstrate the importance of social housing associations to take responsibility of defining their own quality compliance procedures if they seek to improve the thermal performance of their buildings. They should ensure that contractors are responsible for providing evidence of quality compliance and this task is not entirely assigned to third parties, such as the building control bodies. In addition, results have demonstrated that both social housing providers and contractors are missing opportunities of continuous quality improvement by not recording and analysing quality defects, including those affecting the thermal performance, from project to project, and therefore more efforts need to be invested in defects investigation and reporting.

This study also identified limitations on the statutory quality approval process. Results suggest that a different method of funding building control bodies' activities must be adopted, ensuring that a transparent and independent quality appraisal is undertaken. Firstly, the resources allocated must be in line with the set of quality appraisal procedures, allowing sufficient time for quality inspections to take place on a more regular basis, before construction elements related to the building thermal performance are covered. Secondly, contractors should not have the option of choosing who the quality appraisal parties are, because this creates a clear conflict of interests between building control bodies and contractors.

6.2 Impact to society and environment

The UK social housing sector has engaged in a large-scale effort to reduce carbon emissions, mitigate fuel poverty and increase the comfort level of their tenants. This has been carried out mostly by means of upgrading heating systems in existing dwellings and improving thermal insulation of building fabric in new homes. Unfortunately, many factors such as inadequate quality during construction have proved to hinder the achievement of the intended energy saving targets. This study has explored the reasons related to quality management and has contributed by identifying areas of improvement in the definition and implementation of the PQP. By addressing these recommendations, it is believed that quality aspects associated with the thermal performance of the dwellings would no longer be overlooked and defects such as ruptures in air/vapour barriers, thermal bridging and discontinuity of insulations layers, would be prevented or identified in time to be corrected, thus reducing energy bills, fuel poverty and carbon emissions.

6.3 Future research

It is recommended for future research in this area that the findings of this study should be tested against a larger sample. This would either increase the generalisation of the research findings or perhaps enable the identification of new emerging concepts, thus contributing to a greater understanding of the challenges faced in the implementation of Project Quality Plans with focus on thermal performance in social housing projects in the UK.

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