Northumbria University

Department of Architecture, Engineering and Construction

Reducing the performance gap in energy efficient construction through improved project management

09028135

Submission Date March 2012

UNIVERSITY OF NORTHUMBRIA AT NEWCASTLE

SCHOOL OF THE BUILT AND NATURAL ENVIRONMENT

Reducing the performance gap in energy efficient construction through improved project management

A DISSERTATION SUBMITTED TO THE
SCHOOL OF THE BUILT AND NATURAL
ENVIRONMENT IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE
OF

Bsc (Hons) Building Project Management

By
09028135

March 2012

DECLARATION AND ACKNOWLEDGEMENTS

For the purpose of simplification the masculine gender is being used; it shall be taken to include the feminine gender.

The author would like to make acknowledgement to the following for their help, support and guidance in the redaction of this paper.

Mark Siddall for his guidance and support which were above and beyond a tutor's duty, from the initial idea through the conclusion of this dissertation.

Sarah Hudson, Pamela Jackson and especially Douglas Silva for their advice and time at the conclusion of this research.

ABSTRACT

Project managers and construction processes in general are adapting to new sustainable requirements, often materialised through certification tools. In spite of these, an important gap between designed and built performance has been recorded, with management as a key cause throughout Design & Planning, Construction and Operation.

Innovative processes however appear to offer solutions to bridge that gap. Passivhaus has proven to perform through Design & Planning and Construction, while Soft Landings addresses Operation. Their costs can be reduced through Lean, with the Integrated Design Process to secure coherence in and between these processes.

Based on the essence of these models, ten interviews have been conducted to evaluate process performance, looking at its correlation with building performance. Analysis of the data reveals that project following these best practice processes are those using certification tools known to perform best.

This dissertation suggests project managers as key role in the performance gap reduction through their process management and early and cross-disciplinary influence on clients and project teams.

CONTENT

LIST OF ABBREVIATIONS

APM	Association for Project Management
BSI	British Standards Institute
CDM	Construction (Design and Management)
CEPH	Certified European PassivHaus Designer
CIOB	Chartered Institute of Buildings
IEA	International Energy Agency
IPD	Integrated Project Delivery
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LEED	Leadership in Energy and Environmental Design
MHRV	Mechanical Heat-Recovery Ventilation
NEAT	NHS Environmental Assessment Tool (Department of Health, 2012)
PEP	Project Execution Plan
PH	Passivhaus
PHPP	Passive House Planning Package
PMV	Predicted Mean Vote
POE	Post-Occupancy Evaluation
PPD	Predicted Percentage of Dissatisfied
PROBE	Post-occupancy Review Of Buildings and their Engineering
RIBA	Royal Institute of British Architects
SAP	Standard Assessment Procedure
SBEM	Simplified Building Energy Model

GLOSSARY OF TERMS

BREEAM	The Building Research Establishment Assessment Method is a British sustainability certification model similar to LEED, elaborated below (BRE, 2011).
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Society for Sustainable Construction). Sustainable certification tool with Bronze, Silver or Gold level can be reached according to the total points awarded. Each criteria can reach up to ten points with an importance factor of one to three. A pre-certification is handed over based on documentation on the intentions, and the final certificate is awarded based on documentation review and sampling (DGNB, 2011).
Fabric	“The building fabric refers to the ceiling, walls, windows, floors and doors of a building.” Carbon Trust (2007, p.2)
LEED	First implemented in 2000 (Moskow, 2008), Leadership in Energy and Environmental Design is the US Green Building Council's sustainability assessment scheme, considering various elements such as energy, location, public transport connection or materials used (US Green Building Council, 2011). Various equivalents are BREEAM in the UK, ÖGNI in Austria, DGNB in Germany or Bâtiment Basse Consommation in France (Zira, 2010).
ÖGNI	Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft (Austrian Society for Sustainable Estates Management).The Austrian certification uses the DGNB tool with slight amendments to correspond to the national standards (ÖGNI, 2012).

Passivhaus	A clear distinction has to be made between the expressions ‘Passivhaus’ and ‘Passive House’. Although the latter is a correct English translation of the German word, a deliberate choice is being made not to use the English phrasing because of two incorrect implied interpretations: firstly, the word ‘Haus’ can be understood as ‘house’ or generally an occupied building. The Passivhaus standard applying to a wide range of building types including public infrastructure, retail or offices (Hodgson, 2008) in spite of starting off with domestic buildings, an interpretation reducing the applicability of Passivhaus solely to houses should be avoided. Secondly, despite being inspired by the passive systems of insulation and solar gain in Sweden (Hunt, 2011) a need of additional active elements has been expressed through the inclusion of a mechanical heat recovery ventilation system (Hodgson, 2008) to control the exit of heat in the air flow. Although this distinction is being outlined in the great majority of literature examined for this study, some have been found to do otherwise. The Scottish Passive House Centre (SPHC, no date) uses the terminology ‘Passive House’, while Zira (2010, p.10) considers mechanical ventilation being a passive system despite the need for electrical supply in opposition to natural ventilation.
Performance	In the context of this dissertation, performance refers to the fabric performance of buildings concerning their energy usage.
Primary energy	Naturally available resources (e. g. oil, gas or wind) used to produce energy carrier (Liphe4 and the Institut de Ciència i Tecnologia Ambientals, 2011).
PROBE studies	Post-occupancy Review Of Buildings and their Engineering. Evaluates the performance and adequate operation of a building through four aspects: the level of personal control,

	building responsiveness to user behaviour, building proportions and functional and superficial space distribution (Lützkendorf, T. and Lorenz, D., 2005).
Thermal comfort	The DIN EN ISO 7730 norm defines and measures comfort through Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), both subjective data gathered on the individual perceptions of well-being according to thermal ambiances parameters. An ideal ‘comfort span’ can be created through combinations of the following four parameters: ▪ The air temperature ▪ The radiant temperature (i.e. surface temperatures) ▪ Air speeds and turbulence ▪ Humidity. (Passivhaus Institute, 2009)
U-Value	The amount of heat lost through materials. The lower the value, the more insulating a material is (Oppenheimer, 2008). U-Values are expressed in W/m²K (Irish Energy Centre, no date).

GLOSSARY OF UNITS

ACH	Air Changes per Hour. It is one of the two expressions to measure airtightness. It corresponds to the number of times the total air volume of the building can be changed in an hour at 50 Pascal. ACH = 60 * fresh air flow in the building [m^3/min] / volume of the building [m^3] (The Engineering Toolbox, 2012; Karlp, 2011). It is the airtightness-unit used by Passivhaus, with a requirement of 0.6 ACH.
kWh/(m^2a)	The amount of energy per square meter per year. Can also be written kWh/m^2/a or kWh/(m^2.yr).
m^3/m^2/h at 50 Pascal	Air leakage. Based on a surface ratio loss of air of the building. It is the airtightness-unit used in the Approved Documents, Part L, with a requirement of 10.0 m^3/m^2/hour at 50 Pa (NBS, 2011, p.21).
W/m^2K	The amount of heat lost through a material in the U-Value

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 PROBLEM STATEMENT

Construction processes and the role that project managers play in it seem to be clearly defined and are to be found in numerous literature sources (Lewis, 2011; APM, 2010; CIOB, 2010; British Standards Institute, 2010; Walker, 2007). Present throughout all project phases, project managers use both soft and hard skills to plan, monitor and control the project, its processes and team members.

This role however is encountering changes through new sustainability demands: recent resource and climate change studies lead to a raised public and private awareness, resulting in the introduction of new standards across industries to tackle the highlighted issues (Zero Carbon Hub, 2010). The built environment responded amongst others with regulations, 'sustainability certification systems' such as BREAAM, LEED and the Code of Sustainable Homes and low-energy building standards.

Measurements undertaken amongst others by the PROBE studies (Usable Building Trust, 2012) outline the clear gap between designed and as-built performance in these 'green' buildings, more so with general certification tools than low-energy certifications. Although no strong research has been conducted on the causes of this performance gap, management has been identified as key reason and can be identified in three phases: Design & Planning, Construction and Operation.

1.2 AIM

In response to this problem, this dissertation will explore the following hypothesis:

> Hypothesis H_1 – The reduction of the performance gap through innovative processes by project managers.

1.3 OBJECTIVES

In an attempt test the hypothesis, the following steps will be taken:

- Analyse existing innovative processes in literature which could respond to the performance gap causes.
- Extract the essence of these processes to create a single coherent model.
- Explore the correlation between best practice processes usage and the performance gap reduction.
- Assess how project managers are key to the implementation to these processes.

1.4 DISSERTATION STRUCTURE

First a literature review is conducted in Chapter 2, retracing project management as known, the new sustainable requirements and their failing implementation demonstrated by the performance gap. After analysis of the causes of the performance gap, four best practice processes will also be explored and analysed to offer a possible solution to the management deficiencies which emerged.

Chapter 3 will explain the methodology chosen, whereby the literature review sets the ground for theoretical findings which will be tested in practice in Chapter 4, including data gathering and analysis.

Chapter 4 will analyse the collected primary data to attempt an answer to the set hypothesis.

A conclusion will sum up the research process of this dissertation, relating the answer offered to the hypothesis and exploring further steps to be taken.

2 THEORY: LITERATURE REVIEW

The literature review will firstly analyse the project process and the project manager's business-as-usual tasks within it. This set order however is changing to adapt through new sustainable requirements, which are mostly implemented through certification tools in construction. Post-Occupancy Evaluations however reveal that these don't perform as-built as they were designed, general certification tools more so than low-energy certification tools which are based on measured values instead of estimates. Process and management are the main aspects highlighted across the performance gap causes, which can be broken down in three phases: Design & Planning, Construction and Operation. Four best practice processes are analysed to offer a solution to the highlighted causes.

2.1 PROJECT PROCESS

Lewis (2010) defines projects as sets of unique and non-repetitive tasks to achieve a purpose, with a start and an end. Construction projects follow a similar process starting with client's requirements identification followed by design, construction, handover and post-completion stages. Numerous institutes and authors proposed to split the whole process in different stages according to the trade they focused on (Curtis, 2011, p.20; Lewis, 2011, p.36; British Standards Institute (BSI), 2010; CIOB, 2010; RIBA, 2010).

The detail range and segregation varies considerably, but many institutions and authors (CIOB, 2010, p.XX; Ballard and Howell, 2003, p.121; IEA-SHC, 2003, p.20) mitigate their rigid linearity by emphasising the overlapping of the phases, as illustrated in Figure 2.1. Phases do not have to be finished before the next ones start; many management tasks in fact overlap on many phases, e.g. scheduling (CIOB, 2010).

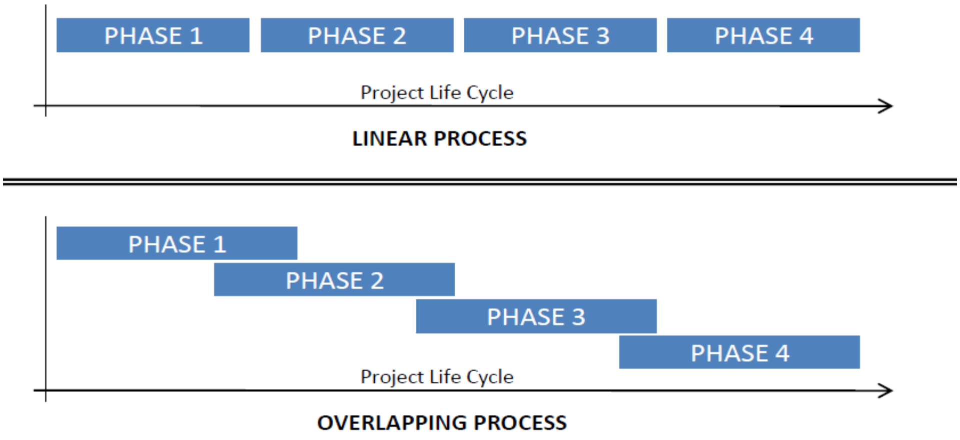

Figure 2.1: Linear and overlapping process

Adding to this overlapping, the same authors insist on iteration which is based on the feedforward and feedback of information loop-wise between the phases (Figure 2.2).

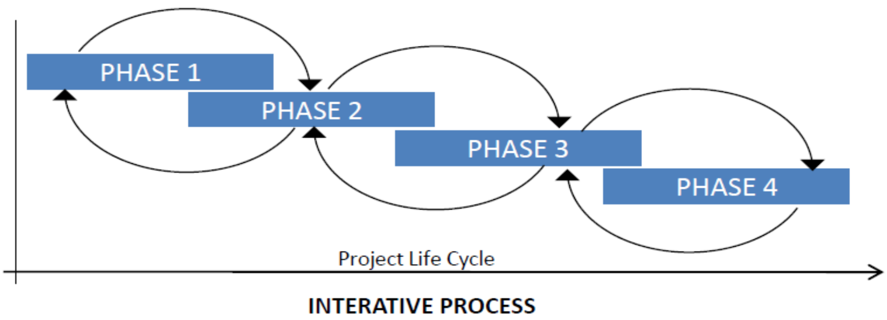

Figure 2.2: Iterative process

The International Energy Agency (IEA-SHC, 2003) offers integrational processes as an evolution of iterative process (Figure 2.3). These will be further explored in Chapter 2.5 as part of best practice processes.

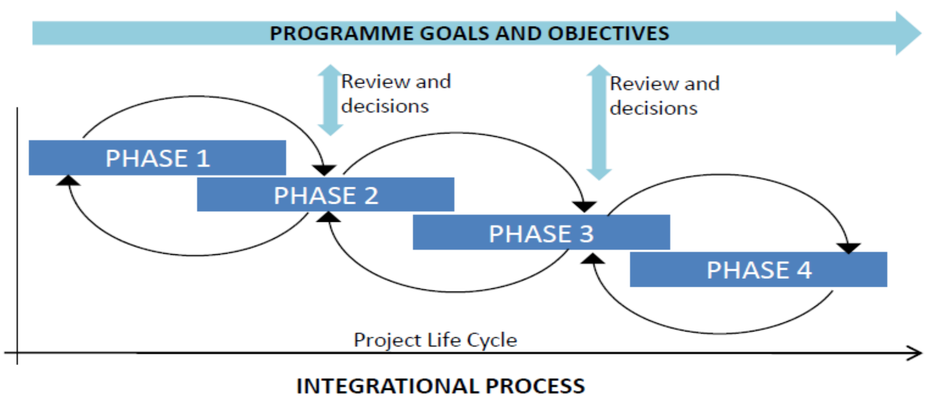

Figure 2.3: Integrational process (Adapted from IEA-SHC, 2003)

Figure 2.4 compares three project phasing, selected because of their relevance to the project management profession. Although the RIBA model has been developed for architects, this study will focus on it as it is the most widely used across all trades.

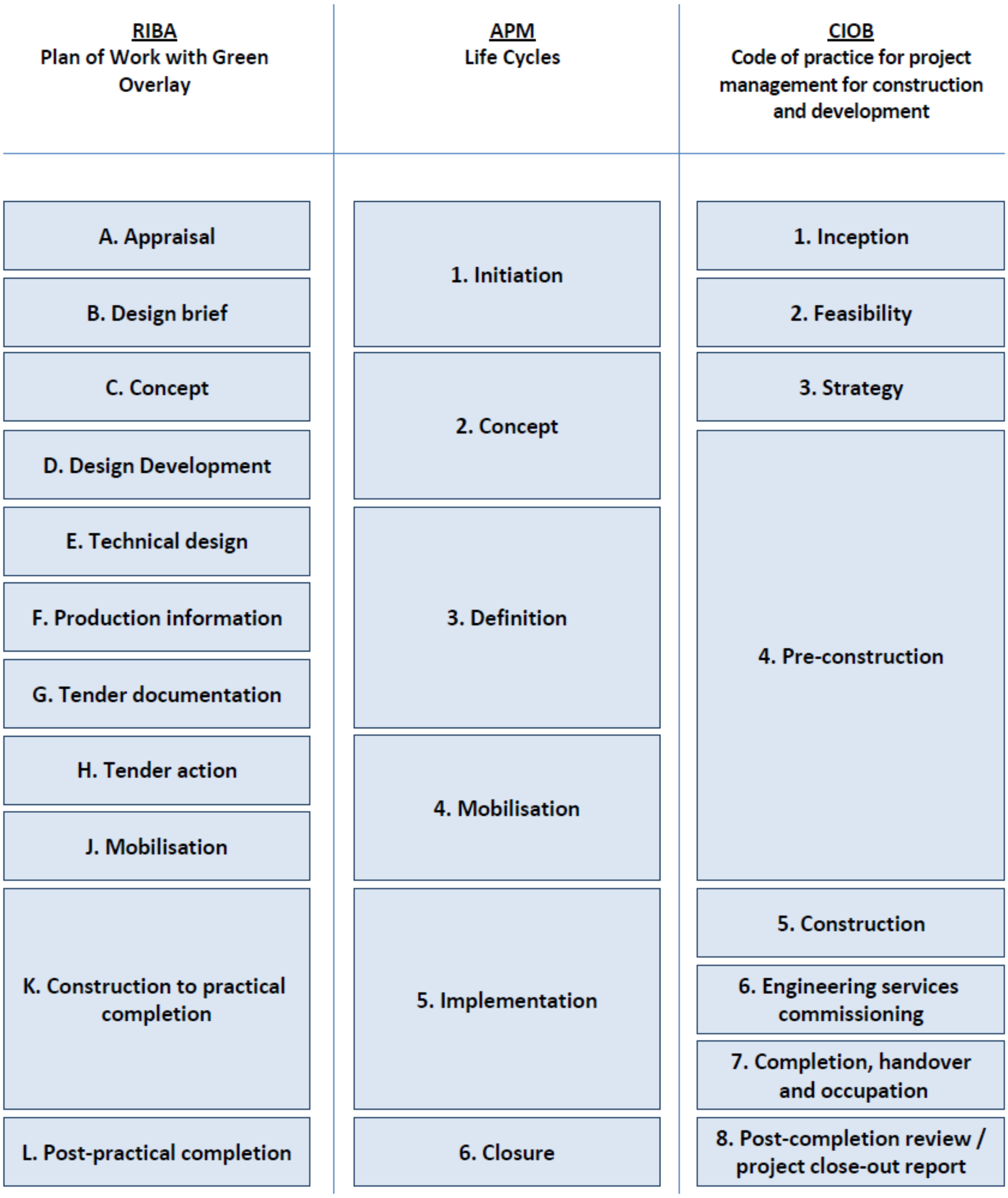

Figure 2.4: Construction process (Based on CIOB, 2010, Curtis, 2010 and RIBA, 2011)

2.2 Project Manager's Role: Business-as-Usual

Project managers are involved from the start of construction projects. Their role is to ensure the execution of clients' needs, while these might differ from what they want

(Walker, 2007). Whilst Walker (2007) defines the clients' needs in terms of the end product, a smooth delivery of the whole project process insures clients' trust, which can lead to further projects.

The main features of project managers' role are organising, planning, monitoring and controlling of processes and stakeholders (BSO, 2010; CIOB, 2010; Lewis, 2010; Walker, 2007). Stakeholders are all those who are affected in any way by the project (Chinyio and Olomolaiye, 2010). The IEA maps the project manager's environment, including processes, client's objectives and stakeholders into goals, activities and actors according to Figure 2.5. This will be further developed in subchapter 2.5.4.

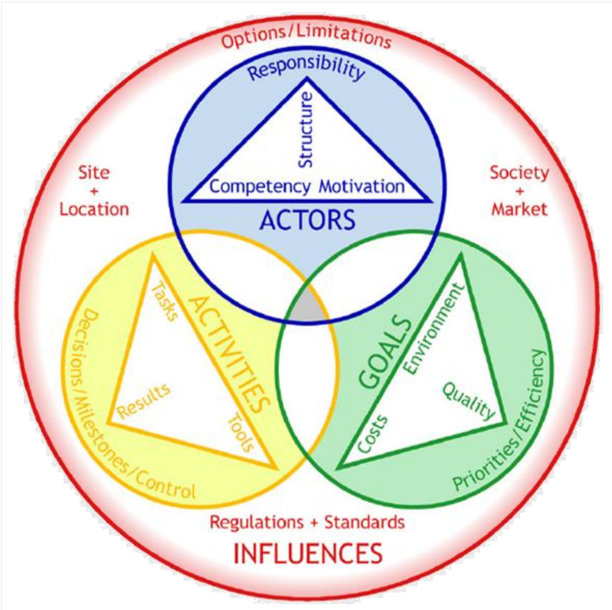

Figure 2.5: Interrelation and interdependence of structural elements of a project environment IEA-SHC (2003)

Project managers have two types of skills to achieve their tasks: hard skills, which is the knowledge and handling of tools and systems, and soft skills, based on human relationships. Whilst hard skills are more tangible, Paverz et al. (2010) comment on an overbearing focus on those at the expense of soft skills. Walker (2007, p.67) develops further by saying that the command of soft skills is the condition for the validity of hard skills. Table 2.1 summarises hard and soft skills project managers require in construction projects.

Hard skills	Soft skills
Organisation	Communication
Planning	Co-ordination
Measuring	Leadership
Monitoring	Motivation
Controlling	Delegation
Use of PM tools (mostly computerised)	Negotiation
Reporting	Initiatives
Scheduling	Advising
	Early problem identification
	Cultural understanding
	Diplomacy

Table 2.1: Project management hard and soft skills (researcher's own)

The tasks expected from project managers vary according to the projects, the consultants contracted by the clients, and their own position towards the clients: project managers can be in-house or act as consultants for clients (CIOB, 2010). This influences how much decision-power they have in projects and where their loyalty lies (Walker, 2007, p.72). Overcoming the project team members' individual loyalties towards their companies by making them prioritise the clients' objectives is one of the challenges project managers have to face.

Table 2.2 summarises the tasks project managers can encounter in construction projects, based on the descriptions of APM (2010), BSI (2010), CIOB (2010), Lewis (2010) and Walker (2007).

Present from inception until post-practical completion with an involvement in a large number and variety of tasks, project managers create coherence between the project elements and actors through management of its process, using hard and soft skills to plan, monitor and control work and project members. Their scope however is currently expanding to answer to new sustainable requirements in the construction industry.

Task	A. Appraisal	B. Design Brief	C. Concept	D. Design Develop.	E. Technical Design	F. Prod. Info.	G. Tender doc.	H. Tender Action	J. Mobilisation	K. Construction to practical completion	L. Post-practical completion
Development of own brief if inexperienced client & experienced PM	x										
Stakeholder analysis	x										
Project need assessment	x										
Requirement identification	x	x	x								
Sustainability inquiry	x	x	x								
DQI	x	x									
Business case	x	x									
Life-Cycle Costing	x	x	x	x	x						
Risk assessment input	x	x	x	x	x	x	x	x	x	x	
Set up and implementation of procurement route	x	x	x								
Project team definition	x	x	x	x	x	x	x	x			
Measuring and monitoring of design team	x	x	x	x	x	x	x	x	x	x	x
Project Execution Plan (PEP)[1]		x	x	x	x	x	x	x	x	x	x
Objectives and constrains analysis		x	x								
Feasibility studies (incl. H&S, site, cost, schedule, risks, environmental impact)		x	x	x							
Site selection and acquisition		x	x								
Project brief management (project outline, risk, objectives, quality)		x	x								
Design brief management (brief, budget and master programme)		x	x								
Funding and investment appraisal		x	x								
H&S coordination (with CDM co-ordinator and design team)			x	x	x	x	x	x	x	x	
Project phasing			x	x							
Capital cost plan			x	x							
Information gathering (design team, costs, reports etc.), documentation and reporting			x	x	x	x	x	x	x	x	
Resource identification				x							
Solutions optimising & detailing				x	x	x					
Statutory and legal compliances (incl. planning permission in some cases)				x	x	x	x	x	x	x	x
Measuring and monitoring through system and processes				x	x	x	x	x	x	x	x

[1] Can include plans, procedures, processes, roles and responsibilities, quality requirements and control measures, project definition and brief, objectives, business plan, financial analysis (market, necessary procedures, sponsors), procurement strategy, risk assessment, scheduling, project team scope, design and budget reconciliation, project method statement, H&S, communication and information (CIOB, 2010)

Task	A. Appraisal	B. Design Brief	C. Concept	D. Design Develop.	E. Technical Design	F. Prod. Info.	G. Tender doc.	H. Tender Action	J. Mobilisation	K. Construction to practical completion	L. Post-practical completion
Project handbook				x	x	x	x	x	x	x	x
Change management				x	x	x	x	x	x	x	
Site establishment organisation							x	x	x		
Project team selection, appointment, integration, motivation								x	x	x	
Pre-start meeting for project team								x			
Awareness of meetings									x	x	x
Fee payment management									x	x	x
Benchmarking									x	x	x
Site works monitoring and reporting										x	x
Commissioning preparation							x	x	x	x	
Facilities Management definition								x	x	x	
Commissioning management (testing and checking)										x	x
Management of defects correction											x
Defects report system for client during liability period											x
Closing execution and finances											x
Handover of responsibilities to client											x
Training of users & staff											x
Migration management											x
Project reviews & Lessons learnt											x

Table 2.2: Project management tasks in construction projects, based on the RIBA phasing (2011)

2.3 DEMAND FOR SUSTAINABILITY

Key publications from the main construction bodies have recently been updated to introduce new tasks related to sustainability demand (CIOB 2002 and 2010; RIBA 2008 and 2011). This study, in an attempt to clarify the causes of these developments, will define sustainability and its increased level of awareness with governmental reaction which then lead to carbon and energy reduction in the built environment through various initiatives.

2.3.1 DEFINITION OF SUSTAINABILITY

Whilst many definitions exist, numerous authors (Edwards, 2010, p.26; Lützkendorf and Lorenz, 2005, p.213) still cite the Brundtland Report (1987), defining sustainability as a “development that meets the needs of the present without compromising the ability of future generation to meet their own needs”. Three aspects, designated as the ‘triple bottom line’ (Elkington, 1997, cited in Christopher, 2011, p.241; Lützkendorf and Lorenz, 2005, p.213) have been identified to reach this: the environmental, economic and social. Whilst this model exists in various forms and similar models have been created (see Appendix 1), these three values seem to be commonly shared when defining sustainability. Adding to Brundtland’s definition, it can be argued that sustainable construction should not just address needs but also improve the quality of life (Grundey, 2008).

2.3.2 FROM CLIMATE CHANGE TO CARBON EMISSION AND ENERGY CONSUMPTION

Official reports and reviews based on the latest scientific analyses, such as the Stern Review (2006) and large mediatisation such as the documentary An Inconvenient Truth (2006) have recently increased awareness on the impact our current lifestyle has on the environment. Governments across the world[2] chose to centre their attention to carbon emission and energy consumption to minimise this impact.

Carbon emissions correspond to the release of CO_2 into the atmosphere, accelerating the green-house gas effect responsible for global warming (Edwards, 2010, p.3). Energy consumption, representing 98% of CO_2 emissions in the U.S. (U.S. Energy Information Administration, 2011) is the main cause of carbon emission and increases in a nearly-identical rate.

Building operation alone is responsible for 40-50% of the overall energy consumption, without even including building or disposal processes and resources (Edwards, 2010 p.85; Great Britain. HM Government. Department for Business, Innovation and Skill and Department of Energy and Climate Change, 2010; Gifford,

[2] Examples of Governmental action plans: Internationally, the Kyoto Protocol, agreed on by 193 parties (UNFCC, 2011); on a European basis, the Action Plan for Energy Efficiency has been adopted (Commission of the European Communities, 2006). In Germany, the EnEV (Energy Saving Ordinance, 2005, cited in Zira, 2010) can be found whilst the UK is is the Zero Carbon Hub (2010) and Energy White Paper (2007, cited in Zira, 2010).

2009; Bruhns, 2003; OECD, 2003, cited in Lützkendorf and Lorenz, 2005) therefore highlighting the importance of the reduction of energy consumption in the built environment which will be the main focus of this study.

2.3.3 SUSTAINABLE CERTIFICATION AND LOW-ENERGY

In response to the new sustainable demand and the built environment's vast energy consumption, certification models have emerged across the world. They can be divided in two classes:

- General sustainability certification
    - BREEAM (United Kingdom)
    - LEED (United Stated)
    - ÖGNI (Austria)
    - DGBN (Germany)
    - Code of Sustainable Home (United Kingdom)
- Low-energy certification
    - Passivhaus (international with German origin)
    - Niedrigenergiehaus (Germany)
    - Niedrigstenergiehaus (Austria)
    - Minergie (Switzerland)

The terms are briefly described in the Glossary of Terms.

This list is by no means exhaustive. The general sustainability assessment has a broad range of criteria which are set in a rating system where points are earned for achieved targets such as the installation of bicycle racks or the use of recycled materials, whilst low-energy certification focuses upon the energy in use, often described in kWh/(m²a).

2.3.4 CONCLUSION ON SUSTAINABILITY

The increased sustainability awareness and demand resulted in various approaches to reduce carbon emission, covering the 'triple bottom line' (Lützkendorf and Lorenz, 2005, p.213) either through a wide range of criteria or focusing on energy consumption to tackle carbon emissions, which also impacts on the environment

(less emissions and resource preservation), the economy (low running costs) and the society (higher comfort and ‘green’ image).
With an increasing popularity in certification systems as tools for sustainable construction is an important step towards meeting the carbon reduction targets, the quality these projects are being delivered with can be interrogated.

2.4 Are Green Buildings Performing?

With a large amount of buildings having been built using sustainable certification systems, the quality of their end result can be challenged. The most objective and reliable evaluation can be made from their energy usage, upon which post-occupancy evaluations (POEs) focus. The Usable Buildings Trust (Bordass, 2009) and the Zero Carbon Hub (2010) have executed a significant amount of POEs, revealing a gap between designed and built performance. However, this gap is less present in low-energy certified buildings such as Passivhaus. After offering an explanation for that difference, causes for the gap overall will be analysed.

2.4.1 Low-Carbon Buildings’ Performance

The Elm Tree Mews POEs (Bell, 2011; Lane, 2011) and the Usable Buildings Trust’s (2012) PROBE studies (see Glossary of Terms) are amongst the most published POE results, both measuring domestic buildings which used general sustainable certification systems. Figure 2.6 and Figure 2.7 compare carbon and energy values as set in the design to the as-built.

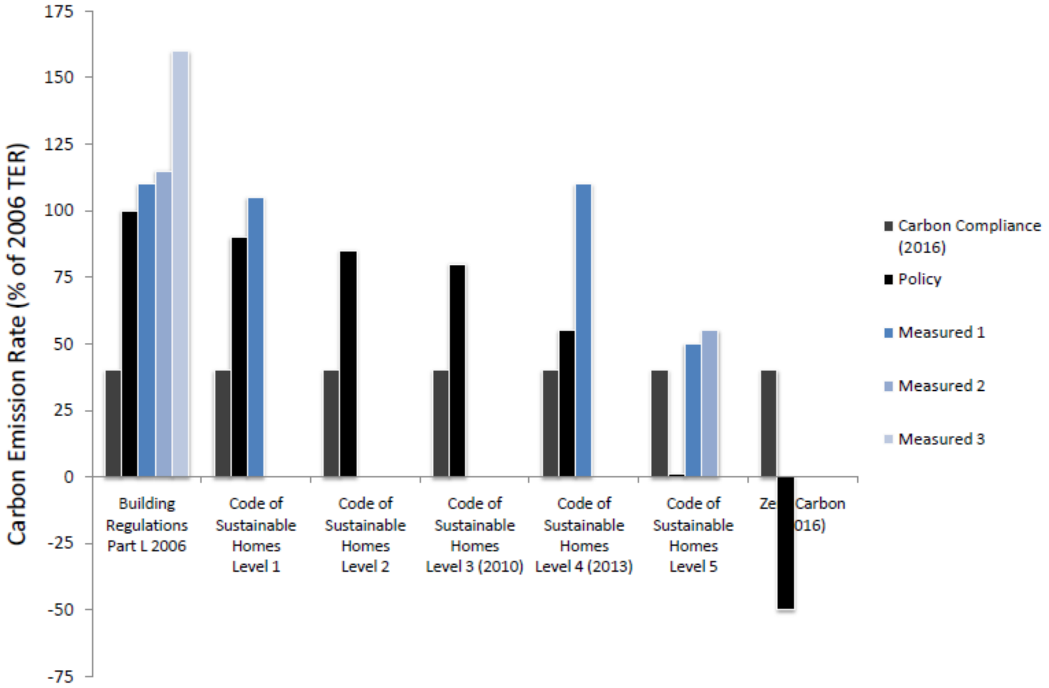

Figure 2.6: Performance gap between aimed policy values and values measured on constructed projects (Adapted from Bell, 2011)

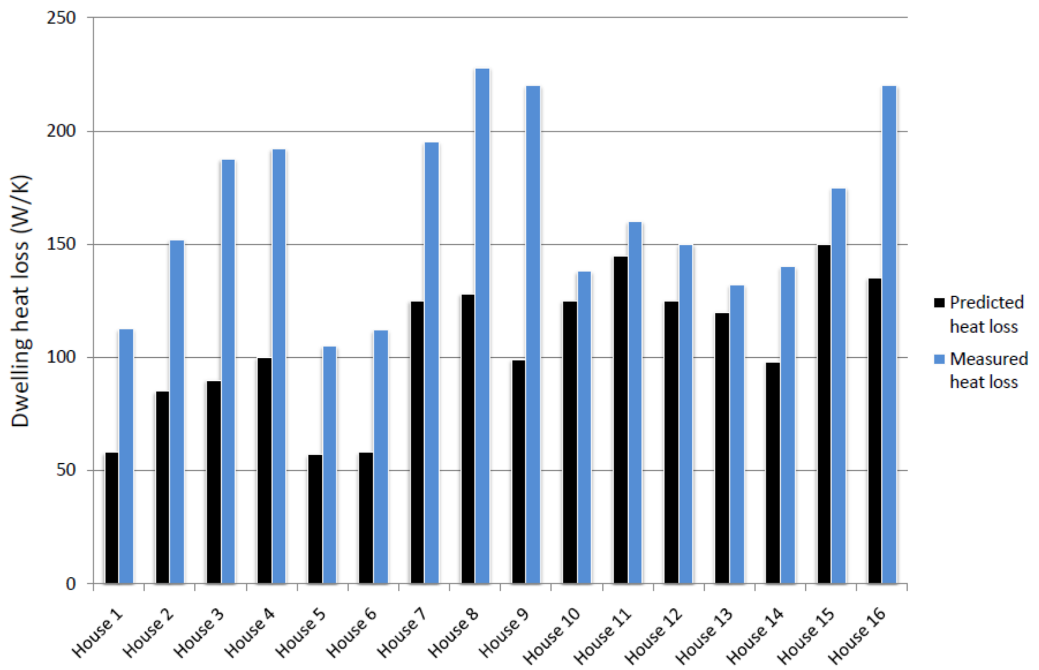

Figure 2.7: Predicted vs. Measured whole house heat loss for 16 dwellings[3] (adapted from Zero Carbon Hub, 2010)

[3] All dwellings are built to standards between Part L 2006 Building Regulations to Levels 4 and 5 of the Code for Sustainable Homes (Zero Carbon Hub, 2010).

Both reveal an important difference known as performance gap. Values in Figure 2.7 rang from 10% to 125%, whilst only five are situated between 10% and 15% as illustrated by Bell (2011) in Figure 2.8.

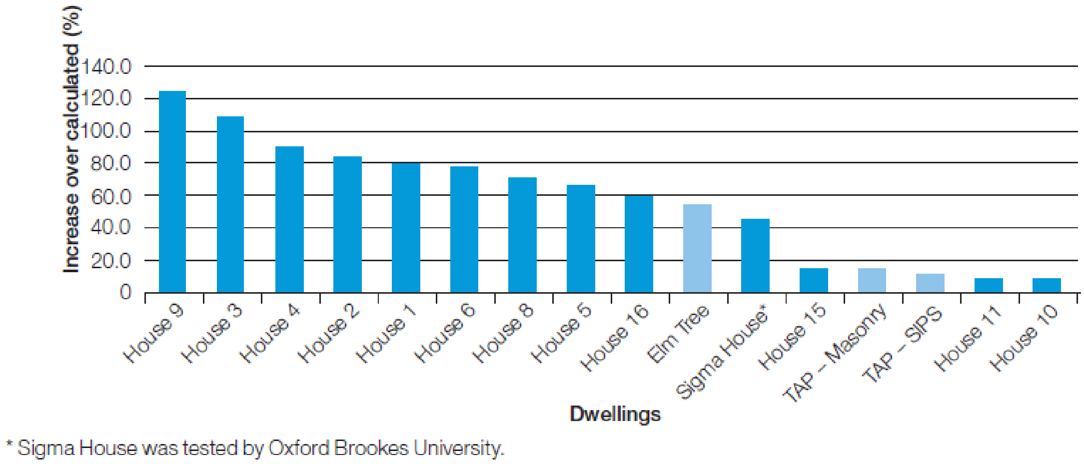

Figure 2.8: Predicted vs. measured whole house heat loss – percentage discrepancy in decreasing order (Bell, 2011, p.80)

In spite of this significant performance failure, are there any examples supporting the feasibility of low-carbon and energy targets?

2.4.2 Low-Energy Buildings' Performance

This study analyses the performance gap through domestic data due to availability although the focus will be on non-domestic buildings over £500,000, as project managers appear to be appointed over this threshold (Hall, 2012). Whilst little measurements have been executed on non-domestic buildings due to their important cost (Zero Carbon Hub, 2010, p.19), Figure 2.9 compares schools to set benchmarks and the BSF framework target.

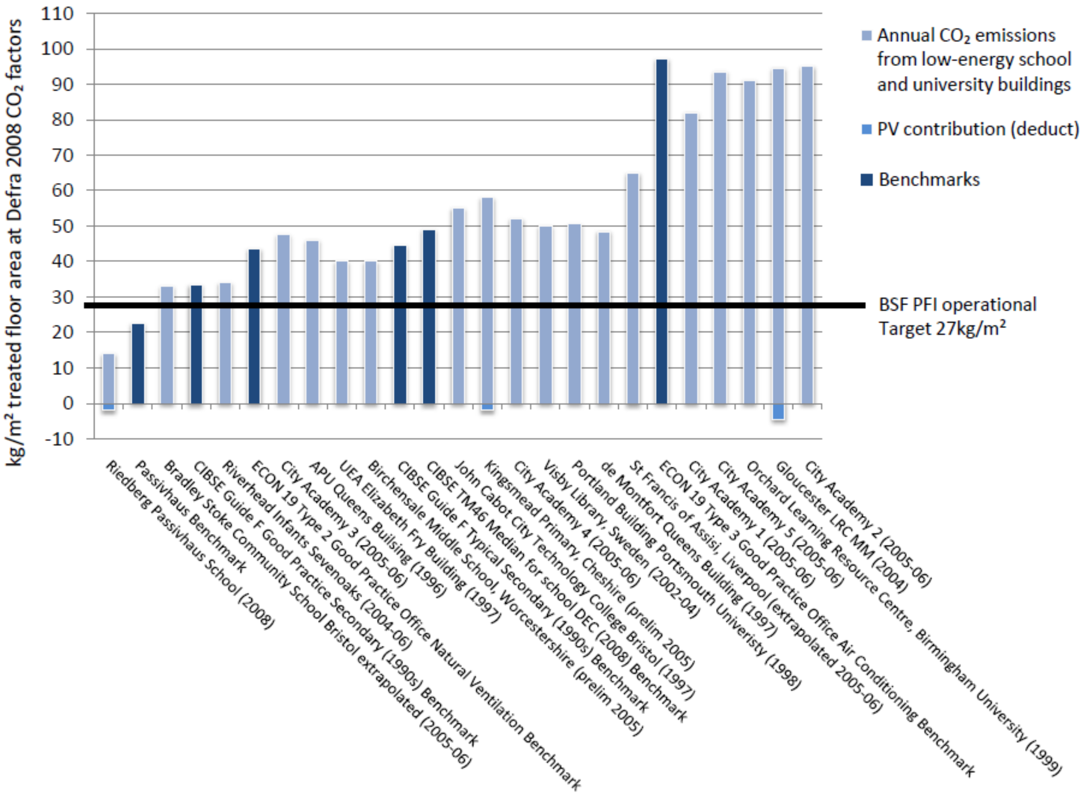

Figure 2.9: Annual CO_2 Emissions of Low-Energy Schools (based upon Bordass, 2009)

Figure 2.9 reveals only one school under the BSF performance requirements: a Passivhaus school. The Passivhaus performance will therefore be further explored in Figure 2.10 through POEs on 32 Passivhaus certified dwellings.

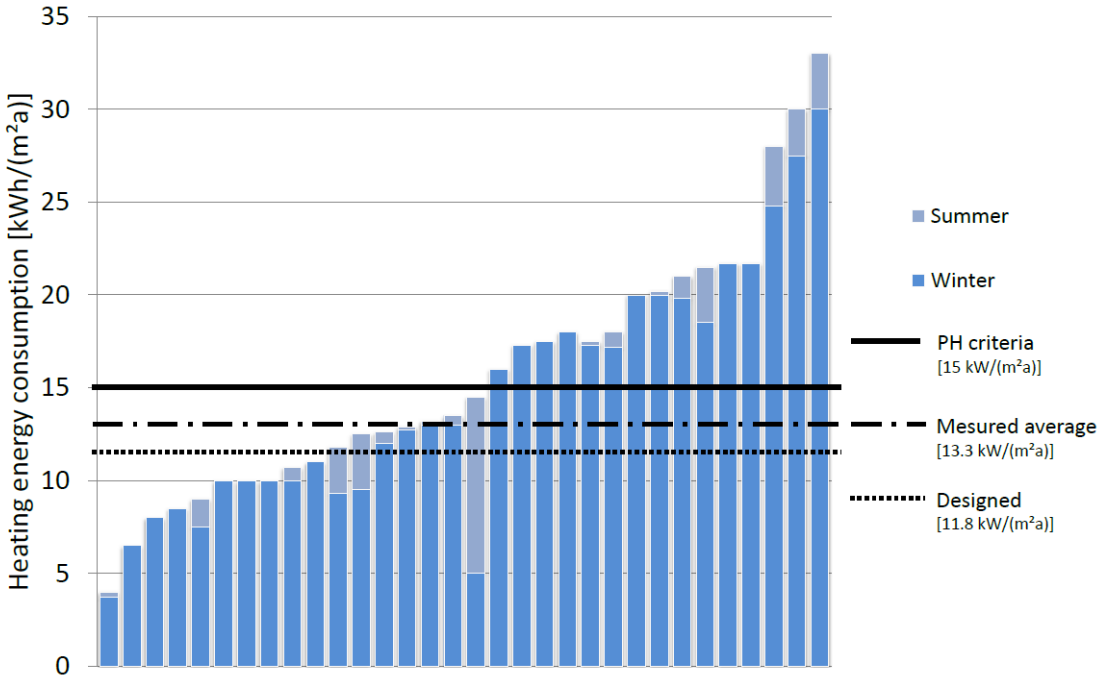

Figure 2.10: Predicted vs. measured whole house heat loss for 32 Passivhaus dwellings (based upon Feist, 2005, p.78)[4]

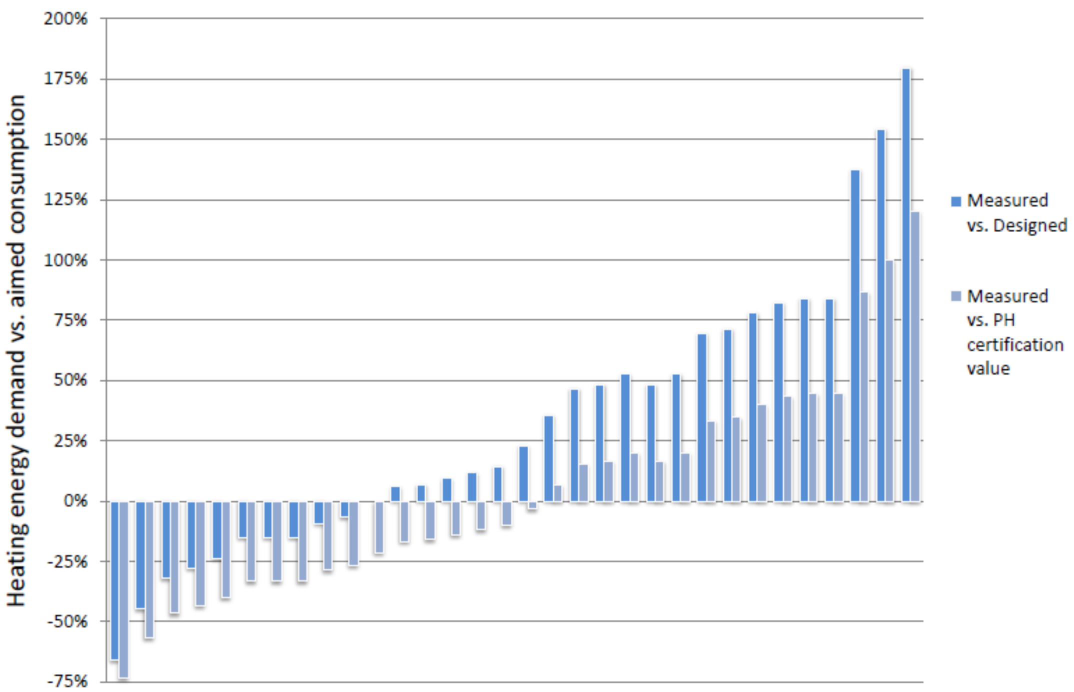

Figure 2.11: Predicted vs. measured energy consumption of Passivhaus dwellings in percentage (based upon Feist, 2005)

[4] The designed value is lower than the 15 kW/(m²a) targeted to allow for an error margin in the execution, which would not compromise the certification.

While caution is required when comparing Figure 2.10 to the previous ones due to different sources, where results might be influenced by different measuring techniques, Passivhaus dwellings seem again to have a good performance average. Excluding outstanding differences due to occupant behaviour (Feist, 2005) and considering the targeted value of 15kWh/(m²a), it could be concluded that half the dwellings performed better than aimed for, the other half being within a 50% performance gap margin as illustrated in Figure 2.11. Passivhaus will therefore be further explored to understand the difference in performance to other sustainable approaches.

2.4.3 PASSIVHAUS

Instigated by Dr. Wolfgang Feist and Bo Adamson in the late eighties, Passivhaus is a low-energy and high-comfort standard aiming 70% to 90% energy saving compared to the current building stock (Isover, no date; Passivhaus Institute, 2009) based on restrictive values to achieve certification (Feist, 2011):

Criteria	Maximum Value
Space heating demand Or building heat load	15kWh/(m²a) 10W/m²
Useful cooling demand	15kWh/(m²a)
Primary energy demand	120 kWh/(m²a)[5]
Building airtightness	0.6 ac/h-1
Excess temperature (> 25°C) frequency	10%

Table 2.3: Passivhaus criteria. (Based upon Feist, 2011)

Passivhaus uses PHPP, the Passivhaus Planning Package (Passivhaus Institute, 2011b), to assess building efficiency. In form of an excel-spreadsheet, it requires the input of numerous values including building location, orientation, surfaces according to type, materials with their U-values, etc. and calculates automatically the performance based upon this (Feist, 2011). Thermal imaging and pressure tests are used throughout the construction and commissioning to validate the performance values.

[5] If sufficient proof is provided, non-domestic buildings can be assessed and certified individually while requiring more than 120 kWh/m²/a when is it justified (Feist, 2009).

LEED and BREEAM certifications on the other hand are based on estimates at the design stage based on SAP (Zira, 2012) without measured evidence. This leads to major investments in elements perceived as efficient (e.g. solar panels) to the detriment of actual efficiency measures (Gifford, 2009) and to a lacking sense of obligation towards quality assurance on site.

Since the realisation of the first four certified houses in 1991 in Kranichstein, Germany (Hunt, 2011) 30,000 buildings, of which around 10% are certified, have been built or refurbished to the Passivhaus standard (Oppitz-Plörer, 2011) following the six main principles illustrated Figure 2.12.

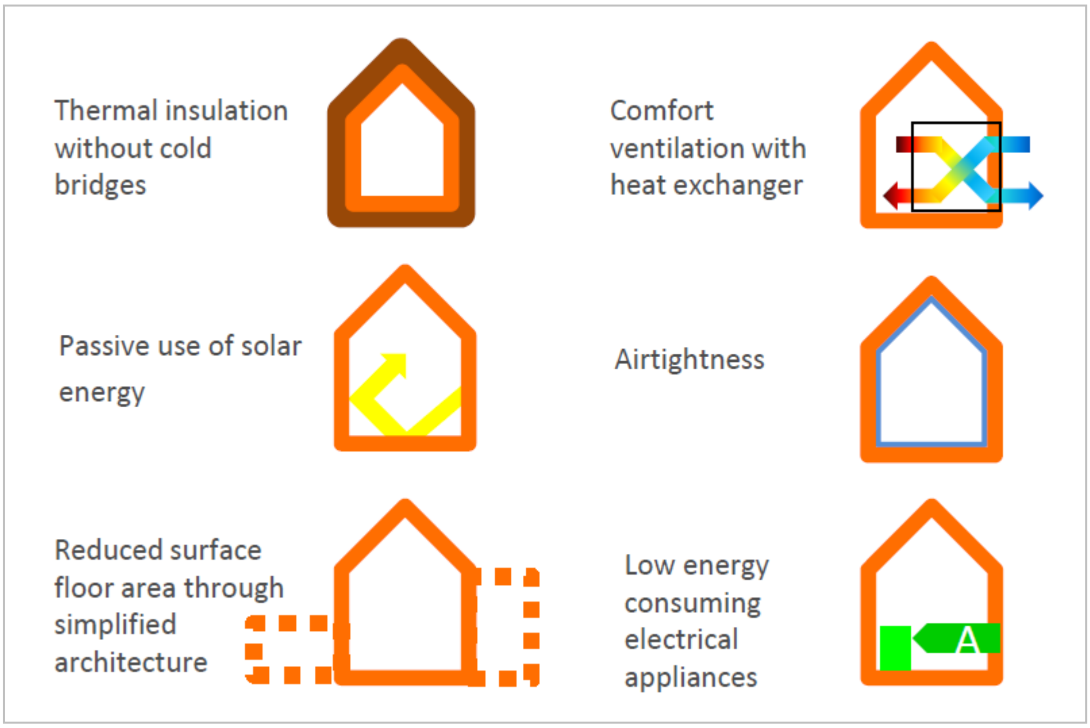

Figure 2.12: Passivhaus principles (researcher's own)

Whilst detailed technical explanations can be found in Appendix 2, it can be concluded that Passivhaus and low-energy certification processes are focused on fabric efficiency and high quality assurance including as-built measurements to achieve certification. This can explain the difference in achieved performance in comparison to sustainable certificates such as BREEAM.

2.4.4 Causes of the Performance Gap

Although to different levels, the performance gap appears to be a global issue, with its extent however still at early understanding stages (Gardiner, 2011; Lane, 2011) and causes yet even less explored. Various explanations can be found in recent literature (Gardiner, 2011; Lane, 2011; Menzes, 2011; Zero Carbon Hub, 2010; Usable Building Trust, 2009), including insufficiency in following areas:

- Detailed design
- Accuracy of SAP
- Consideration for the services as a whole system
- Quality assurance manager
- Process integration
- Execution standard
- On-site learning and training
- Communication
- Calculations, design and construction control
- User-understanding of the building and systems
- Accounting for unregulated and behaviour-related energy use
- Regulation of systems according to seasons
- Understanding of the user rhythm.

Although the blame is often orientated towards design and construction (Zero carbon Hub, 2010), this non-exhaustive list highlights occupants' behaviour and facilities management as third main performance gap cause (Benich, 2011), which will be associated as operation for the need of this dissertation. Operational influence on performance is also demonstrated by the use of testing methods which are deemed scientifically more accurate because of the exclusion of this factor, such as the co-heating test (Lane, 2011).

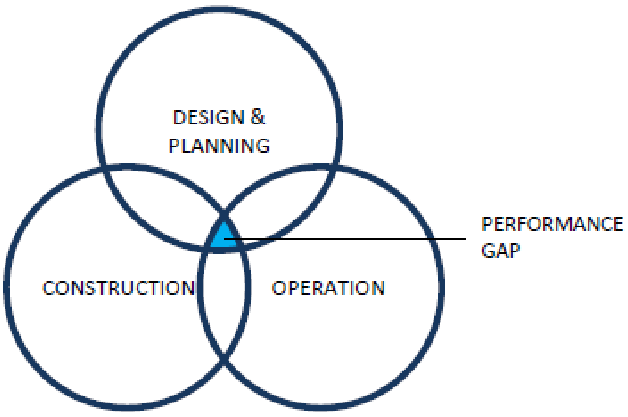

Figure 2.13: The three categories of performance gap causes (researcher's own)

Education and training could be added to the three causal areas illustrated in Figure 2.13 (Zero Carbon Hub, 2010) but it is the author's choice to target issues within projects teams' scope and direct influence. While blame is mostly on the operative side of design, construction and operation, Lützkendorf and Lorenz (2005, p.222) highlight the impact of management through all phases on the performance gap, leading back to the key role of project managers in its reduction.

2.4.5 Conclusion on the performance gap

POEs of 'green' buildings revealed a substantial gap between designed and as-built performance (Bell, 2011; Zero Carbon Hub, 2010; Bordass, 2009). This appears to be less the case when using low-energy certification tools due to focus on fabric and the measurement of as-built values to reach certification. Although the performance gap is a wide-reaching issues, its causes are not yet clearly defined. This research suggests three areas where the causes lie: Design & Planning, Construction and Operation. Although the operative side is most often looked at, many reasons relate to the process itself and management of the project (Lützkendorf and Lorenz, 2005, p.222). This study will therefore look at best practice processes which can help reduce the performance gap.

2.5 Processes to Close the Gap

Processes with direct impact on the three performance gap areas will be analysed. While Passivhaus tackles design, planning and construction as low-energy concept, Soft Landings (SL) improves operation through increased monitoring user involvement. Lean can reduce the financial impact of these two processes through increased value with reduced waste, and the Integrated Design Process (IDP) secures the coordination of all these elements through collaborative working.

2.5.1 Passivhaus

Although Passivhaus is a fabric-first concept oriented towards building technology and science, it leads to an improved process amongst others through training, closer supplier involvement, testing and measuring and scheduling.

The Passivhaus Institute, inaugurated in Darmstadt, Germany, in 1996 (BRE, 2011), created both formal and informal sources of training for designers and builders. With the support of the European Union, CEPH courses for designers (Passivhaus Institute, 2009) have emerged and a course for trades should be appearing soon (Feist, 2011). Knowledge is also shared through Passipedia, a free Passivhaus database (Passivhaus Institute, 2011) or national and international conferences. With these means and the introduction of experienced staff onto site to train the trades, understanding and training are provided for the whole project team increasing quality assurance on the project.

In the same sense, the relationship to suppliers is tightened. With high requirements on airtightness, thermal bridging and U-values, the incorporation of building elements in the envelope is crucial. Suppliers therefore often have higher quality assurance responsibilities and either train the trades for the element installation or are present themselves on site (Ryan, 2011).

Testing and measuring is essential to reach Passivhaus certification, as well during the construction as at hand-over. High quality assurance and control is required to secure the best results possible before each test as there are costly and disrupt the construction process. The schedule has to include these tests and be adapted to the fabric requirements, clearly defining for example when the services have to be installed in relation to the erecting of the airtightness barrier.

These high quality standards result in an average of 15% additional costs over the regulatory standards (Newman and Whidborne, 2011), which are however mitigated by lower running costs and higher product value, resulting in 20% more return over a 20 year life cycle if performance has been guaranteed (Kats *et al*., 2003, cited in Lützkendorf and Lorenz, 2005, p.217).

Whilst design, planning and construction are addressed by Passivhaus as one example of low-energy tools, a follow-up at operation is required to cover the three performance gap areas. This can be approached by Soft Landings (SL).

2.5.2 Soft Landings

SL aims to improve client occupancy, building usability and the Design Teams' knowledge capture and understanding (Way, 2005, p.24) through five phases with client-orientated procedures:

<u>RIBA</u> Plan of Work with Green Overlay	<u>Usable Building Trust</u> Soft Landing Frameworks
A. Appraisal	1. Inception and briefing
B. Design brief	
C. Concept	2. Design and construction
D. Design Development	
E. Technical design	
F. Production information	
G. Tender documentation	
H. Tender action	
J. Mobilisation	
K. Construction to practical completion	3. Pre-handover
L. Post-practical completion	4. Initial aftercare 5. Extended aftercare

Table 2.4: Soft Landings phases compared to the RIBA stages of work (based upon RIBA, 2011 and Usable Buildings Trust, 2010, p.3)

Client leadership and user involvement should be encouraged from inception and briefing onwards (Usable Buildings Trust, 2010, p.25), first with the identification of their requirements which can be facilitated through Design Quality Indicators (DQIs). Used to determine a "variety of physical, aspirational and emotional needs of occupants and users" (Gann *et al*., 2003, p.318), they are best suited to be executed by project managers due to their early project involvement and the architects' reluctance towards formal briefing techniques (Walker, 2007, p.111). Lessons Learned Workshops based on previous projects an organised with the design team and Facilities Management (FM) further support the briefing. Whilst FM tends to be introduced for the commissioning stage, their early selection is recommended for input from inception on.

During design and construction, designs should not only be reviewed by the Project Team but also by project-external consultants and FM, and regular clients and users meetings are to be held, including the whole Project Team.

At pre-handover, procedures need to be firmly documented through logs and operating books, a tight and friendly relationship between the Project Team and the users is encouraged. Workshops to ensure the clients' and users' comprehension of their buildings are also organised.

The SL initial aftercare requires a Project Team member to be accommodated in the commissioned building, although budgets rarely allow for this (Usable Buildings Trust, 2010, p.25) unless planned in the tender. This presence allows for pro-active management through early discovery of failures and quick reactions to rectify these, compensating the staff fee against expensive defect corrections. The Building Services contractor and Mechanical & Electrical (M&E) engineer should also regularly visit the building, hold meetings with the client and users (Way, 2005, p.34) to collect data.

Project aftercare lasts for three years in the SL Framework (Way, 2005, p.24). This allows for situational amendments according to seasonal changes, handing over monitoring to FM (Way, 2005, p.38), maintaining continuous communication with the rest of the team and the execution of POEs (Usable Buildings Trust, 2010).

The SL Framework is not a procurement route in itself (Usable Buildings Trust, 2009, p.9), but a “process carrier” covering all disciplines and stakeholders (Way, 2005, p.25) and resolving some fragmentation that resulted from the industry’s specialisation (Usable Buildings Trust, 2010, p. 22). To ensure satisfactory delivery of the process, a SL champion is encouraged to act as an overall liaison person. The Usable Buildings Trust (2010, p. 22) suggests to add this role to the project manager, although it is currently often executed by the architect (Way, 2005, p.34).

The main difficulty in SL is for clients to finance monitoring as it is very expensive and little direct benefit is noticed. Added to the higher investment costs for Passivhaus, processes able to reduce these costs are essential for clients to afford performing construction processes. This can be found in the Lean methodology.

2.5.3 LEAN

The concept of ‘lean’ emerged first in automotive manufacture (Salvatierra-Garrido and Pasquire, 2011; Seddon, 2005) with the aim to maximising value through “meeting client requirements” while minimising waste (Forgues et al., 2008, cited in Salvatierra-Garrido and Pasquire, 2011; London and Kenley, 2001, cited in Walker, 2007, pp. 153-154). Based on system and process management, this model is also applicable to the construction industry and has been encouraged in the Egan Report (Construction Task Force, 1997). To understand this principle, the terms ‘value’ and ‘waste’ need to be examined.

Price is what is paid for a product or service, and value is the personal perception of this product or service, supported by comparison similar ones on the market (Lützkendorf and Lorenz, 2005). A clear distinction therefore needs to be made between the price and cost of a building and its value. Values vary according to the stakeholders’ consideration and the focus of their interests (Seddon, 2005, p.191).

Extending the usual definition of waste corresponding to unnecessary material in construction, seven types of waste have been defined by Ohno (1988) and adopted by numerous authors and organisations as follows:

Waste Type	Description
Overproduction	Production of material which is not directly used for the construction project or left over.
Waiting	Labour, machines and plant not used to their full availability amongst others through lack of parallel operations.
Transportation	Excess of material and labour movements to achieve tasks (e. g. lack of local service and products usage, long distances between storage areas and working areas etc.).
Processing	Activities unnecessary to the project or duplicated.
Inventory	Excess of materials stored as opposed to directly needed, as opposed to just-in-time delivery.
Movement	Excess of labour activity due to the lack of equipment and tools to speed up the process. At the design stage, BIM (Building Information Modeling) reduced drawing duplication and measurements (Smith, 2012). In construction plant can be used to move materials instead of manual lifting.
Defective products	Defects in products or activities due to poor-quality material.

Table 2.5: The seven wastes (based upon I Six Sigma, 2012; Resource Engineering Inc., 2012; Winser et al., 2009; Ohno, 1988)

To realise maximum value for minimal waste, the ‘system’ or process, which holds 95% of influence on projects, needs to be adapted as opposed to people, who only hold 5% influence (Lewis, 2011 p.95; Seddon, 2005). Seddon (2005) defined four main stages in Lean processes (2005, p. 169):

- Understand what matters to the clients, thereby reducing risks and the need from permanent control and monitoring (Seddon, 2005, p.128).
- Determine the appropriate work method
- Execute the work
- Review the work against the initially analysed goal

Seddon (2005) further details the following key actions:

- Create flatter hierarchies, thereby reducing the ‘end-to-end’ process, which starts at the client’s requirement to the achievement of those. It is comparable to Paverz *et al*.’s “Dynamic complexity” (2010). Simplifying the supply-chain reduces the number of internal handovers which bear high risks of error creation and allows for instant reactivity towards variations, therefore reducing cost, quality and time impacts due to late changes (Seddon, 2005), as well as reduces Walker’s (2007) ‘transaction costs’, which are those due to managerial and organisational tasks in projects.
- Include workers into decision-making and reduction of administrational and figurative roles.

- Eliminate unnecessary usage of tools.
- Conform the project time to what is needed for the work instead of adapting resources and work methods to a deadline.
- If there already is failure demand (claims or losses caused by the wrong execution of work), the causes need to be analysed and corrected instead of simply reacting to consequences by resources adjustments.

Delivering best value for clients depends much on their background: owners, users, society (Bertelsen and Emmitt, 2005, cited in Salvatierra-Garrido and Pasquire, 2011) or investors. Present from inception on, project managers need to identify and regularly update the project stakeholders list including roles, importance, influence and where their interests lie (Chinyio and Olomolaiye, 2010; CIOB, 2010; Seddon, 2005; IEA-SHC, 2003). The Project Team will therefore be continuously aware of the dynamic changes in value and aim (Salvatierra-Garrido and Pasquire, 2011, p.11), which are influenced by the unique characteristics of projects (Pavaraz *et al*, 2010, p. 29; Walker, 2007).

Numerous tools such as the Last Planner System (LPS) have been created especially to support the Lean system (Paverz *et al*., 2010). Seddon (2005) however considers these as systemising, hampering change management and clouding the essence of lean principles.

Seddon (2005) furthermore comments on the benefits of decreases of activities, especially controlling, leading to a minimal and linear flow, allowing thereby fast and effective responses to clients' wishes. Reducing control however increases the risk of errors not being noticed in time, thereby increasing their impact.

Passivhaus, SL and Lean are individual processes, therefore a strong collaborative framework is recommended to integrate them in a harmonious process. Such a framework can be found in the Integrated Design Process (IDP).

2.5.4 INTEGRATED DESIGN PROCESS

The IDP has been created by the International Energy Agency to permit clients to “reach a very high level of performance and reduced operating costs, at very little extra capital outlay” (IEA-SHC, 2003, p.8) for high-performance sustainable buildings through iterative knowledge analysis and capture, and an integrated Project Team.

To limit unexpected changes which grow more onerous as the project progresses (see Figure 2.14), the clients’ requirements need to be captured by the whole project team at pre-project stage and be translated into several design solutions straight away.

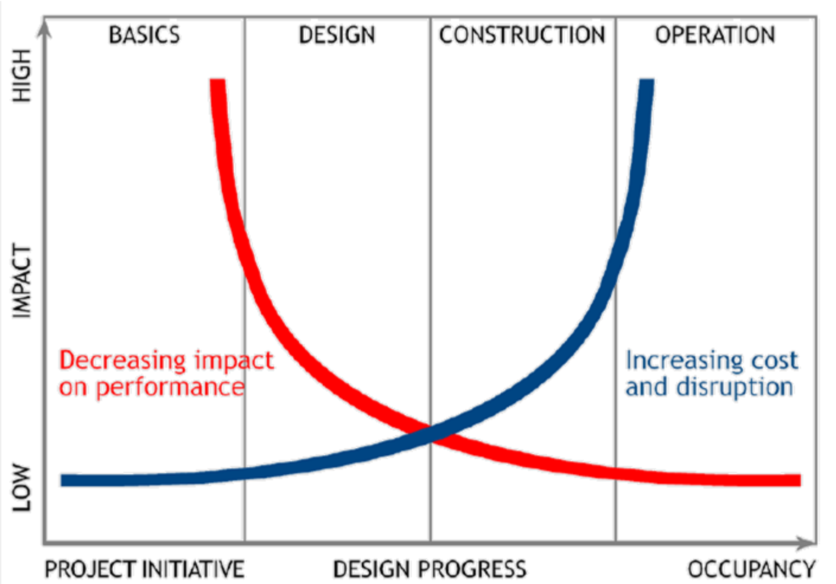

Figure 2.14: Impact of design changes in the construction process (IEA-SHC, 2003)

The most adequate solutions are then assessed through modern simulation tools with regular interim reviews allowing for better planning, control and reactivity through feedback and feed-forward on a task scale (Figure 2.15) or project scale (Figure 2.3).

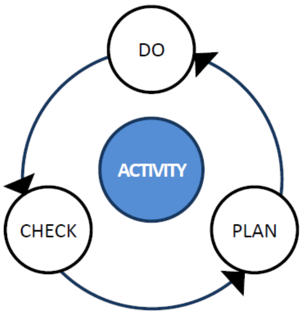

Figure 2.15: Check-plan-do model (based upon Seddon, 2005)

This iterative life cycle process can be compared to Passvihaus' Quality Assessment through PHPP: regular decisions lead to information input into PHPP. Interim results lead to feedback (review chosen solution) and feed-forward (chose certain solutions to keep the overall values to those specified by Passivhaus; see Table 2.3). Consideration of the whole project life cycle allows for a holistic view on cost, quality and time.

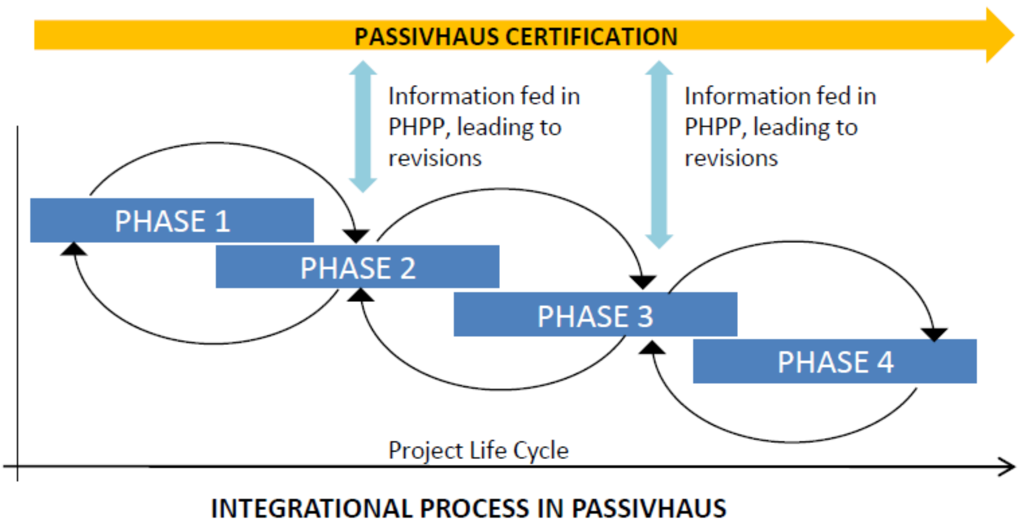

Figure 2.16: Integrational process adapted to Passivhaus (based upon IEA-SHC, 2003)

The condition to maintain such high quality standards is a collaborating team, bridging the fragmentation caused by high levels of specialisation (Great Britain. HM Government. Department for Business, Innovation and Skill and Department of Energy and Climate Change, 2010). Figure 2.17 illustrates how reciprocal interdependency achieves this as opposed to pooled or sequential interdependency

(Walker, 2007). Decreasing risk of communication and waste in the supply chain (Seddon, 2005), this collaboration also improves knowledge and skills of the team members, reducing the skills shortage found in the construction industry (Great Britain. HM Government. Department for Business, Innovation and Skill and Department of Energy and Climate Change, 2010; Abdel-Wahab *et al*., 2008; O'Donnell *et al*., 2008). Input from all members is vital from the requirement definition on as communication between all parties insures correspondence between the diverse team members, the project goals and actions taken. Figure 2.5 represents the interrelation and interdependence between these elements, the tools to achieve them and their external influences.

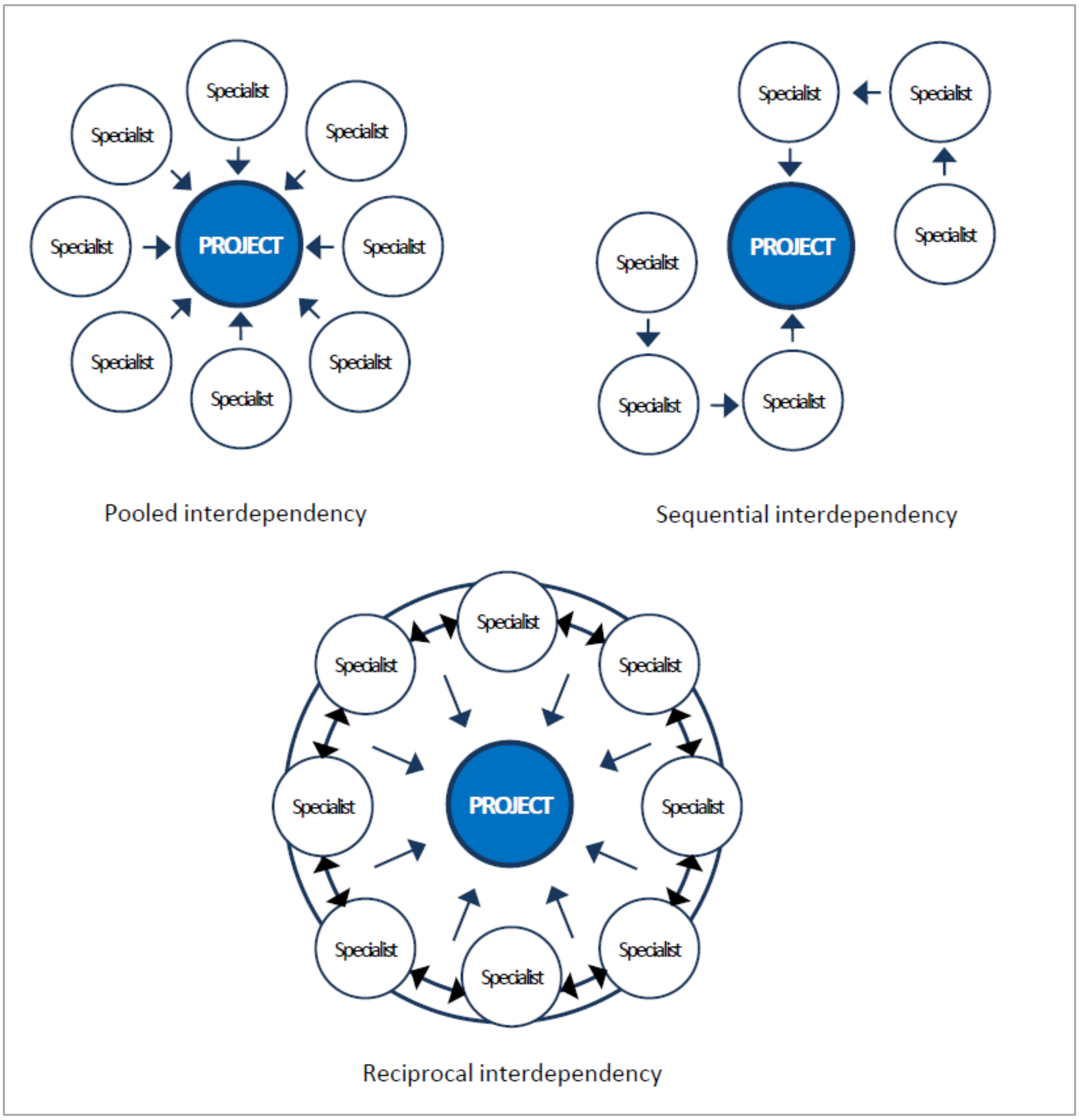

Figure 2.17: Dependency models of Project Team members (based upon Walker, 2007)

To realise a close cooperation through the IDP, the IEA (IEA-SHC, 2003, p.9) suggests the architect's leadership on design, the use of an energy specialist the reach the best possible efficiency values, as well as a the appointment of a 'Design Facilitator'. His role is the reconciliation between design and management, with strong communication skills, to achieve high sustainable goals. Project managers, through their planning, monitoring, controlling and communicating skills (Lewis, 2011; CIOB, 2010), design objectivity and presence during the whole project life cycle, are key to a Project Team's collaboration (Walker, 2007, p.23, 142). With enhanced design training they can assume the Design Facilitator role over architects, who appear to lack design and management polyvalence (Walker, 2007, p.94; IEA-SHC, 2003, p.23).

Although increasing teamwork and communication often implies investment in time and money, the return on both are considered higher (Construction Task Force, 1997).

2.5.5 Process Improvement Essence

Passivhaus, SL, Lean and the IDP all offer responses to the performance gap reduction through process improvement. Although refereeing to Lean specifically, Seddon (2005) explains the importance of label absence:

> Taiichi Ohno did not call it 'lean'. Creating the label 'lean' (what it is) leads naturally to the notion of tools (how you do it), obscuring the importance of perspective (how to think about it). Obscuring the importance of perspective leads to a failure to appreciate that Ohno's ideas represent a philosophy for the design and management of work that is diametrically opposed to today's norms. The codification of method misses this important issue: thinking. While the tools are accurate descriptions of what happens in terms of method, it is the context that is more important. (Seddon, 2005, p.182)

Table 2.6 therefore extracts the essence behind the labels according to the three defined areas causing the performance gap:

	Design & Planning	Construction	Operation
PH	▪ Fabric first testes with PHPP ▪ Service seen as system, not just element ▪ Schedule set up with testing and measuring milestones, impacting on the construction phasing	▪ Measurements of heat loss, air-tightness, energy consumption ▪ Tight relationship with suppliers ▪ Specialist quality insurance on site (air-tightness champion...) ▪ Qualified/trained workers	▪ Continuing measurements
SL	▪ Involvement of client and users in the design ▪ Involvement of facilities management and specialists in design ▪ Lessons Learnt workshops from previous projects used	▪ Regular meetings involving client, users and facilities management ▪ Documentation of all procedures	▪ Presence of Project Team member on the delivered site for 3 years for various adjustments and repairs ▪ Induction workshops for users and client ▪ Monitoring
Lean	▪ Design tailored to client's need ▪ Identification and increase of value for client (often entailing high quality and low cost) ▪ Identify possible sources of waste and create prevention measures	▪ Flat hierarchy ▪ Tracing issues back at the source ▪ Interrupting process if necessary to avoid issues having additional impact on it ▪ Limit reporting, administration and usage of tools as a support only	▪ Service tailored to client's needs
IDP	▪ Schedule outlining all important steps in advance ▪ Analysis task dependencies	▪ Presence of a Design Facilitator to secure the integrated process ▪ Regular review of the executed work, with feedback and feed-forward	▪ Lessons Learnt for future projects

Table 2.6: Correspondence of best practice processes and performance gap areas (researcher’s own)

2.5.6 Conclusion on Best Practices

Where Passivhaus appears to have design, planning and construction tools to reduce the performance gap through high quality assurance, Soft Landings improves on operation by securing the clients’ and users’ wishes and needs through monitoring over a three-year period after hand-over. Lean can considerably cut costs by reducing waste and increasing value, and IDP can excel project processes through iteration and collaboration. Project Managers can then function as the missing lead and ‘cross-cutting’ role to administer the processes including the new energy-performance related tasks (Great Britain. HM Government. Department for Business, Innovation and Skill and Department of Energy and Climate Change, 2010, pp. 13 and 22).

2.6 CONCLUSION

The project manager role seems to be well rooted into the current construction industry, with main skills in planning, organising, monitoring, controlling and communicating through all project phases. However, the built environment has been changing to adapt to new sustainability targets. Tools in form of sustainable and low-energy certificates have been created to reach the carbon and energy targets set by governments. Analysis of the built performance however shows a significant gap to the designed values. Although low-energy certification seems to provide better performance, the subject has important proportions and little research has been undertaken to understand the causes, which seem to have their roots in Design & Planning, Construction and Operation, the latter including occupant behaviour and facilities management.

Passivhaus (Feist, 2012) as a low-energy certificate seems to provide a response to Design & Planning and Construction through better fabric solution and increased quality control. Soft Landings (Usable Building Trust) addresses issues of behaviour and neglected aftercare through all project phases. Both concepts however represent an increased investment for clients and therefore might be ignored in an economic downturn. Lean offers, as a solution, a process to increase value with reduced waste, which coupled to the two first processes reduce considerably the performance gap. The Integrate Design Process (IEA-SHC, 2003), based on iteration in the tasks and processes as well as a strong collaboration, as recommended by the Egan Report (Construction Task Force, 1997), can be added to these three processes to support their seamless integration and overlapping. A model based on the essence of these four best practices can be created as represented in Figure 2.18. It includes the processes and tasks recommended based on the best practice models according to the three performance gap phases of Design & Planning, Construction and Operation. In spite of a strong overlapping of these processes, an attempt at distinguishing these according to their impact has been made, whether it is on building performance, cost or overall cohesion of the project process. The created model is designed to functions a guideline to reduce the performance gap through improved process and project management.

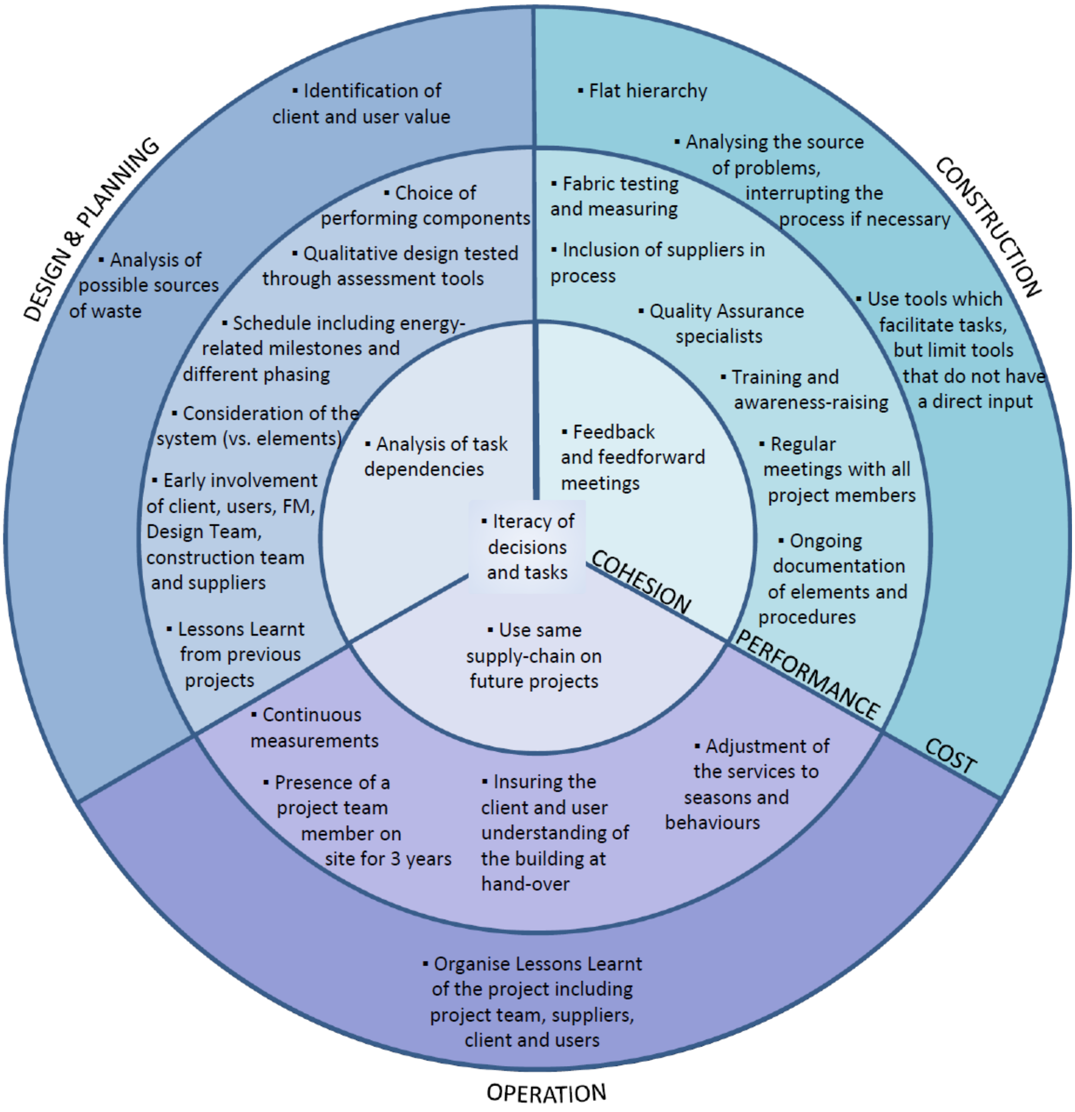

Figure 2.18: Model for performing sustainable buildings (researcher’s own)

The model in Figure 2.18 implies a strong over-arching entity tying all project members into a collaborative framework, a competent proactive and reactive change management, strong quality assurance throughout the process and the creation of a knowledge sharing no-blame policy. Corresponding to the project management tasks set out in Table 2.2, this model takes them a step further towards sustainable performance. These new demands appear best suited to this role through the project managers’ overview through all phases and over all stakeholders and project members. They act as the interface between clients and projects, influencing their decisions and advocating their values.

This model results in improvements on existing practices. Primary research will analyse to what level these processes are implemented in current projects and their correlation with the performance of the studied cases, including a consideration to the initiator of the certification process and his impact on it.

3 METHODOLOGY

The aim of this dissertation is to reveal the influence of processes on building performance, and how project managers can improve it by introducing best practices through a strong presence.

This Chapter will describe how, based upon the secondary research undertaken in Chapter 2, primary data has been recorded and analysed the validity of this assumption.

3.1 DATA GATHERING

3.1.1 PROCEDURE

This dissertation uses the grounded theory which "involves a systematic process of gathering and analysing a finite set of data to evolve a theory based upon the data" (Knight and Ruddock, 2008, p.86), a hypothesis being formulated based on findings in secondary data.

For the reasons illustrated in Figure 3.1, the hypothesis will be tested through primary research, conducted in form of survey of case studies through semi-formal interviews using open questions.

Figure 3.1 represents the most used and relevant methods for this dissertation, highlighting the differences to understand why the chosen path is most significant for this study.

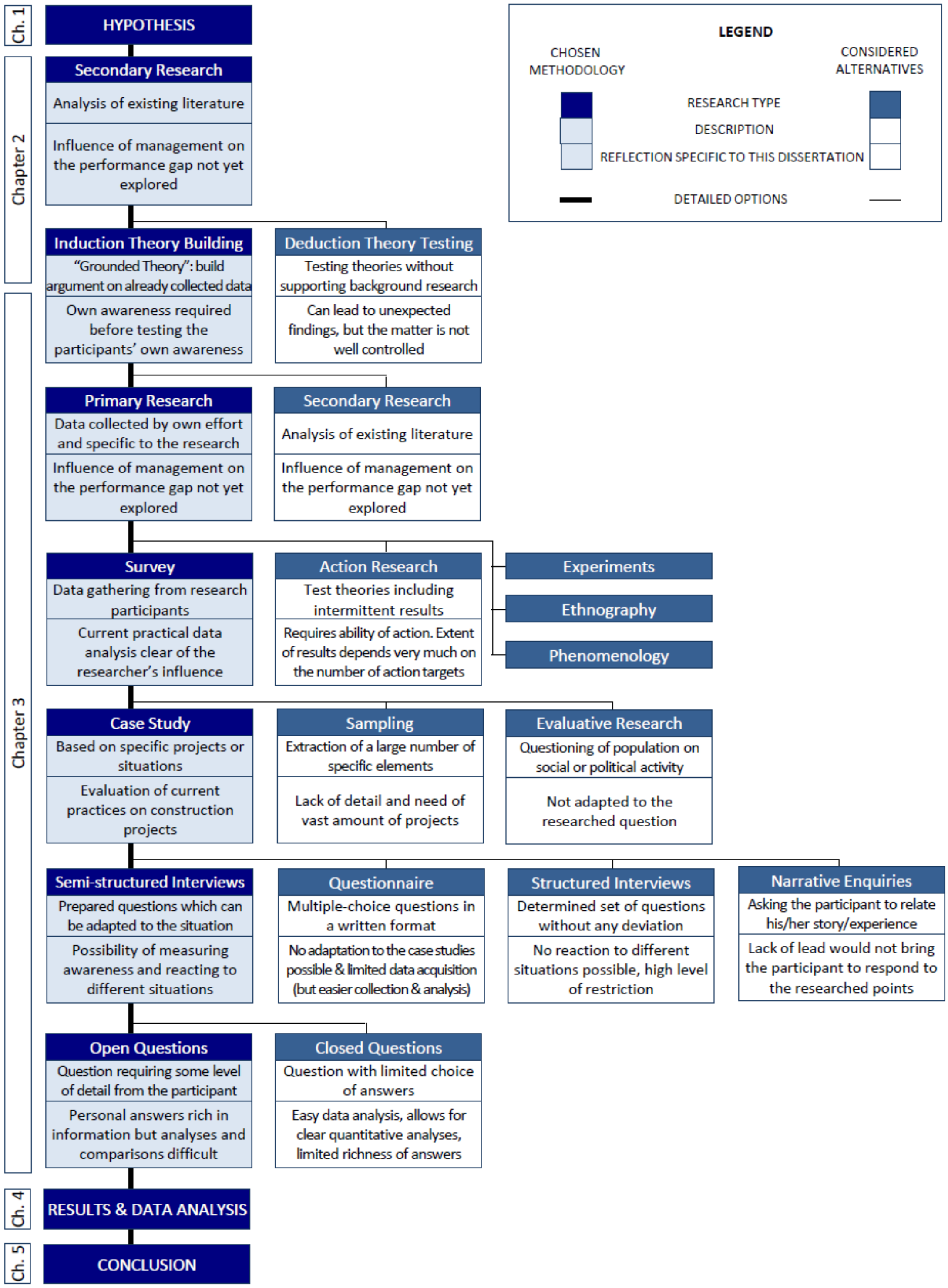

Figure 3.1: Dissertation methodology (based upon Farrell, 2011; Knight and Ruddock, 2008; Naoum, 2007; Swetnam, 2004)

3.1.2 TARGET

Participants have been selected according to the following criteria:

Criteria	Description
Company	Participants have been selected amongst different companies to limit impact of similar corporate culture on working methods or knowledge. Only two participants are from the same company.
Awareness	Participants and companies known to have practice and knowledge in these best practice process (through their presence in conferences on this topic or having realised known Passivhaus projects) have been contacted, as well as some known working at the industry standard. This choice should reflect the whole panel of awareness in the industry.
Profession	With a myriad of different professions on construction projects, a panel of architects, contractor's project managers, client project managers, engineers and environmental managers have been sought out to balance perspectives on processes and awareness in the built environment.
Projects	Different projects have been selected to avoid the repetition of information, with an effort to select educational buildings. Whilst the projects are different, their type had to be adapted to the companies' and participants' experience. The priority set is as follows: ▪ Educational ▪ Commercial ▪ Other non-domestic ▪ Domestic These priorities have been set because of the presence of project managers in non-domestic projects over £500,000 (Hall, 2012).

Table 3.1: Participants & case study selection (researcher's own)

3.1.3 INTERVIEW QUESTIONS

Confidentiality, anonymity and interview ethics have been secured as dictated in the interview brief (see Appendix 3) sent to the participants with a consent form (see Appendix 4) which had to be returned signed before the interview. Participants signed a release consent form on their agreement on the data extracted from the recordings before they were included in this research (Appendix 5).

Two pilot interviews have been conducted with participants following the same selection criteria to secure the validity of the questions, to assess and improve the professional conduct of the interviews and measure the average time required to conduct them. Although minor changes have been applied to the questions after the first pilot interview, the second has proven successful and due to the relevance of its content was later included in the actual results.

Although 25 professionals were initially approached, a total of ten interviews have been conducted, including the second pilot, due to compromise between the time and volunteer limitations and the aim to create a sample large enough to allow for a stronger validity in its generalisation.

A guideline of questions asked can be found in Appendix 6. They involve attitudinal research which "'subjectively' evaluates the 'opinion', 'view', or the 'perception' of a person, towards a particular object" (Naoum, 2007, p.41), allowing participant awareness to be tested. Their perception on the difference between low-carbon and low-energy, and their definition of value has been recorded.

To prevent invalid samples through the Hawthorne Effect, defined by Swetnam (2004, p.37) as the participants' change of behaviour due to their awareness of the experiment, possibly by giving answers that they expect the interviewer is looking for, following measures are set:

- Only stating the purpose of evaluating the industry's awareness of the energy-efficiency processes and methods, with a more detailed explanation at the interview.
- Reinsuring the absence of personal judgement by guaranteeing anonymity and the inclusion of the answers to a larger pool of similar case studies.
- Avoiding giving any lead as to what the expected answers or outcomes might be through detailed questions without their larger context.
- Direct interviews, giving no possibility for participants to update their knowledge before answering.

The interviews were conducted face-to-face possible, or over Skype if the interviewee was remote. In all cases the interview was recorded and the data extracted according to subject areas (see Appendix 7). To prevent any breach of anonymity or confidentiality, sensitive data within the recording has been masked. Contemporary tools were used to support this process, such as Doodle (Doodle, 2012) to facilitate the appointment-making or Glumbo (Glumbo, 2012) to send the large audio files to the participants for confirmation.

3.2 Data Analysis

The data will be analysed through a quantitative and qualitative approach, the former focusing on numbers and the latter on words and ideas (Farrell, 2011). The first step is analytical coding, where the ideas and meanings are examined, not the wording, to homogenise the participant's response themes. This is conducted with an inductive approach, allowing for additions and revisions as the interview progresses.

The quantitative analysis undertaken in Chapter 4 using an assessment model devised by the author solely for the purpose of this particular research. Based upon the three main energy performance gap categories identified in Chapter 2 and the content of the responses to the interviews, also organised around these three areas, detailed criteria have been set according to sub-categories as illustrated in Table 3.2, acting as an indicative sample of the full assessment.

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	--%					
	Consideration for fabric first						
	Lucidity on "eco-bling"						
	FM involvement [in all phases]						
	Planning	--%					
	Early involvement of project team members						
	Certification milestones included						
	Different planning approach to achieve standard						
	Buildability	--%					
	Design understandable by construction team						
	Involvement of subcontractors in construction						
	Involvement of suppliers in construction						
	Materials or techniques facilitating construction						

Table 3.2: Indicative sample of the process competency evaluation (researcher's own)

Each criteria is marked up to a 100% for achieving the set aspects with a 20% interval. Points are awarded based on the author's judgement and a comparative performance between the case studies. Whilst this marking is subjective, especially in points such as the appointment of carbon/energy specialists, where no number or type was set, the systematic approach increases the objectivity of the qualitative data it is extracted from. All the marking sheets can be found in Appendix 8.

A qualitative analysis is also conducted, on information volunteered by the participants.

3.3 CONCLUSION

This research follows a grounded theory, where a hypothesis is created based on secondary research, and tested through primary research. The latter is conducted through ten case studies with semi-structured interviews. The qualitative data collected via open question is analysed through both a quantitative and qualitative approach, which will assess the correlation between competency in the process with the building performance and the influence project managers have in this process.

4 PRACTICE: PRIMARY DATA

The correlation between best practice processes and the realisation of energy performance as designed is explored through the analysis of ten interview-based case studies, as described in Chapter 3. The analysis will be conducted through a quantitative study on the project process performance, supported through qualitative interpretation of the participants' opinions and remarks relating to the project manager's role.

4.1 SELECTED CASES

Figure 4.1 represents the different disciplines, project types and sizes selected for the interviews.

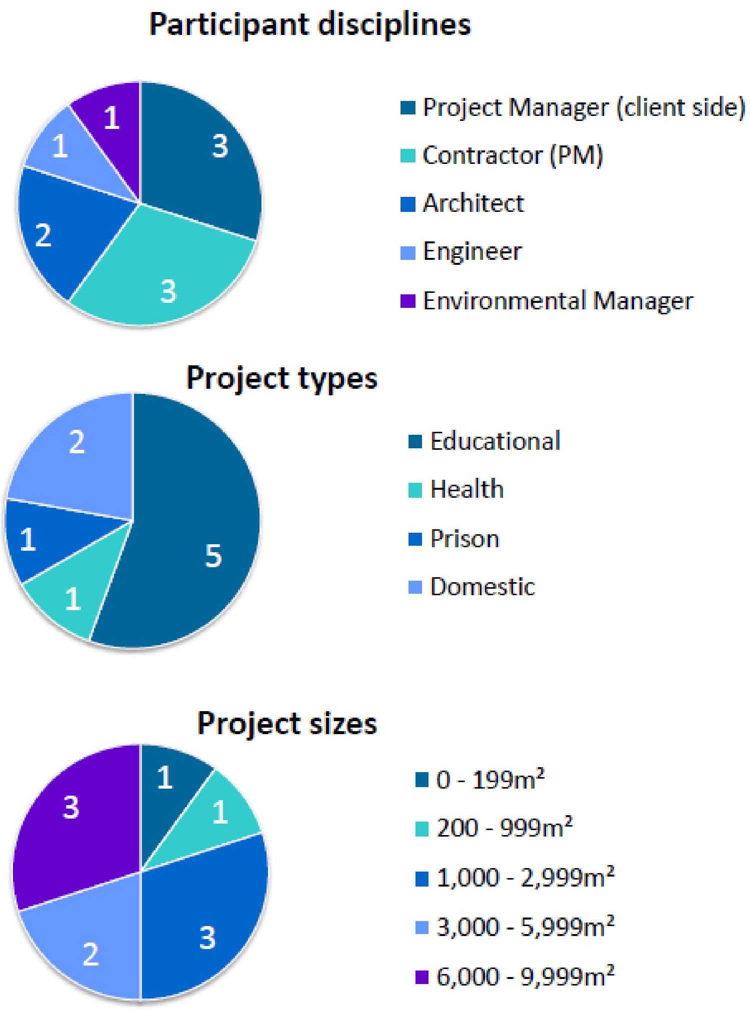

Figure 4.1: Case studies details (researcher's own)

The case studies were used following certification tools and processes:

	BREEAM very good	NEAT (NHS certificate)	Code of Sustainable Homes (Level 3)	Passivhaus	Some Lean principles	Lean	Soft Landings
Case Study B	x				x		
Case Study C	x			x			
Case Study D		x					
Case Study E	x						
Case Study F			x	x			
Case Study G	x			x			x
Case Study H	x[1]						
Case Study I					x		
Case Study J	x			x		x	x
Case Study K							

[1] one BREEAM certified project in the framework

Table 4.1: Certifications and best practice processes used in the Case Studies (researcher's own)

4.2 QUANTITATIVE ANALYSIS

The following results have been extrapolated from the author's process competency assessment, which can be found in Appendix 8. Case Study H will regularly be represented as a BREEAM and non-certified project as it was based on a framework of which one of the buildings received BREEAM very good certification.

The studied cases seem to have a strong disparity in process competency, overall mean values ranging from 22% to 94%. Figure 4.2 shows the cases ranked in increasing order according to their overall mean average score with a more detailed representation in Appendix 9, Figure 5.9.This provides a general overview of the results and supplementary analysis of competency clusters are studied in this Chapter according to Figure 4.4.

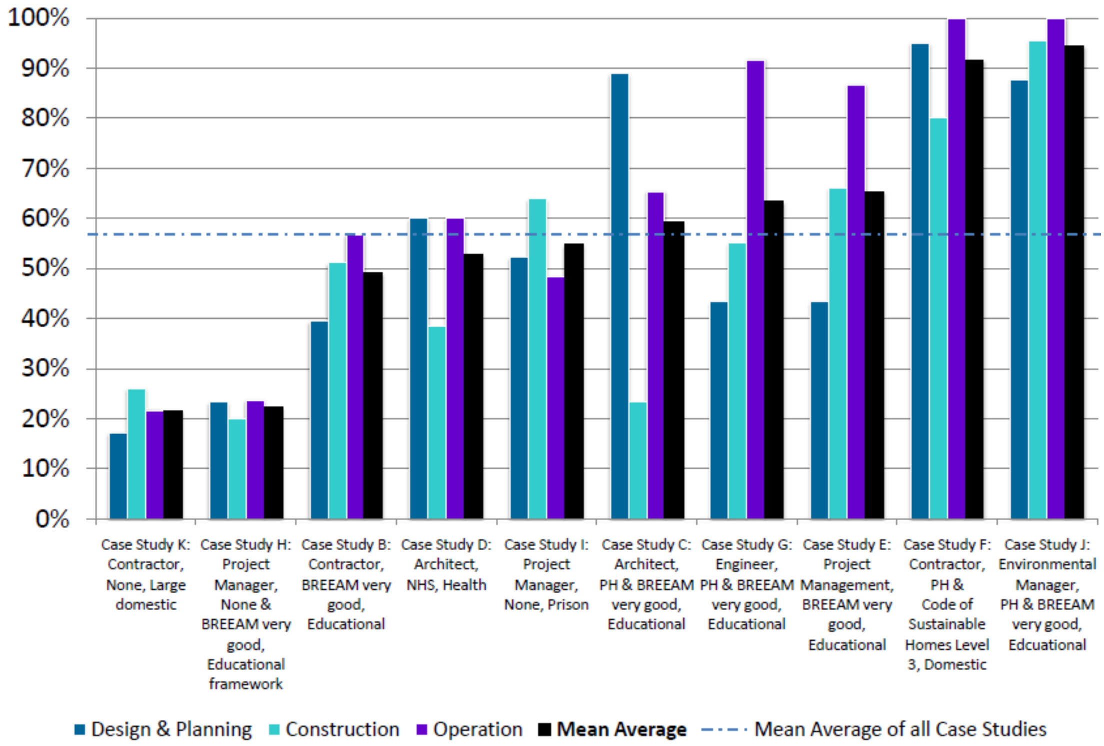

Figure 4.2: Mean averages of the case studies' process performance according to the three main building performance gap categories (researcher's own)

Figure 4.3 shows that a relatively constant average between Design & Planning, Construction and Operation is similar, ranging from 52% to 55%. Organised in clusters according to certification tools, it appears that this similarity is repeated. BREEAM certification performs lowest in Design & Planning, which could be explained through the high flexibility in choice for the certification criteria, exempting the project of high discipline required for Passivhaus certifications, strongly guided through PHPP. The Passivhaus and NEAT projects surprisingly perform lowest in Construction whilst it is the built performance which is measured. Suggestions on the reasons can be made towards the difficulty to work at this high standard compared to the 'average' UK construction industry, which presented a much lower process competency if the non-certified case studies are contemplated.

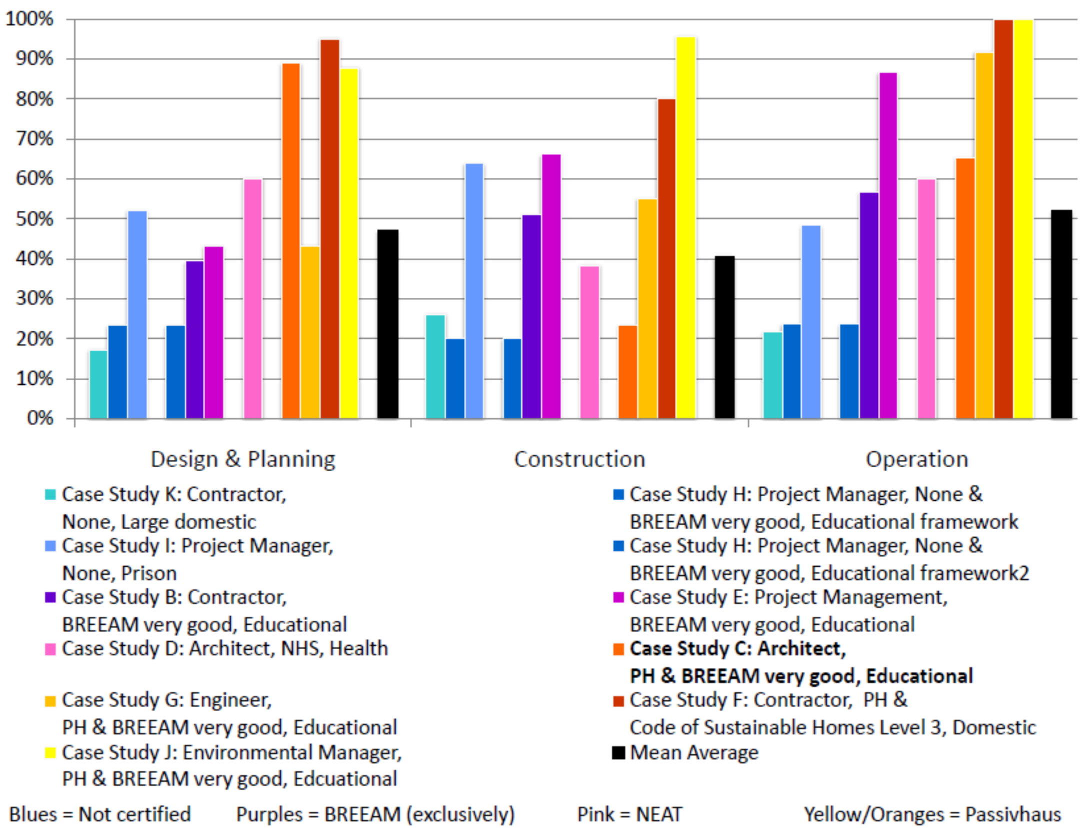

Figure 4.3: Process competency in the three gap areas according to case studies, split in certification tool clusters (researcher's own)

Figure 4.4 represents the case studies' process competency according to the certification tool they were subjected to. Although the author considered adding Soft Landings in Lean in this comparison, as represented in Figure 5.10 (see Appendix 9), it will be neglected in the main body of the dissertation due to the low number of case studies which implemented these. The results would thereby have a limited validity through their representation by a maximum of two projects each.

Considering the process competency of the certification clusters, a clear correlation with the building performance they are being attributed, according to Chapter 2, supporting the idea that best practice process management influences the as-built energy performance of a building.

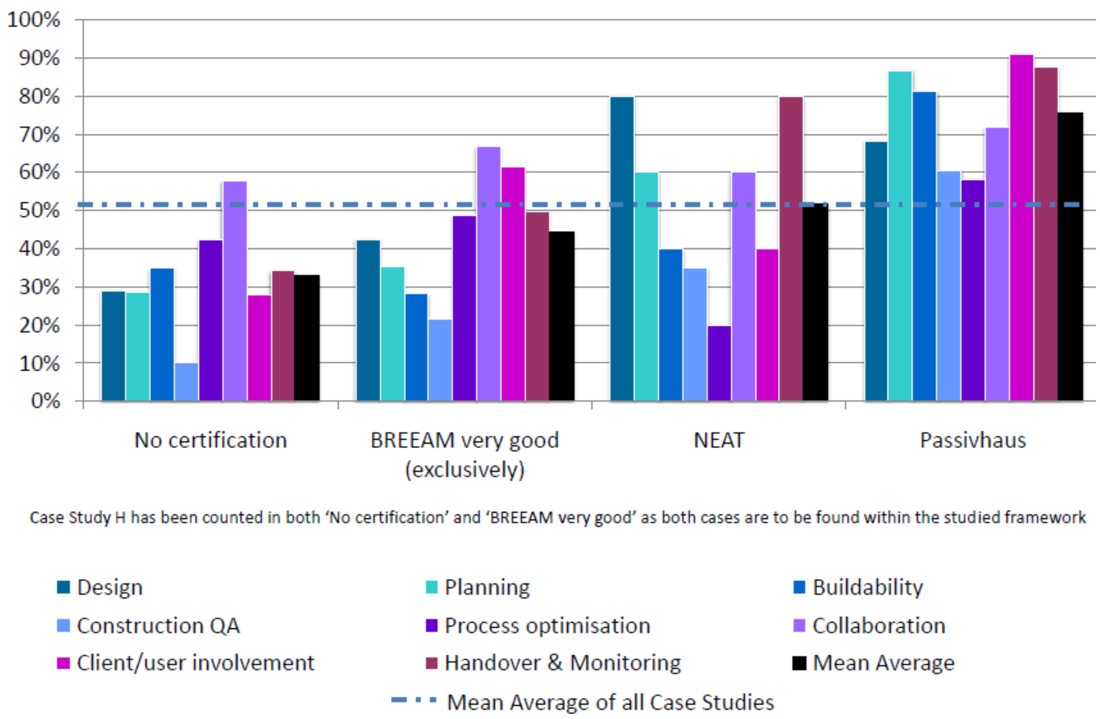

Figure 4.4: Process competency according to sustainable certification tools (researcher's own)

Based upon the results pictured in Figure 4.4, further examination of the certification clusters individually is provided as follows.

Projects without any certification model present a process competency mean average of 33%. A reason for this can be that clients who do not seek certification are mostly focused on the cost of their project as opposed to quality. This evaluation is supported through the location of the highest scores in process optimisation and collaboration (respective averages of 42% and 58%) which are at the heart of the lean concept – aiming at reducing waste and therefore cost. Collaboration seems to be well executed throughout all projects independently of the certification. An explanation can be found in the increasing popularity of partnering forms of contracts, such as PPC2000 and NEC3 which have both been mentioned in several of the conducted interviews. The lowest score obtained for non-certified projects is the Quality Assurance (average of 10%), which is indeed marginal if no strong quality requirements have been set.

BREEAM certified projects reached a process competency mean average of 44%. This result corresponds to the failing energy performance of these projects, which has been underlined in Chapter 2. The process competency values range from 22% to 67%, where the lowest is Quality Assurance, neglected in general sustainability models as highlighted by Gifford (2009) aa the certification only evaluates estimations as opposed to as-built performance.

The NHS building certified under NEAT scored 8% higher than the BREEAM certified buildings, although NEAT is based upon the BREEAM certification tool (Department of Health, 2012). This might be justified by the health sector's higher demands in building performance, and its increased complexity leading to a stronger design and handover process, both reaching a level of 80% process competency.

Passivhaus projects, proven to perform as-built (Feist, 2005), also reached the highest process competency mean average according to the author's criteria with an overall average of 76%. Whilst the process optimisation reaches an average much higher than all other projects according to the certification tools with 58%, it is the lowest score for Passivhaus projects. Resolving this weakness could lead to the reduction of the 15% additional costs highlighted by Newman and Whidborne (2011).

Overall, the evaluated process competency graphically represented in Figure 4.4 corresponds to the energy performance of the different certification approaches as identified in Chapter 2.

4.3 QUALITATIVE ANALYSIS

4.3.1 PARTICIPANTS PERSONAL INFLUENCE

Whilst project performance cannot be attributed to a single project member's awareness or priorities, Table 4.2 appears to demonstrate that the type of sustainable certification tool does not impact on their awareness or priorities, whatever the discipline.

	Consideration for low-baron and low-energy			Consideration of value (main priority)				
	Design & Planning	Construction	Operation	Client wishes and needs	Cost (incl. life-cycle)	Own profit	Building quality	Community & environment
Case Study K Contractor				x	x			
Case Study H PM	x		x	x	x			x
Case Study B Contractor	x	x		x		x		
Case Study D Architect	x	x	x	x				
Case Study I PM	x			x				
Case Study C Architect	x						x	
Case Study G Engineer						x		
Case Study E PM	x		x	x				x
Case Study F Contractor	x	x		x	x			x
Case Study J Environm. M.	x	x	x	x	x		x	x

Table 4.2: Evaluations on participant's perceptions: low-carbon and low-energy association to the three performance gap areas; definition of value [case studies in increasing process performance order]

The projects with a high building performance level however seem to have done so through the presence of a knowledgeable key role, such as environmental manager or the contractor who also had the roles of designer and consultant for Project F. Whilst they

Although the participants haven't been asked directly about the initiator of the certification process, they volunteered this information. Table 4.3 summarises whether it has been purely a client initiative, the consultant's initiative, or if it was the client's choice with a heavy input and influence from the consultant.

With the Case Studies arrange in increasing process competency order in Table 4.3, it appears that the less performing half is exclusively lead by client choices, whilst the more competent – and by association made earlier, the most energy performing buildings – are either lead or supported by the consultants. Three out of four choices or certification for Passivhaus projects appear to be lead by consultants, which indicated a heavy influence on the Project Team members an suggests internal competencies in the first instance which would have impacted on the project delivery.

	Initiator of the chosen certification level			Certification tool and process used						
	Client lead	Consultant lead	Client lead with strong consultant	BREEAM very good	NEAT (NHS certificate)	Code of Sustainable Homes (Level 3)	Passivhaus	Some Lean principles	Lean	Soft Landings
Case Study K Contractor	x									
Case Study H PM	x			x[1]						
Case Study B Contractor	x			x				x		
Case Study D Architect	x				x					
Case Study I PM	x							x		
Case Study C Architect			x	x			x			
Case Study G Engineer	x			x			x			x
Case Study E PM			x	x						
Case Study F Contractor		x				x	x			
Case Study J Environm. M.			x	x			x		x	x

[1] one BREEAM certified project in the framework

Table 4.3: Initiator of the certification process in relation to the tool (researcher's own)

4.3.2 Delegation of Responsibility

Table 4.4 illustrates where the participants referred to other disciplines on the project for the interview answers. No parallel between these and the participants' own discipline can be drawn considering that the three participants who referred to another discipline most often each have a different role. However a clear pattern of systematic referral appears on projects with lower process competency. This can indicate a lack of collaboration due to construction teams becoming more segregated through high levels of specialisation (Walker, 2007). Improvement can be offered through project managers' influence in encouraging and leading partnering and collaboration through the contract choice, early appointment of the project members through proactive tendering, and strong involvement of the members through toolbox talks and workshops, all of these elements which are the essence of the Integrated Design Process. The corollary is an improvement on the skills level deplored by the Government (Great Britain. HM Government. Department for Business, Innovation and Skill and Department of Energy and Climate Change, 2010) and waste reduction through proactive management and participation.

	How to reach low-energy and low-carbon	Thermal comfort	Definition & implementation of client priorities	Client /user involvement	Client /user understanding of the building	Energy estimation	Reasons for M&E equipment choice	Supplier involvement	Quality assurance measures adopted	FM involvement & input	Monitoring
Case Study K Contractor											
Case Study H PM			x				x	x	x	x	
Case Study B Contractor	x					x	x				x
Case Study D Architect		x[1]		x	x	x	x[1]		x		
Case Study I PM						x	x		x		
Case Study C Architect											
Case Study G Engineer			x							x	
Case Study E PM						x	x[1]				
Case Study F Contractor											
Case Study J Environm. M.											

[1]Although refers to another discipline, has knowledge on it.

Table 4.4: Interviewees referring to other discipline for diverse aspects; projects in increasing process competency order (researcher's own)

Earlier engagement of the Project Team and the implementation of partnering contract with proactive change management have also been mentioned by most interviewees from their own initiative, underlying the importance of these tasks. These procedures are attributed to the project manager's role through his early engagement with the client and his leading and initiating role in procurement, tendering and setting up contracts (refer to Table 2.2 in Chapter 2).

A model of reciprocal interdependency such as represented in Figure 2.17 has also been recommended by Interviewee C, with at its centre a core group composed of the architect, M&E engineer, contractor and client. Project managers, being the client's advocate and managing the process through hard and soft skills, would lead this model from tendering through handover and monitoring.

4.4 CONCLUSION ON THE PRIMARY RESEARCH

Process competency, assessed according to the author's criteria, does not differ greatly between the three performance gap areas defined in Chapter 2: Design & Planning, Construction and Operation. The case studies however reveal very disparate results which appear to cluster according to the certification tool they were subject to. Those certifications identified to deliver buildings with performing as-built energy consumption levels also scored higher in the process competency evaluation.

Project managers seem to be the key driver of such a process optimisation, with their tasks already revolving around the project process and team members itself. Architects might be considered to champion this role considering their diversity on smaller projects, their primary focus however being design they thereby loose objectivity as a contributing project member to oversee and manage the whole project. Project managers are also present from the briefing stages on where they can induce stringency of performance target, possibly through low-energy certification tools, considering that proactive project members' involvement improves on the building delivery performance.

Their present role already including contracts, procurement, stakeholder and project control, they can direct these approaches according to Soft Landings, involving the client more and securing the follow-up on the project, Lean to analyse potential waste sources and eliminate them across disciplines, tasks and phases, and the Integrated Design Process based on iteration and collaboration, supported by contracts such as PPC2000 and NEC.

The need for project management for building performance is confirmed by leading members of the industry on the Green Building Store Blog (2012) and Interviewee F, who benefits of a large cross-disciplinary professional experience in construction.

5 CONCLUSION

5.1 GENESIS OF THE THESIS

This research started with the realisation that project managers were not involved in Passivhaus, where the focus is on designers and builders in the CEPH courses as well as the presence on conferences. The correlation between the two has been explored in existing literature leading to reveal an underlying issue to the situation which will be explored through a grounded theory, where a hypothesis formed on secondary data is tested through primary research.

5.2 SECONDARY DATA

Current literature already defines well the project manager's role around managing people, processes and the project environment throughout all RIBA phases, based upon soft and hard skills. This role however is adapting to new sustainable requirements, lead in construction by carbon reduction measures, mainly implemented through energy reduction.

Tools to address carbon and energy reduction have emerged, either as a general model giving a flexible choice on sustainable criteria (e.g. BREEAM in the UK) or as low-energy certificates where the reduction of energy is targeted through set values. Upon analysis of the as-built performance compared to the designed values through Post-Occupancy Evaluations, a gap between these values has been found. Low-energy buildings however seem to be hardly concerned by this issue because they are certified upon measured as-built values, whereas the general sustainable certification is based upon estimates.

Whilst the performance gap has barely been researched upon, management and processes are at the core of most cited causes. These can be split in three main phases: Design & Planning, Construction and Operation. Best practice processes to tackle these issues are therefore analysed.

Low-energy certificates such as Passivhaus improve on the first two phases through a rigid and well defined quality control system. The Operation phase includes facility management as well as the occupant's behaviour and usage of the building. These can be improved through the Soft Landings Framework, in which the client and users are heavily engaged in the project and a the delivered building is being monitored for three years by a continuous presence of Project Team members on the premises during that period. Lean aims at the reduction of waste and increase of value through a reduction of the supply chain and a simplification of the process tailored to solely fulfil the clients' needs. This would improve affordability of low-energy certification processes and Soft Landings, considering a current average additional cost of 15% to reach the Passivhaus standard (Newman and Whidborne, 2011) and monitoring which is rarely included in budgets at all. These three processes can be reinforced by iterative task and project management, encouraging proactive engagement and collaboration. The Integrated Design Process offers a model supporting iteration and reciprocal interdependency of project team participants.

A model based on the essence of these four best practices is offered in this research organised around the three identified performance gap phases. With elimination of labels a focus on idea is allowed, which appear to overlap on several areas such as project members interaction. This model leads to a consolidation of these ideas without restriction to specific tools or approaches, offering the flexibility of adaptation to individual projects. The skills and tasks emerging from this model are already integrated in the project manager's role, although with specific focus on quality and building performance.

5.3 PRIMARY DATA

Based on the findings of the secondary research, the author suggests that project managers can reduce the performance gap through improved processes. This hypothesis is tested through semi-structured based interviews conducted on ten professionals.

A assessment model has been created by the author to evaluate the process competency across the case studies. The results suggest a correlation between the building performance, judged according to the certification tool used, and the process competency. Projects using low-energy certification tools, demonstrated to perform according to the designed energy values, reached a high level in the process competency assessment, confirming the impact processes can have on the building. The weaknesses identified according to the author's scoring system support individual analysis on the certification processes, where non-certified projects clearly lack quality assurance and low-energy certification models perform worst in process optimisation although higher then on average projects. Improvement recommendations can be made to individually tackle issues based on this process improved approach, directly extracted from the model created based on the four best practice processes.

Project managers, as the client's advocate from the very start of the project, already have most 'tools' to improve the processes as suggested by the author and the participants. With their main function on briefing, contracts and procurement, quality control - rarely in the construction performance itself, but of all activities which are feed back to them – stakeholder management and other factors, project managers appear to be pre-disposed to lead this improvement.

First steps have already been taken with a clear increase of project collaboration through the use of partnering contracts. Considering the project manager's current functions and his cross-disciplinary presence focuses on the project process and the conclusive results obtained on the comparison of building performance and process optimisation, they have the possibility of influencing project outcomes and their energy performance through the proactive implementation of innovative processes.

5.4 RECOMMENDATIONS FOR FURTHER RESEARCH

Before leading to another research based on this dissertation, the consolidating the current work should be considered. Without the same financial and time constraints, the following steps could be taken:

- Secondary research
    - Collect more results on non-domestic building performance
    - Explore different best practice processes
- Data gathering

    - Utilise a more selective interview target (more similarity in project type and size to allow for better comparison)
    - Expand participants to an international level to avoid the bias of British construction practice
    - Interview different disciplines in the same project to reduce the impact of the participants' subjectivity on the project data
- Data objectivity
    - Request designed and as-built values (depending on their availability) of all projects, to confirm their actual performance level currently limited to a generalisation based on the certification model used.
- Data analysis
    - Increase systematic analysis through quantitative approaches such as standard deviation

A triangulation is also recommended to consolidate the findings, possibly through measured action research. Once this process improvement model is being reached, research is suggested on their performance against current standards including low-energy certification systems and their cost impact.

REFERENCES

Abdel-Wahab, M. S., Dainty, A. R. J., Ison, S. G., Bowen, P. and Hazlehurst, G. (2008) 'Trends of skills and productivity in the UK construction industry Engineering', *Construction and Architectural Management*, 15 (4), pp. 372-382.

An Inconvenient Truth (2006) Directed by Davis Guggenheim [Film]. Hollywood, California: Paramount Pictures.

APM (2006) *Project Management Body of Knowledge*, 5th edn. High Wycombe: Association for Project Management.

Ballard, G. and Howell, G. A. (2003) 'Lean project management', *Building Research & Innovation*, 31(2), pp. 119-133.

Bell, M. (2011) *Low carbon housing: Lessons from Elm Tree Mews* [Online]. Available at: http://www.jrf.org.uk/publications/low-carbon-housing-elm-tree-mews (Accessed: 30 November 2011)

Benich, A. (2011) 'Closing the gap. Air sealing and attention to IAQ offer a boost for home energy efficiency', *ed+c mag*, October, pp. 68-70.

Bordass, B. (2009) 'Building services: avoiding unnecessary energy demand and use through careful design and operation', Passivhaus schools conference RIBA, London, 11th December. Usable Buildings Trust. Available at: www.aecb.net/PDFs/PHS_Conference_09/PHS_BillBordass.pdf (Accessed: 03 December 2011).

BRE (2011) *Passivhaus*. Available at: http://www.passivhaus.org.uk/page.jsp?id=66 (Accessed: 07 December 2011).

BREEAM (2012) *Education case studies*. Available at: http://www.breeam.org/page.jsp?id=392 (Accessed: 29 February 2012).

British Standards Institute (2010) *6079-1:2010: Project management – Part 1: Guide to project management*. 3rd edn. London: British Standard Institute.

Carbon Trust (2007) CTV014 Technology Overview. Building fabric: Energy saving techniques to improve the efficiency of building structures . [Online] Available at: http://www.carbontrust.com/resources/reports/advice/technology-and-energy-management-publications (Accessed: 25 February 2012).

Center for Sustainable Energy (2012) *Energy certificate data* [Online]. Available at: http://www.cse.org.uk/pages/resources/open-data#display_energy_certificate_data (Accessed: 29 February 2012).

Chinyio, E. and Olomolaiye, P. (2010) *Construction stakeholder management*. Oxford: Blackwell Publishing Ltd.

Christopher, M. (2011) *Logistics Supply Chain Management*. 4th ed. Harlow: Pearson Education.

CIOB (2002) *Code of Practice for Project Management for Construction and Development*, 3rd edn. London: Blackwell Publishing.

CIOB (2010) *Code of Practice for Project Management for Construction and Development*, 4th edn. London: Blackwell Publishing.

Commission of the European Communities (2006) *Action Plan for Energy Efficiency: Realising the potential* [Online]. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0071:EN:PDF (Accessed: 14 December 2011).

Construction Task Force (1997) *Rethinking Construction* [Report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction].

Curtis, N. (2011) *Life Cycles - Application to Project Planning* [Online]. Available at: http://www.google.co.uk/url?sa=t&rct=j&q=apm%20project%20life%20cycle&source=web&cd=1&ved=0CCcQFjAA&url=http%3A%2F%2Fwww.apm.org.uk%2Fprotected_download%2Fsites%2Fdefault%2Ffiles%2Fprotected%2FLife%2520Cycles%2520-%2520Application%2520to%2520Project%2520Planning%2520Presentation%2520Neil%2520Curtis.pdf&ei=RsGzTt_NNpP48QPLtNCUBQ&usg=AFQjCNGrrv3Ix3zsMQkhpa5jLIZjH-5owA (Accessed: 04 November 2011).

Department of Health (2012) NHS Environment Assessment Tool guidance. [Online] Available at: http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_4119943 (Accessed: 05 March 2012).

DGNB (2011) *Ausgezeichnet. Nachhaltig bauen mit System*.Available at: http://issuu.com/manufaktur/docs/dgnb_ausgezeichnet_nachhaltig_bauen_mit_system?mode=embed&layout=http%3A%2F%2Fskin.issuu.com%2Fv%2Flighticons%2Flayout.xml&showFlipBtn=true&proShowMenu=true (Accessed: 05 February 2012).

Doodle (2012) Doodle easy scheduling. Available at: www.doodle.com (Accessed: 10 January 2012).

Edwards, B. (2010) *Rough Guide to Sustainability. A Design Primer.* 3rd edn. London: RIBA Publishing.

Energist (2012) *SBEM Calculations*. Available at: www.energistuk.co.uk/ (Accessed: 20 March 2012)

Farrell, P. (2011) *Writing a built environment dissertation: practical guidance and examples*. Oxford: Wiley-Blackwell.

Feist, W. (2005) *Climate Neutral Passive House Estate in Hannover-Kronsberg: Construction and Measurement Results*. Available at: http://www.passiv.de/07_eng/PEP/PEP-Info1_Kronsberg.pdf (Accessed: 10 December 2011).

Feist, W. (2009) *Certification as "Quality Approved Passive House". Criteria for Non-Residential Passive House Buildings*. Available at: http://www.passiv.de/ (Accessed: 10 December 2011).

Feist, W. (2011) *Passivhaus Institut*. Available at: http://www.passiv.de/ (Accessed: 10 May 2011).

Gann, M. D., Salter, A. J. and Whyte, J. K. (2003) 'Design Quality Indicator as a tool for thinking', *Building Research & Information*, 31(5), pp. 318–333.

Gardiner, J. (2011) 'Who's to blame for our lack of zero-carbon homes?' *Building.co.uk*, 30 September [Online]. Available at: http://www.building.co.uk/news/analysis/whos-to-blame-for-our-lack-of-zero-carbon-homes?/5025300.article (Accessed: 10 February 2012).

Gifford, H. (2009) 'A Better Way to Rate Green Buildings. LEED sets the standard for green buildings, but do green buildings actually save any energy?', *Northeast Sun*, Spring [Online]. Avaialble at: http://www.nesea.org/uploads/textWidget/876.00013/documents/nesea-sp09_Green_Buildings.pdf (Accessed: 12 December 2011).

Glumbo (2012) File Upload. Available at: http://glumbouploads.com/ (Accessed: 27 February 2012).

Great Britain. HM Government. Department for Business, Innovation and Skill and Department of Energy and Climate Change (2010) *Meeting the Low Carbon Skills Challenge* [Online] Available at: http://www.google.co.uk/url?sa=t&rct=j&q=%20hm%20government%2C%20meeting%20the%20low%20carbon%20skills%20challenge%2C%202010&source=web&c

d=2&sqi=2&ved=0CCIQFjAB&url=http%3A%2F%2Fwww.bis.gov.uk%2Fassets%2Fbiscore%2Fcorporate%2Fdocs%2Fl%2F10-849-low-carbon-skills-consultation.pdf&ei=Gf7UTr_OCMnx8QPa8aGOAg&usg=AFQjCNFiqWJ6iAhaSyDU1B4ip59MZZ9DNQ&cad=rja (Accessed: 29 September 2011).

Green Building Store (2012) Passivhaus Blog: Narrowing the performance gap. Available at: http://www.passivhausblog.co.uk/passivhaus-construction/narrowing-the-performance-gap/ (Accessed: 20 February 2012).

Grundey, D. (2008) 'Applying sustainability principles in the economy', *Baltic Journal on Sustainability*, 14 (2), pp. 101-106

Gunsolus, R. L. and Budaus, M. (2010) 'Lean and green. Improving the health care experience by maximizing efficiency', *The Health Facilities Management Magazine*, March, pp. 32-35.

Hall, S. (2012) APM Featured questions: When are project managers appointed in addition to architects? Available at: http://www.apm.org.uk/community/q-and-a/when-are-project-managers-appointed-addition-architects (Accessed: 27 March 2012)

Hartman, H. (2010) 'PassivHaus round-up. Beautiful and low-carbon: three very different projects showcase the next generation of PassivHaus design', *Sustainability in Practice,* AJ 28.10.2010, pp. 59-62.

Hodgson, G. (2008) 'Introduction to PassivHaus. A guide for UK application', *Bre Information Paper,* December.

Hunt, R. (2011) 'Passive voice heard round the world', *Ecohouse,* April [Online]. Available at:
http://www.google.co.uk/url?sa=t&source=web&cd=1&sqi=2&ved=0CB8QFjAA&url=http%3A%2F%2Fhuntwriter.com%2Fwp-content%2Fuploads%2F2011%2F05%2FEcoHouse_April11.pdf&rct=j&q=ecohouse

%20passive%20voice%20heard&ei=0YJ_Tt6BA4fD0QWR_dG6CQ&usg=AFQjCNF5T7YXWyL9HutO6Jmas84l4b1YOQ&cad=rja (Accessed: 25 September 2011).

IEA-SHC (2003) *International Energy Agency - Solar Heating and Cooling Programme: Task 23 guide* [Online] Available at: http://www.iea-shc.org/task23/publications/IDPGuide_print.pdf (Accessed: 20 October 2011).

Irish Energy Centre (no date) *What is a U-value?* [Online]. Available at: http://www.completehome.ie/files/whatisauvalue.pdf (Accessed: 14 December 2011)

I Six Sigma (2012) *7 Wastes of Lean*. Available at: http://www.isixsigma.com/dictionary/7-wastes-of-lean/ (Accessed: 2 March 2012).

Isover (no date) *Vivre confortablement et économiser de l'énergie. La Maison Multi-Confort : construite pour l'avenir.* [Leaflet obtained at the 15th International Passive House Conference in Innsbruck, Austria], 28 May 2011.

Karlp (2011) *A guide to Volume Calculations for Passivhaus Air Tightness Testing and the Difference with the UK Method*. Available at: http://www.peterwarm.co.uk/a-guide-to-volume-calculations-for-passivhaus-air-tightness-testing-and-the-difference-with-the-uk-method/ (Accessed: 05 February 2012).

Kaufmann, B. (2011) 'What is next for Passivhaus – Current Development at the Passivhaus Institut' UK Passivhaus Conference 2011. London, United Kingdom, 24 – 25 October.

Knight, A. and Ruddock, L. (2008) *Advanced Research in the Built Environment*. Oxford: Blackwell Publishing Ltd.

Lewis, J. (2011) *Project planning, scheduling & control: the ultimate hands-on guide to bringing projects in on time and on budget*. 5th edn. New York : McGraw-Hill

Liphe4 and the Institut de Ciència i Tecnologia Ambientals (2011) *Our Energy Futures: Interfacing Scientists and Society in a Discussion over the Global Energy Crisis*. Available at: http://ourenergyfutures.org/page-cid-7.html#Primary_Energy_Sources (Accessed: 12 December 2011).

Low Carbon Cluster (2009) *Sector Skills Assessment Report* [Online]. Available at: www.goskills.org/download.php?fileid=3579 (Accessed: 29 November 2011).

Lützkendorf, T. and Lorenz, D. (2005) 'Sustainable property investment: valuing sustainable buildings through property performance assessment', *Building Research & Information*, 33 (3), pp. 212-234.

Matzig, R. (2011) 'The world's first Passivhaus hospital with the UK and German Perspective' UK Passivhaus Conference 2011. London, United Kingdom, 24 – 25 October.

McDonough, W. and Braungart, M. (2002) *Cradle to cradle: remaking the way we make things*. New York: North Point Press.

Menzes, C. (2011) 'Bridging the gap between predicted and actual energy consumption in non-domestic buildings', *Innovative & Research Focus*, Issue 87 November. Available at: http://www.innovationandresearchfocus.org.uk/articles/html/issue_87/energy_consumption_in_non_domestic_buildings.asp (Accessed: 16 January 2012).

Moscow, K. (2008) *Sustainable Facilities. Green Design, Construction and Operations*. London: McGraw Hill.

Naoum, S. G. (2007) *Dissertation Research and Writing for Construction Students*. 2nd edn. Oxford: Elsevier Ltd

NBS (2011) *Approved Document L2A: Conservation of fuel and power (New buildings other than dwellings)*. [Online] Available at:

http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/approved (Accessed: 07 February 2012).

Newman, N. and Whidborne, R. (2011) ‘What does Passivhaus cost? Sourcing and supply chain’ UK Passivhaus Conference 2011. London, United Kingdom, 24 – 25 October.

ÖGNI (2012) Verein. Available at: http://www.ogni.at/de/verein/ (Accessed: 05 February 2012).

Ohno, T. (1988) *Toyota production system: beyond large-scale production*. Translated by Rosen, C. B. Reprint, New York: Productivity, Inc.

Oppenheimer, S. J. (2008) ‘Understanding the R and U-Values of Insulation’, *Buildings*, 102 (6), p. 50.

Oppitz-Plörer, C. (2011) ‘Opening remarks by the Mayor of Innsbruck.’ The 15th International Passive House Conference. Innsbruck, Austria, 27 – 28 May. Darmstadt: Passive House Institute, pp. 11-12.

Passivhaus Institute (2009) *CEPH Course* [CEPH course for Passivhaus certified designers] Darmstadt: Passivhaus Institute.

Passivhaus Institute (2011a) *Passipedia; Energy use – measurement results*. Available at: http://passipedia.passiv.de/passipedia_en/operation/operation_and_experience/measurement_results/energy_use_measurement_results (Accessed: 10 December 2011).

Passivhaus Institute (2011b) *Passipedia; Examples*. Available at: http://passipedia.passiv.de/passipedia_en/examples (Accessed: 01 December 2011).

Passivhaus Institute (2011c) *Passipedia; Mechanical Ventilation with Heat Recovery*. Available at:

http://passipedia.passiv.de/passipedia_en/basics/what_is_a_passive_house (Accessed: 01 December 2011).

Passivhaus Institute (2011d) *Passipedia; Thermal bridges*. Available at: http://passipedia.passiv.de/passipedia_en/basics/building_physics_-_basics/heat_transfer/thermal_bridges (Accessed: 01 December 2011).

Paverz, I., Gonzalez, V. and Alarcon, L. F. (2010) 'Improving the Effectiveness of New Construction Management Philosophies using the Integral Theory', *Revista de la Construcción*, 9(1), pp. 26-38.

Resource Engineering Inc. (2012) *The Seven Wastes*. Available at: http://www.qualitytrainingportal.com/resources/lean_manufacturing/form_44a_app1.htm (Accessed: 2 March 2012).

RIBA (2008) Royal Institute of British Architects. *Outline Plan of Work* [Online] Accessed at: http://www.architecture.com/Files/RIBAProfessionalServices/Practice/OutlinePlanofWork(revised).pdf (20 September 2011)

RIBA (2011) Royal Institute of British Architects. *Green overlay on the Outline Plan of Work* [Online] Accessed at: http://www.ribabookshops.com/uploads/9a0204f4-8775-d644-c9d1-b2d508c5924b.pdf (Accessed: 2 December 2011).

Ryan, C. (2011) *AmbiWood products and services*. [Supplier presentation to UK Passivhaus Conference 2011 visitors]. 24 October.

SPHC (no date) Passive House [Leaflet obtained at the London Passivhaus Conference 2011], 24 October 2011.

Sakalauskas, L. (2010) 'Sustainable models and indicators', Technological and Economic Development of Economy, 16 (4), p. 567-577.

Salvatierra-Garrido, J. and Pasquire, C. (2011) ‘Value theory in lean construction’, *Journal of Financial Management of Property and Construction*, 16 (1), pp. 8-18

Seddon, J. (2005) Freedom *from command & control. A better way to make work work*. Buckingham: Vanguard Education Ltd.

Smith, D. (2012) ‘Questions time’, *RICS Construction Journal*, February-March.

Stern, N. (2006) *Stern Review on the Economics of Climate Change.* [Online]. Available at: http://webarchive.nationalarchives.gov.uk/20110218142827/webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/sternreview_index.htm (Accessed: 03 September 2010).

Swetnam, D. (2004) *Writing your dissertation*. Oxford: How To Books.

Treberspurg, M., Smutny, R. and Grünner, R. (2010) ‘Energy monitoring in existing Passive House housing estates in Austria’ The 14th International Passive House Conference. Dresden, Germany, 28-29 May. Darmstadt: Passive House Institute, pp. 35-41.

The Engienering ToolBox (2012) *Air Change Rate*. Available at: http://www.engineeringtoolbox.com/air-change-rate-d_882.html (Accessed: 05 February 2012).

UNFCC (2011) *Status of Ratification of the Kyoto Protocol*. Available at: http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php (Accessed: 10 November 2011).

Usable Building Trust (2009) *The Soft Landings Framework for better briefing, design, handover and building performance in-use*. Bracknell: BSRIA Limited (Building Applications Guide BG 4/2009).

Usable Building Trust (2010) *Soft Landings for Schools. Case studies*. Bracknell: BSRIA Limited (Building Applications Guide BG 9/2010).

Usable Building Trust (2012) *Probe.* Available at: http://www.usablebuildings.co.uk/ (Accessed: 02 February 2012).

U.S. Energy Information Administration (2011) 'Environment', *Monthly Energy Review*, April, pp. 159-171.

US Green Building Council (2011) *What LEED Measures*. Available at: http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1989 (Accessed: 12 December 2011).

Walker, A. (2007) *Project Management in Construction*, 5th edn. Oxford: Blackwell Publishing.

Way, M. (2006) 'Soft landings. A fresh scope of service that ensures users and clients get the best out of a new building', *Journal of Facilities Management*, 4 (1), pp. 23-39.

Williamson, J. (2011) 'Passivhaus occupant satisfaction: POE and measured performance' UK Passivhaus Conference 2011. London, United Kingdom, 24 – 25 October.

Winser, J. D., Tan, K.-C. and Leong G. K. (2009) *Principles of Supply Chain Management: A Balanced Approach*. 2nd edn. Mason: Cengage Learning.

Zero Carbon Hub (2010) 'Topic 4: Closing the Gap between designed and built performance', *Carbon Compliance for tomorrow's new homes. A review of the modelling tool and assumptions* [Online] Available at: http://www.zerocarbonhub.org/definition.aspx?page=8 (Accessed: 06 December 2011).

Zira, C. (2010) *Three European Standards for Energy Assessment of Buildings. A Comparison between The Passivhaus Standard, the Standard Assessment Procedure and the Bâtiment Basse Consommation*. Saarbrücken: Verlag Dr. Müller Aktiengesellschaft & Co. KG.

BIBLIOGRAPHY

Atkinson, R. (1999) 'Project management: cost, time and quality, two best guesses and a phenomenon, it's time to accept other success criteria', *International Journal of Project Management*, 17 **(**6), pp. 337-342.

Blineder, P. (2009) *Passivhaus – Haus der Zukunft. Werden sich Passivhäuser als Baustandard durchsetzen?* Saarbrücken: Verlag Dr. Müller Aktiengesellschaft & Co. KG.

Building4Change (2011) *Wolfgang Feist on 20 years of Passivhaus*. Available at: http://www.youtube.com/watch?v=vRK_a-8IAUU&lr=1 (Accessed: 09 December 2011).

Casakin, H. P. and Miller, K. (2008) 'Individual learning styles and design performance in the metaphorical reasoning process', *J. Design Research*, 7 (3), pp. 275-293.

Construction Skills (2010) Understanding Future Change in Construction [Online]. Available at: www.pyetait.com/wp-content/uploads/2011/08/Link-6.pdf (Accessed: 29 November 2011).

Cutland Consulting Limited (2011) Zero re- re- re-defined. Available at: http://www.cutlandconsulting.co.uk/Article.aspx?aID=23 (Accessed: 10 February 2012).

Department for Communities and Local Government (2010) *Code for Sustainable Homes: Technical Guidance - November 2010* [Online] Available at: http://www.communities.gov.uk/publications/planningandbuilding/codeguide (Accessed: 03 August 2011).

Energy Design Update (2010) 'Conference Explores Gaps and Barriers in Residential Building', *Energy Design Update* October

Gentoo Homes (2009) *Code Word: A Review of Traditional & PassivHaus based designs against the Code* [Online] Available at: http://www.gentoohomes.com/?article=8857&track=/657/688/ (Accessed: 20 March 2010).

Görg, M. (2011) 'Passive House: regionally based – globally efective' The 15th International Passive House Conference. Innsbruck, Austria, 27 – 28 May. Darmstadt: Passive House Institute, pp. 53-61.

Holladay, M. (2008) 'Industry News. An Interview With Wolfgang Feist' *Energy Design Update*, 20(1), pp. 1-6.

Kochendörfer, B., Liebchen, J. H. and Viering, M. G. (2010) *Bau-Projekt-Management. Grundlagen und Vorgehensweisen*. 4th edn. Wiesbaden: Vieweg+Teubner Verlag.

Kyoto Protocol (1997) *The Kyoto Protocol to the United Nations Framework Convention on Climate Change*. Kyoto: UNEP/WMO.

Lane, T. (2011) 'A lot to live up to: Building houses that meet predicted energy use', *Building.co.uk*, 09 December [Online]. Available at: http://www.building.co.uk/technical/specifier/design-and-specification/a-lot-to-live-up-to-building-houses-that-meet-predicted-energy-use/5028420.article (Accessed: 10 February 2012).

Lean Construction Institute (2011) Building knowledge in design and construction [Online] Available at: http://www.leanconstruction.org/ (Accessed: 28 November 2011).

McKinsey (2009) Averting the next energy crisis: The demand challenge. Available at: http://www.mckinsey.com/mgi/publications/next_energy_crisis/index.asp (Accessed: 06 November 2011).

Mintzberg, H. (2009) *Managing*. San Fransisco: Berrett-Koehler Publishers, Inc.

O'Donnell, H., Karallis, T. and Sandelands, E. (2008) 'Reflecting on the skills agenda: a construction industry perspective', *Education + Training*, 50 (1), pp. 59-63.

Morris, P. and Matthiessen, L. F. (2005) 'Budgeting green: A comprehensive methodology', *AACE International Transactions*, EST. 06.1-06.4, 4p.

Pitt, V. (2011) 'Two contractors set to guarantee energy performance', *Building* [Online]. Available at: http://www.building.co.uk/two-contractors-set-to-guarantee-energy-performance/5028966.article (Accessed: 31 January 2012).

Pound, R. (2011) Influencer: the power to change anything [Continuous Professional Development seminar for the APM]. 29 November.

Rose, B. (2010) 'Bridging the Gap Between Building Performance and Architecture', *Energy Design Update* August

Salem, O., Solomon, J., Genaidy, A. and Minkarah, I. (2006) 'Lean Construction: From Theory to Implementation', *Journal of Management in Engineering*, 22 (4), pp. 168-175.

Treberspurg, M. and Smutny, R. (2011) 'The Vorgartenstrasse residential complex in Vienna' The 15th International Passive House Conference. Innsbruck, Austria, 27 – 28 May. Darmstadt: Passive House Institute, pp. 85-96.

Trends - how to maintain your 'green' buildings (2010) ABC Radio National, 24 November. Available at: http://www.abc.net.au/radionational/programs/bydesign/trends---how-to-maintain-your-green-buildings/2969866 (Accessed: 5 February 2012).

Whalley, S. (2011) 'Low carbon project design', *Innovative & Research Focus*, Issue 87 November. Available at: http://www.innovationandresearchfocus.org.uk/articles/html/issue_87/low_carbon_project_design.asp (Accessed: 16 January 2012).

A 1 APPENDIX 1: SUSTAINABILITY MODELS

Figure 5.1 compares the ‘Venn Diagram’ to the ‘Nested Diagram’, where the former allocates equal importance to the three aspects while the environmental aspect is considered central in the latter (Lützkendorf and Lorenz, 2005, p.213-214). Extended versions have also been proposed by Lützkendorf and Lorenz (2005, p.214) in Figure 5.2 and Edwards (2010, p.29) in Figure 5.3.

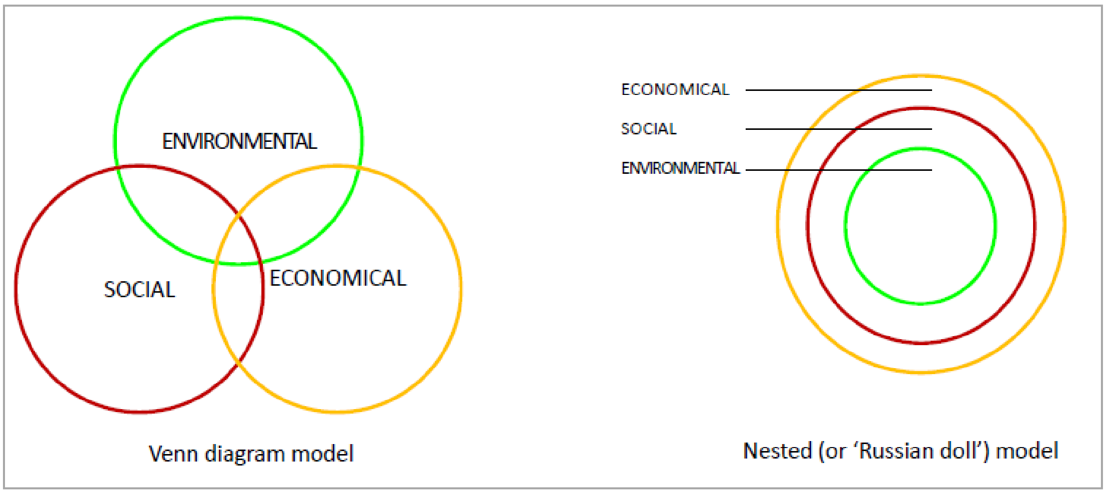

Figure 5.1: ‘Tripple Bottom Line’ models (Adapted from Lützkendorf and Lorenz, 2005)

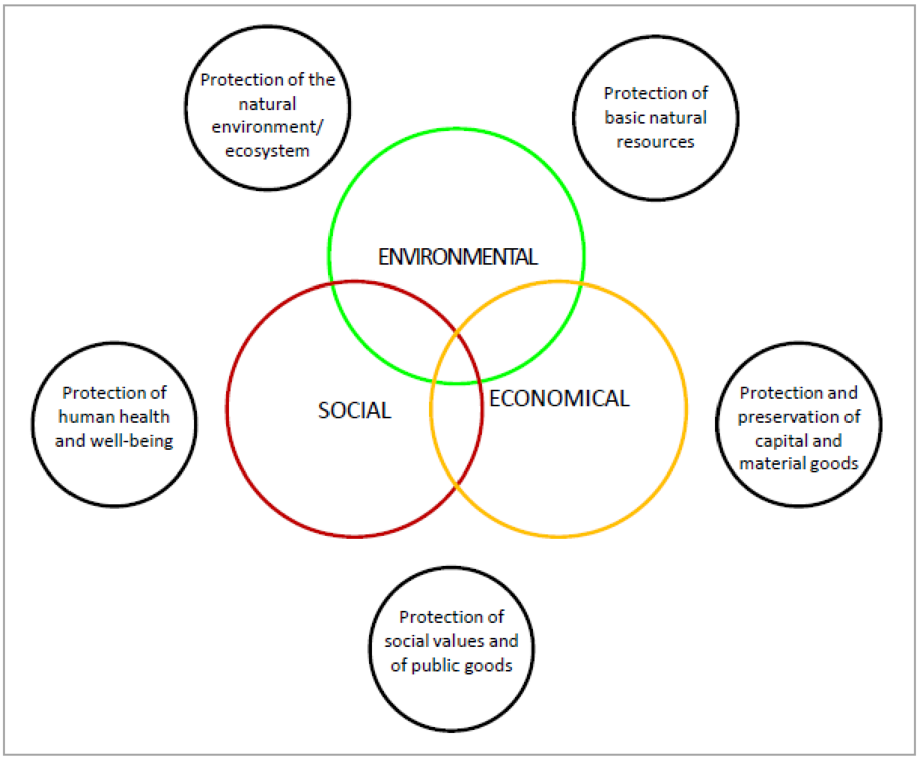

Figure 5.2: Extended sustainability model (Based upon Lützkendorf and Lorenz, 2005)

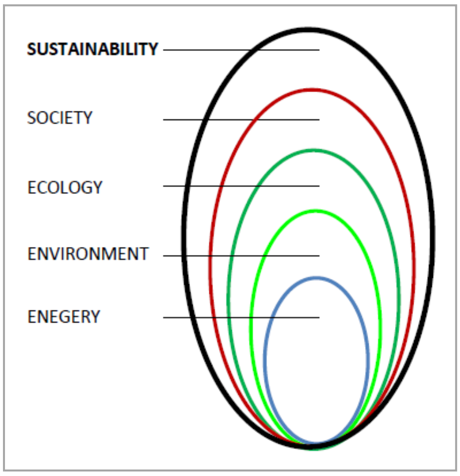

Figure 5.3: Extended sustainability model (adapted from Edwards, 2010, p.29)

A 2 APPENDIX 2: PASSIVHAUS TECHNICAL SUMMARY

Based on the Passivhaus certification criteria stipulated in Chapter 2, certain attributes can be recognised as assisting with achieving the Passivhaus standard in a Northern European Climate. These will be discussed below, based on information from the Passivhaus website (Feist, 2011), Passipedia (Passivhaus Institute, 2011), the CEPH course (Passivhaus Institute, 2009), Isover's multi-comfort house brochure (Isover, no date), and exhibitions and presentations held at the 15th International Conference in Innsbruck (2011) and the UK Passivhaus Conference 2011 in London.

A 2.1 INSULATION

A high amount of qualitative and/or quantitative insulation has to form an exterior skin to the building, protecting any temperature influence from materials (e.g. foundations) or the external climate. Roofs, external walls and floor slabs are typically expected to reach a U-Value of 0.15W/m²K, corresponding to 250-300mm of standard insulation materials (Passivhaus Institute, 2009).
Insulation is part of the 'Fabric First' concept Passivhaus is based on, which creates low-energy buildings by a high quality in material choice and construction techniques.

A 2.2 THERMAL BRIDGING

The Passivhaus Institute (2011d) defines a thermal bridge as a "localised area of the building envelope where the heat flow is different (usually increased) in comparison with adjacent areas (if there is a difference in temperature between the inside and the outside)". Heat loss and surfaces more prone to moulding through increased humidity are the consequences of thermal bridges. It is expressed as a loss coefficient.

Thermal bridges are found at junctions and interfaces between elements and components and where building components reach through the whole building fabric. To limit thermal bridges, a continuous insulation layer has to separate all building components between the interior and exterior skin of the building.

A 2.3 AIRTIGHTNESS

Air leakage through the building means loss of warm air and penetration of cold air. To prevent that, several steps have to be taken:

- External walls constructed with precision.
- Sealing between the walls and openings (windows and doors).
- Great care paid to vulnerable junctions (angles and junctions between the roof and walls).
- Air barrier systems such as the Isover membrane (Isover, no date). The latter has to be protected from any intrusion of services or penetrations from wall hangings. It can only be taped as staples would perforate it and create air leakage.

Figure 5.4: Airtight membrane (Isover, no date)

Airtightness is measured with blower-door tests to ensure performance certainty. All openings are kept close, and a ventilator is installed and sealed at the entrance door's space. Air can be introduced by using the fan to place the building under positive or negative pressure and the corresponding air leakage can then be measured. This test should be executed several times, providing knowledge about the improvements necessary. A crucial moment for frame constructions mostly is after the installation of all services and before any interior fitting. Another one is at when all fittings are in and the building is completed, to measure the airtightness of the final product.

Figure 5.5: Blower-door test (Isover, no date)

Windtightness, although not a specific requirement of Passivhaus, is generally required by Certifiers to provide the desired thermal efficiency. It is the protection of insulation from any air circulation from the outside. The principles are the same as for the airtightness.

A 2.4 MECHANICAL VENTILATION WITH HEAT RECOVERY (MVHR)

Mechanical ventilation is required to compensate for the high airtightness. With the MVHR system, indoor air is extracted from ‘polluted’ rooms (bathrooms, toilets, kitchen), and external fresh air is infused in living spaces (e.g. bedrooms or living room). The difference in air pressure between the rooms guarantees the air flow.

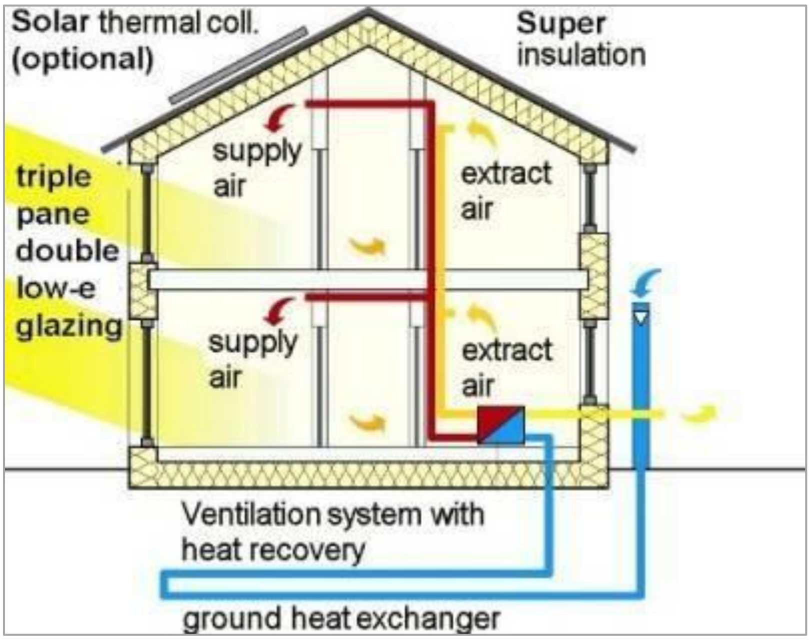

Figure 5.6: MVHR. Source: Passivhaus Institute (2011c)

Before the extracted air is released outside, it goes through a heat exchanger to warm the fresh incoming air, thus keeping the inside warm with minimal or no need of additional heating.

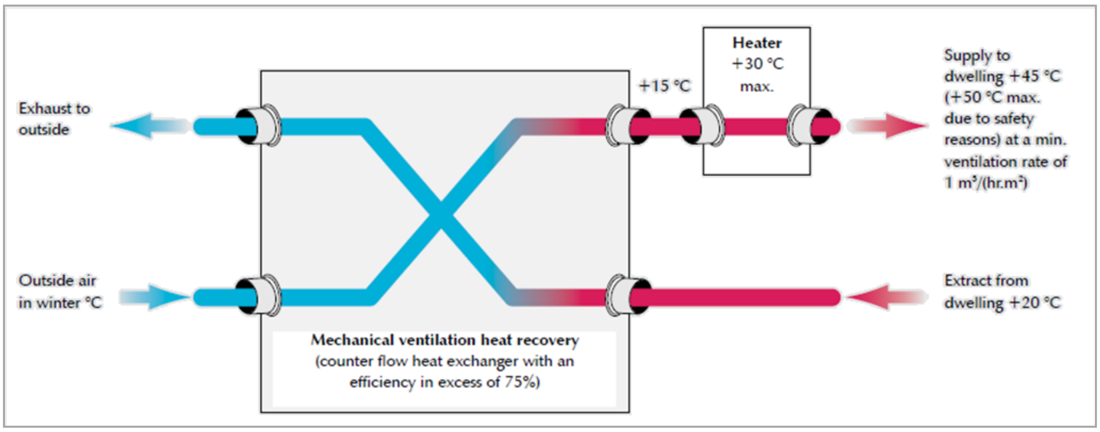

Figure 5.7: Hodgson (2008) The technical basis of PassivHaus

A 2.5 Windows and doors

Windows can reach the very demanding U-value through triple-glazing, preferably Argon-filled, three consecutive joints providing airtightness in closed position and insulated frames. Doors are also heavily insulated and require airtightness in closed position. Junctions between frame and structure for both windows and doors have to be perfectly sealed too. All these criteria prevent thermal bridings and air while securing a high comfort level according to the German DIN EN ISO 7730 (Passivhaus Institute, 2009) and its UK equivalent BS EN ISO 7730. For further detail is provided in the glossary of terms.

Manufacture of these products is mainly in Germany and Austria because of the greater number of Passivhaus constructions in this region. Holbrook Timber Frame only recently became the first UK manufacturer of Passivhaus windows. Due to small quantities and high technical requirements, often added by transportation cost for projects outside of Germany and Austria, the price of products suitable to the Passivhaus standard is very high.

A 2.6 Advantages and challenges of Passivhaus

Table 5.1, based on Feist's (2011) and Lützkendorf and Lorenz's (2005) observations, outlines the advantages of Passivhaus as highly sustainable buildings, as well as the challenges that simultaneously arise.

Advantages	Challenges
▪ Significant running cost savings ▪ High comfort through filtered and constant fresh air ▪ High comfort through minimal surface temperature differences ▪ Better health of inhabitants, leading amongst others to less absenteeism at work ▪ Low maintenance due to simple servicing systems ▪ Low carbon emissions in compliance with new sustainability regulations (in fact much higher than the requirements) ▪ Marketing image ▪ High quality fabric leading to a long lifespan of the building ▪ Higher buildings quality increasing the selling or tenancy price ▪ Shorter letting periods	▪ Likely higher investment cost (Newman and Whidborne, 2011) ▪ Global misunderstandings, e.g. thinking that the design has to be an unpleasant rectangle or windows cannot be opened (Williamson, 2011; Hartman, 2010) ▪ Climate challenges not yet overcome with difficulties especially in hot and humid climates (Kaufmann, 2011) ▪ Difficulties of material supply through manufacturing mostly present in Germany and Austria: high costs and time (Newman and Whidborne, 2011) ▪ Some building types still in prototyping stage, e.g. hospitals, public pools (Matzig, 2011) ▪ Highly skilled staff needed for design and construction ▪ Training courses only available to designers and to trades from 2012 on (Feist, 2011)

Table 5.1: Advantages and drawbacks of Passivhaus buildings

The list of perceived challenges is long, but most are due to the fact that the concept is still at an early stage of the learning curve in most countries (Germany and Austria might be considered as exceptions), and many could be overcome easily when Passivhaus becomes more widely spread:

Challenges	Proposed solutions
Higher investment cost	In average between 10% - 15% (Newman and Whidborne, 2011), but has been found to be between nil and 2% if well executed (Lützkendorf and Lorenz, 2005). The 2% could even be reduced by a better procurement and project management
Global misunderstandings (e.g. thinking that the design has to be an unpleasant rectangle or windows cannot be opened)	Pre-conceived ideas are being tackled and will disappear as Passivhaus will gain in popularity an awareness
Climate challenges not yet overcome (difficulties especially in hot and humid climates)	Passivhaus has been started in Germany and only recently started spreading to regions with such climatic conditions. Some projects have already been successfully realised, and new solutions are continuously explored
Difficulties of material supply through manufacturing mostly present in Germany and Austria: high costs and time (Newman and Whidborne, 2011)	It is the same issue as the previous point. With the recent expansion of Passivhaus projects, the UK has also seen the emergence of national manufacturers such as Holbrook Timber Frame
Some building types still in prototyping stage (e.g. hospitals, public pools)	It is only a temporary issue due to the learning curve, and is already being explored (Matzig, 2011)
Highly skilled staff needed for design and construction	Training courses are expanding, a higher number of trades are trained and it will improve with time (learning curve) as statutory energy efficiency requirements increase
Training courses only available to designers and recently also trades	Might the same courses be sufficient enough to train all the other trades?

Table 5.2: Passivhaus drawbacks analysis

Passivhaus has significant advantages and, considering Table 5.2, great possibilities to improve further. It also fits into the ‘triple bottom line’ (Lützkendorf and Lorenz, 2005, p.213). The Venn diagram model (Figure 5.1) has been chosen to picture Passivhaus’ sustainability compliance in Figure 5.8, due to the equal representation of the three aspects. Keeping the three aspects on equal ground permits a more objective view on the project, independently from diverse client priorities.

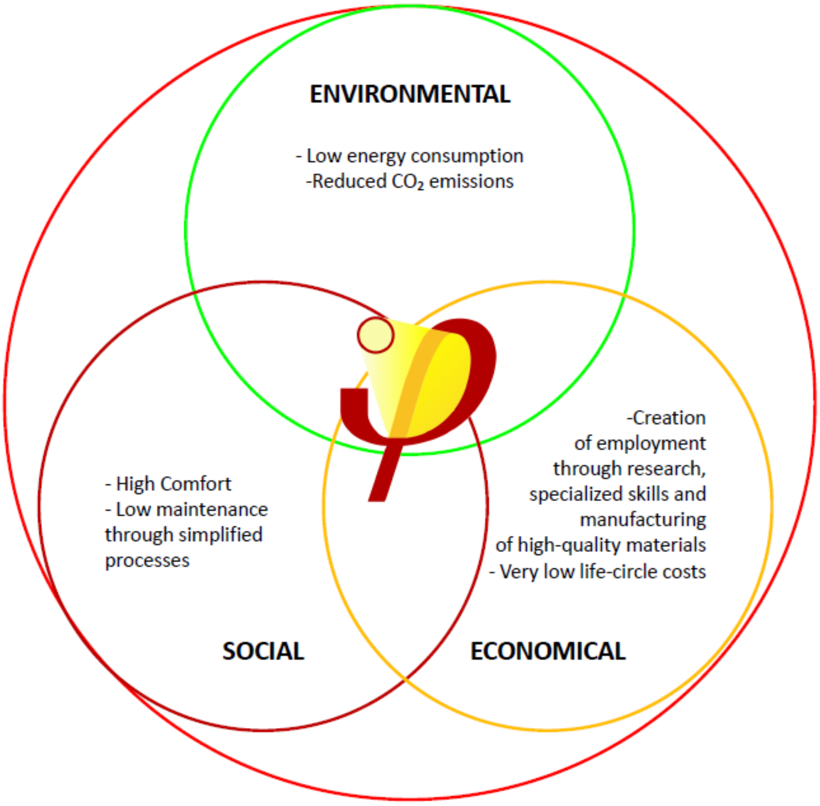

Figure 5.8: Integration of Passivhaus in the sustainable model

A 3 APPENDIX 3: INTERVIEW BRIEF

RESEARCH INFORMATION

Title	Reducing the performance gap through improved project management.
Researcher	Natacha Redon
Course	Bsc(Hons) Building Project Management
University	Northumbria University, Newcastle Upon Tyne, UK
Contact	natacha.redon@northumbria.ac.uk 0044 7552 11 7552
Study supervisor	Mark Siddall

BRIEF PROBLEM STATEMENT

New sustainable construction standards have emerged to respond to environmental issues. BREEAM, LEED, Code for Sustainable Homes or Zero Carbon Homes are examples or these standards which emerged and recently increased in popularity. Post-occupancy studies such as the PROBE studies however revealed an important gap between the designed and as-built performance. This study analyses several innovative processes and aims to evaluate if they can close this gap through case studies of both performing and non-performing buildings.

No further details are being revealed before the interview to preserve your objectivity towards the subject.

INTERVIEW PREPARATION

To facilitate the response to technical questions, please choose a new-built commercial or educational project you worked on; reviewing the project facts is recommended before the interview, including technical aspects and size indications such as surface, cost and timeframe of the overall project.
To facilitate the interviewer’s understanding of the project team member’s hierarchy, it would be appreciated if you could provide a project organogram before the start of

the interview. The data will be protected and only be used as an anonymous analysis of the structure.

Interview timeframe: 50 minutes – 1 hour

ETHICAL CONSIDERATIONS

- The interview will be recorded to capture all the information. The data will be protected and will be used purely for academic purpose.
- Confidentiality and full anonymity will be secured: you will be referred as "Interviewee X" and any person or company mentioned will only be referred to through their role in the project.
- A signed consent form will be required from you before proceeding to the interview. Please find the consent form along with this brief.
- Any names or sensitive data on the recording will be blanked before the file is added to the evidence file for the examiners. Your consent will be asked for the use of direct quotes.
- The results will be used for the dissertation. An electronic copy of the final study will be sent to you upon your request.
- You are free to retract your participation to the study at any moment.

If you have any questions or concerns, you can contact myself or my dissertation supervisor:

Mark Siddall
Senior Lecturer
School of the Built Environment
Northumbria University
Ellison Place
Newcastle Upon Tyne NE1 8ST
mark.siddall@northumbria.ac.uk

Thank you for taking the time to read this information sheet carefully.

A 4 APPENDIX 4: CONSENT FORM

SCHOOL OF THE BUILT AND NATURAL ENVIRONMENT

RESEARCH PARTICIPANT CONSENT FORM

Name of participant	
Organisation	
Researcher's name	Natacha Redon
Title of research project/dissertation	Reducing the performance gap through improved project management
Programme of study	Bsc(Hons) Building Project Management
Supervisor's name	Mark Siddall

Standard statement of participant* consent (please tick as appropriate):

I confirm that:

I have been briefed about this research project and its purpose and agree to participate* ☐

I have discussed any requirement for anonymity or confidentiality with the researcher** ☐

I agree to being audio taped / videotaped during the interview ☐

** Participants under the age of 18 normally require parental consent to be involved in research.*

***Specific requirements for anonymity or confidentiality*

Signed **Date**

Standard statement by researcher

I have provided information about the research to the research participant and believe that he/she understands what is involved.

Researcher's signature Date

1

A 5 APPENDIX 5: CONSENT FORM FOR THE EXTRACTED DATA

SCHOOL OF THE BUILT AND NATURAL ENVIRONMENT

RESEARCH PARTICIPANT CONSENT CONFIRMATION FORM

RECORDING

Name of participant	
Organisation	
Researcher's name	Natacha Redon
Title of research project/dissertation	Reducing the performance gap through improved project management
Programme of study	Bsc(Hons) Building Project Management
Supervisor's name	Mark Siddall

Standard statement of participant* consent (please tick as appropriate):

I agree to the direct use of the following recorded data:

Censored audio file ☐

Information extract as follows in this document. ☐

Quotations as follows in this document. ☐

** Participants under the age of 18 normally require parental consent to be involved in research.*

***Specific requirements for anonymity or confidentiality*

Signed **Date**

1

The table with the extracted data as well as selected quotations from the recording follow this first page in the individual consent form.

A 6 APPENDIX 6: INTERVIEW QUESTIONS GUIDELINE

1 Project

1.1 Name & Address

1.2 Type (Commercial, Educational)

1.3 Surface

1.4 Cost

1.5 Project Start and End (all RIBA stages)

1.6 Did the project receive any sustainable certificates? BREEAM, Code of Sustainable Homes, LEED, Passivhaus…

2 Interviewee

2.1 What was your Appointed Role(s) in the Project?

3 Design

3.1 What do you judge important for the delivery of low-carbon buildings, considering process and building technology?

3.2 Now that Low-Carbon has been addressed, what do you judge important for the delivery of low-energy buildings?

3.3 How would you ensure the execution of the measures you mentioned for the delivery of low-energy buildings?

3.4 How did you assess which M&E services equipment should be adopted? (In your opinion, how could it have been improved?)

3.5 How has thermal comfort been addressed in the project?

3.6 Did the schedule include specific performance-relevant milestones? (airtightness measuring stages, fit-out after services etc.)

3.7 What approach has been used to estimate energy consumption? (SAP, PHPP, rough estimate based on previous projects…)

3.8 In your opinion, how could the results have been improved?

3.9 How do you define value?

3.10 How did you try and evaluate the client’s priorities?

3.11 How did you try to implement those priorities?

3.12 Did you set any DQIs, KPIs, earned value or benchmarks? If yes, how have they been implemented through the project?

3.13 How has the supply-chain interdependence been optimised? (Geography, contracts, scheduling, suppliers etc. In your opinion, how could it have been improved?)

3.14 How were conflicting demands reconciled through the change management process? (task dependency, cost, time – supply, energy performance, KPIs/DQIs etc)

3.15 To what extent have the client and/or user been involved in the design up to stage D?

3.16 To what extent has the client and/or user been involved in the design up to stage L?

3.17 At what point was a FM appointed?

3.18 How much input did he have into the design and construction? (In your opinion, how could it have been improved?)

3.19 Have Lessons Learnt from previously completed similar projects been analysed at the project start? If yes, what has been raised?

4 Construction

4.1 Have any airtightness tests and measurements been executed on the project? If yes, how and what standard of performance was achieved? (blower-door test, air injection, suction, gas test if failed)

4.2 Have any specific quality assurance measures been adopted to reduce the carbon emissions/energy use? (Thermography, pressure test,)

4.3 In your opinion, how could the results have been improved?

4.4 Were there any specialists for quality insurance on site (air-tightness champion, design facilitator...)?

4.5 Were there any measures to secure a close working relationship to suppliers? (In your opinion, how could it have been improved?)

4.6 Did you commission the mechanical services equipment? Which equipment? (system or single)

4.7 Could you please explain the hierarchy of the project?

4.8 How were project specific challenges addressed? (prevention, mitigation, reparation, analysing the source of the problem… In your opinion, how could it have been improved?)

4.9 How did you optimise the project process? (7 forms of waste: excessive documentation, waste of movement etc. In your opinion, how could it have been improved?)

4.10 How closely did the project team work together? Why do you think was that the case?

4.11 Was improvement/ innovation encouraged? How? (incentive; penalty; awareness…)

4.12 How has buildability been addressed? (design facilitator; coordination between design and construction etc. In your opinion, how could it have been improved?)

4.13 Have there been any feedback or feedforward workshops? If yes, when, who was included and what matters have been raised? (internal to project, to the supplier…? At what stage were they adopted?)

5 Operation

5.1 Was there any monitoring after project hand-over? If yes, what, for how long and what were the resulting values? (In your opinion, how could it have been improved? Achieved values compared to designed values?)

5.2 Have Lessons Learnt been delivered at the end of the project? If yes, in what form and to whom (report, workshops, client, contractor, supplier etc.

5.3 In your opinion, how could it have been improved?)

5.4 Can you describe how the handover process has been executed? (giving a manual, workshops, who was involved…?)

5.5 How have the building occupants' use and understanding of the facilities been ensured?

5.6 What presence did the project team have at the building after handover and for how long? (who went there, has there been a system monitoring and adjustments made according to behaviour and seasons; was he based on site; how much contact with the users. In your opinion, how could it have been improved?)

Thank you for your participation.

A 7 APPENDIX 7: INTERVIEW DATA

	Interviewee B
Company	Company B
Role	Planner - Contractor PM
Project type	New-built educational building incl. medical labs – next to existing
Project size & duration	8,000m² £18m 08.2008 – 01.2010
Certifications	BREEAM very good
Understanding of low-carbon requirements	Design should be understandable for construction team (was in this case neither clear nor explained). Airtightness test.
Difference made between low-carbon and low-energy	Only look at installing designed solutions – no further opinion.
Implementation measures for low-energy	Communication with the client and designer. Workshops from designers to management, who passes on to operatives (ideally direct communication, but not realistic) Videos on best practice (e.g. on Youtube)
Assessment of M&E equipment	Build what was specified by the M&E engineer
Thermal comfort in the project	Build what was specified (time & cost more important – quality is defined by design) Chilled beans (active & passive) Build at specified U-values Air-flow consideration Temperature Room size adapted
Impact on schedule	Usual programme + tests (4 weeks of airtightness testing) and commissioning period Mostly H&S milestones
Energy estimation tool	Doesn't know
Definition of value	What is important to a person, i.e. design to a client and money for a contractor – the rest is waste (thinking of lean)
Definition of client priorities	Requirements to respond their bid to it.
Implementation of client priorities	Communication, especially design explanation from contractor to sub-contractors. Time is easy to 'sell' to a client, whereas quality is more difficult because of cost
DQI, KPI, earned value, benchmarks	Earned value: only works in theory KPIs on H&S or overall programme and budget BREEAM assessment requirements
Optimisation of supply-chain interdependency	Preferred and approved sub-contractors: cost is however chosen before quality & M&E consultant according to client wish. Involve everyone earlier, especially main contractor who starts too late at the moment
Conflicting demands and change management	NEC contract to improve time & change management. Budget did increase due to late client changes but the programme was on time with a 4-week extension
Client/user involvement up to stage D	Large involvement, including steering group (user rep)

	Interviewee B
Client/user involvement up to stage L	Fortnightly design meetings & client meetings
FM input	Estates department, which was involved throughout & importance laid on O&M manual. Also clerk of work on site at all time, inspecting amongst others insulation. On the last 6 months of the project a M&E inspector involved.
Lessons Learned from previous projects	None known of. Contractor is bad at passing on Lessons Learnt from management to workers - criticised
Measurements and testing on project + achieved values	Good airtightness to his knowledge (better than building regulations standard). Used mastic to seal gaps
Quality assurance measures adopted	Monitoring of water and electricity usage on site – no proactive mitigation yet. Improvement suggested through the use of local companies.
QA specialists	Contractor and client in-house specialists. Design manager supporting QA (sealed air leaks with foam himself)
Measures to secure close working relationship to suppliers	Contractual and communicational pressure on sub-contractors.
M&E commissioning (single components or system)	Managed by specialist commissioning sub-contractor.
Hierarchy	Very vertical with a lot of sub-contracting (especially M&E).
How were project challenged addressed	NEC contract: monthly updated programme Reduce a 12 week delay through re-sequencing of steelwork. Identified issues before reacting. Parties helpful once they see that there is teamwork, not looking for blame “fire-fighting” behaviour: no prevention, only reaction
Process optimisation	Could have been possible if contractor involved earlier. Talked to sub-contractors to find solutions on how to reduce programme.
Opinion on how well the project team worked together	Retrospectively all worked well as individuals and as a team thanks to the personalities & attitudes & teambuilding at the start.
Improvement/innovation encouragement	Innovation within their own disciplines. Last Planner meetings held (lean)
Buildability	Acting and see how it goes.
Suggested improvement on buildability	Using BIM Earlier involvement of all parties Virtually build the project with the whole team before actual construction.
Feedback and feedforward on the project	Meetings where everyone was defending their position Informal discussions. Teambuilding events at the start of the project-
Monitoring: who and for how long	Doesn’t know
Delivered Lessons Learnt	Doesn’t know because Interviewee B wasn’t involved in the project at its end, but doubts it due to recession cuts.
Handover process	Specific commissioning sub-contractor engaged. Long (16 weeks) & detailed commissioning breakdown in the programme allowing for great control and transparency for contractor, client and estates department.

	Interviewee B
	Client didn't want to take over as he could difficulty move in due to the severe winter conditions.
Measures for user understanding	Steering group
Presence on site after handover	1-2 contractors present for defects during liability period. Checked once a week

	Interviewee C
Company	Company C
Role	Architect (focus on detailed design specifications for PHPP)
Project type	New built educational building
Project size & duration	4,010m² £7.2m (£10m including everything) 12.2009 – 08.2011 construction start –09.2012
Certifications	BREEAM very good and Passivhaus
Understanding of low-carbon requirements	As efficient building as possible. Fabric efficiency. High U-values (as opposed to building regulations which do not improve) Biomass boiler good for carbon reduction, but rarely used because of the gas boiler also installed and there isn't enough resource, and have often to be sourced outside of the UK to comply with the boiler requirement. Low-carbon focus is a mistake: proven by Part L 2010 because they moved the focus away from Carbon towards DFEE. However update every 3 years impairs overall carbon/energy improvement (set high standards straight away)
Difference made between low-carbon and low-energy	PHPP even if not as tight on the Passivhaus criteria of 15kWh/m²a
Implementation measures for low-energy	PHPP drives this. Well detailed Address cold bridging, airtightness Design being carried out on site through contractor supervision (quality control) Prefabrication such as SIP panels (but can be expensive) Could have been improved through better form factor, but the client aspirations needed to be taken into account too.
Assessment of M&E equipment	PH accredited components MVHR: used one model which wasn't accredited which PHPP counts with a reduction of 12.5% reduction towards the promised product efficiency Reduce IT and use more efficient equipment (e.g. plasma screens instead of projector and smartboards, efficient laptops and PCs etc.) Biomass boiler installed because of M&E insistence although Estates Management was against it due to bad experience
Thermal comfort in the project	PH: is all about thermal comfort Natural ventilation not realistic in schools because of room sizes (would need windows on both sides) and would depend on people to be opened by people at the right place and time ⇨MVHR and radiators for the holiday return. Radiators could be placed on side walls due to high airtightness and glazing U-values.
Impact on schedule	Airtightness tests before plasterboards to be able to improve on issues should there be insufficient performance. Cold bridge analysis of all details.

	Interviewee C
	Thermal imaging of the roof once it is in place (Interviewee C doubts its usefulness).
Energy estimation tool	The M&E engineer used SBEM but not very relevant as it is mostly misused.
Definition of value	In terms of a building: achieve a long-term interior environment quality standard
Definition of client priorities	Client wished for PH and made it public in the media BREEAM very good H&S Satisfaction of insurers.
Implementation of client priorities	The client's PH priority could be used 'against' him when conflicts in design choices. Should have had M&E engineers who understand PH.
DQI, KPI, earned value, benchmarks	Educational authority had its own KPIs on how the building is used.
Optimisation of supply-chain interdependency	It hasn't been optimised! Framework of 6 schools where only the contractor is the same, the rest of the teams changes completely between the projects because of tendering on lowest price. Lack of uniformity creating new design measures for each, no sharing of lessons learnt or training etc.
Conflicting demands and change management	Recurrent issue of PH vs. cost, however mediatisation brought leverage for PH. Continuous issues with the implementation of new design ideas because of lack of open communication.
Client/user involvement up to stage D	Client set different stages of approval by educational authorities where end-users were involved, concerning cost, daylight, colour scheme…
Client/user involvement up to stage L	Same
FM input	Estates department from school – tight relation to users. The rejection of the idea of a biomass boiler came from them! Insurers wanted visual control/proof during construction stage, Estates Department less so.
Lessons Learned from previous projects	Experienced architect in this type of school.
Measurements and testing on project + achieved values	The first resulted in 0.4ACH. They did the smoke test and added tape on the weak spots. The next test is to be done after SIPs and windows are finished installing (end of March).
Quality assurance measures adopted	PHPP methodology.
QA specialists	Mostly managers (CM, PM and DM present on site) but Interviewee C doubts their usefulness in QA because of their limited PH knowledge. SIP sub-contractor also tests airtightness PH assessor at the end for accreditation.
Measures to secure close working relationship to suppliers	Meetings held with everyone who could have an effect on the PH performance.
M&E commissioning (single components or system)	Everything is tested. PH assessor will look at all the documentation.
Hierarchy	Relatively flat except for sub-contracting of suppliers. Reporting directly to contractor but no communication whatsoever between other team members (not even services engineer and architect)
How were project challenged addressed	Planning issues at the start. Closed book attitude. No communication so no prevention measures and only reparations and could not get

	Interviewee C
	to the ground of the issue because all the information was kept by the contractor.
Process optimisation	Bad because of absence of uniformity and no noticeable process improvement. Every time there was an idea, Interviewee C had to prove consequences of all options through PHPP calculations.
Opinion on how well the project team worked together	Mistrust. Lack of communication.
Improvement/innovation encouragement	Publicity for PH.
Buildability	Only scribbled notes on drawings, sometimes even wrong…
Suggested improvement on buildability	n/a
Feedback and feedforward on the project	Only individually to avoid coping with blame.
Monitoring: who and for how long	"There should be" but doesn't think so. Soft Landings is too expensive for such a cost-orientated project.
Delivered Lessons Learnt	Nothing planned.
Handover process	Some training considering it is a slow decanting, initially organised by contractor, then by school itself.
Measures for user understanding	There will be, and some staff comes over regularly to understand what is happening.
Presence on site after handover	Only defects checking after 6 months, but the contractor will be present afterwards because they will be demolishing the existing building.

	Interviewee D
Company	Company D
Role	Architect (technical team)
Project type	New built energy centre next to existing buildings
Project size & duration	1,250m² £100m incl. equipment and plant 2008 – 10.2011
Certifications	NHS sustainable certification system (BREEAM for healthcare?)
Understanding of low-carbon requirements	Airtightness Insulation Building well Site location Building orientation Efficient generation of power on site can be added.
Difference made between low-carbon and low-energy	Take on board previous points. Solar gain Passive ventilation measures if possible Internal layout Lighting ⇨ depending on project and brief

	Interviewee D
Implementation measures for low-energy	Understand client priorities Building according to design (depends on builder understanding) Team working together Training Some projects use airtightness champions Interviewee advised to improve fabric of exiting buildings
Assessment of M&E equipment	Services engineer. Mostly natural ventilation, cross-ventilation A lot dependant on site constraints
Thermal comfort in the project	Services engineers Interviewee would limit cold spots through efficient galzing/perfoming windows Thermal efficiency of envelope Location of radiators Low variation of temperature across the room 19-21°C internal temperature
Impact on schedule	Airtightness tests
Energy estimation tool	Knowledge of SAP, and guesses the services engineer would have used it.
Definition of value	Giving the client what they want and something extra
Definition of client priorities	Energy consumption of existing buildings was already done (cost: £1m/year!), so high priority to reduce this. Should have been done by PM, but they did not seem to have understood them (very incomplete brief) Whole team sitting together and discussing ideas Use drawings and 3D models to make the client understand
Implementation of client priorities	NHS: high airtightness requirements. Acoustics high priority considering important plant.
DQI, KPI, earned value, benchmarks	Workshops to assess performance according to criteria set by client at each key stage of the project. Contractor had his own assessment of project and team performances.
Optimisation of supply-chain interdependency	Principally local labour although not specified so Suppliers chosen because of quality and speed of work Some suppliers did not design or advise as they promised they would: more responsibility for architect Difficulty getting some equipment priced by suppliers because they weren't familiar with technology
Conflicting demands and change management	No one wanted to take responsibility of choosing the M&E equipment to limit responsibility: architect took over much of the design and choices
Client/user involvement up to stage D	Very involved in options appraisal, approving process etc. until stage E
Client/user involvement up to stage L	Little involvement: left to the specialists
FM input	Have their own Estates Department, only involved after Stage D with various representatives throughout the construction process, with involvement in details.
Lessons Learned from previous projects	Strong engineering knowledge brought and shared in workshops.
Measurements and testing on project + achieved values	Airtightness tests. Results very high because of NHS requirements (0.1 ACH?)

	Interviewee D
Quality assurance measures adopted	Someone going on site so seal air-leakage sources. Mostly managed by engineers
QA specialists	Acoustician. Contractor functioned as airtightness champion. Was advised by specialist and was very competent although he didn't have a specific training.
Measures to secure close working relationship to suppliers	Architect could contractually threaten suppliers due to their working relationship with the contractor. In some cases detailed design done by architect and signed off by supplier.
M&E commissioning (single components or system)	All the different systems. Some individual commissioning by suppliers.
Hierarchy	Very vertical client structure with long reporting lines
How were project challenged addressed	Architect flagged up many issues. Engineer often not aware of structural issues. Many design issues caused by client's rush for planning permission (to get funding)
Process optimisation	Loss of labour effort due to lack of specialist involvement in design (initial design to be revised instead of drawn right in the 1st place) However, limitation of work to what was contractually demanded through internal expert advising them on it continuously.
Opinion on how well the project team worked together	Chain of command didn't work. Understood well as a team where improvement was needed. Worked well overall because of very competent team members (especially engineers)
Improvement/innovation encouragement	Used innovative materials and procedures
Buildability	Chose fast installation products
Suggested improvement on buildability	More implication of specialists/suppliers in design
Feedback and feedforward on the project	Mostly initial input, not enough team members involvement afterwards
Monitoring: who and for how long	Services were monitored ⇨ feedback session for client soon
Delivered Lessons Learnt	Are going to be delivered end of March with the evaluation criteria from the client and contractor. Includes representatives from client, contractor, engineer and architect. Project used as best practice model by the client.
Handover process	Several months of commissioning due to the technical equipment. A lot of troubleshooting
Measures for user understanding	Weren't really involved in it. Did a manual, but mostly contractor manual and responsibility. Explanations given at design stage Meetings with the team regularly during the process
Presence on site after handover	Interviewee D present several times on site to check if there were issues. Thinks the services engineer did the same.

	Interviewee E
Company	Company E
Role	Client project manager and contract administrator

	Interviewee E
Project type	New built educational building – next to existing
Project size & duration	8,000m² £21m 09.2006 – 12.2009
Certifications	BREEAM very good
Understanding of low-carbon requirements	Payback period for client. Value for client = return. Use-friendly building: installations that can't be handled by the client don't make sense. Holistic and early design.
Difference made between low-carbon and low-energy	*confusion* Very similar to low-carbon (never thought of a difference) More detailed aspects to look at, mostly equipment & lighting installed Look at footprint. Energy-reducing equipment. No universal solution, projects have to be looked at individually.
Implementation measures for low-energy	Use of powerPerfector to reduce energy consumption, but no way to judge how much it saves. Low-energy/carbon measures have no guarantee to be ensured as it is generally the first cost to be cut from the client's budget. ⇨ resort to life-cycle costing (good PR not sufficient). Critical factor: physical milestones and KPIs from design team.
Assessment of M&E equipment	Much already chosen by design team, M&E engineers involved too late (end of Stage C), which lead them to have the services fit in the building instead of something that works together ⇨ design well thought with natural ventilation. ⇨ Issue where ground heat pump was planned but at tender only realisation implications on the foundations and almost double cost. Taken out from design and other measures such as powerPerfector used. Measures to go around certification instead of actual carbon/energy focus. Carbon/energy measures only based on what was left from the budget.
Thermal comfort in the project	Trench heating. Natural ventilation through main atrium, most windows not openable. Various heating input according to floor. High glass U-values. No HVAC causing temperatures over/under thresholds. Some AC will probably be installed in executive suits. BMS system should have included temperature measurement in the slabs: omitted in design by M&E engineers
Impact on schedule	Airtightness tests. BREEAM steps Should have had more.
Energy estimation tool	Doesn't know. BREEAM assessor took care of various measurements.
Definition of value	It's how the client defines it (e.g. no working disruption essential for client, but holds no importance for the project team itself) Try to find a 'happy medium' of the golden triangle under which the client requirements fit.
Definition of client priorities	Critical success factors of the client set at the start with PM.
Implementation of	Interviewee E asks 'stupid' questions to the project team to make sure client would

	Interviewee E
client priorities	understand it too even without his technical support and looks at everything before its installation. Critical success factors evaluated at all key stages of the project & at handover.
DQI, KPI, earned value, benchmarks	Critical Success Factors
Optimisation of supply-chain interdependency	Through contract choice with close relationship and client approval for each appointment at tendering. Possible improvement: earlier involvement of the parties (only end of Stage C here); use of BIM for integrated design; reducing meetings for the sake of meeting (often set by client)
Conflicting demands and change management	Use of NEC contract which allows for more and better change management. Company E however warned that cost lies in changes and too many have been undertaken. Contractor didn't estimate cumulative impact, leading to 1 month delay. Importance of understanding the impact of changes at the start. Issues with little communication to the new chief executive who changed during the project and wasn't present locally: other wishes to the realised project because he hadn't taken the time to understand the project before handover.
Client/user involvement up to stage D	High: estates department and users (through representatives of each department). User meetings every month.
Client/user involvement up to stage L	Addition of migration planning including user involvement. Monthly to fortnightly meetings and site visits. Constant coordination with the other project on the same university. Stage reports to be signed off by each department rep but was rarely actively read (questions or misunderstandings discovered later).
FM input	Taken by estates department, present from the commissioning on. Had a handbook of requirements (out of date).
Lessons Learned from previous projects	PM visited other building on campus already realised with BREEAM accreditation before design start, taking in user comments.
Measurements and testing on project + achieved values	Pressure test. No other known.
Quality assurance measures adopted	BREEAM accreditation measures. Pressure test by M&E engineer.
QA specialists	BREEAM assessor.
Measures to secure close working relationship to suppliers	Client's preferred suppliers. When specific specialist suppliers were asked for, a direct contract has been made to avoid the NEC tendering process.
M&E commissioning (single components or system)	Look at equipment before installation and consideration taken that lab results are not the same as on the bespoke site. Mostly single components tested.
Hierarchy	D&B 2-stage tender: quite vertical.
How were project challenged addressed	Prevention through change management and partnership contract. Setting up Critical Success Factors & monitoring them. Inclusion of project specific clauses.
Process optimisation	Tool developed by Company E to use the NEC contract better. Corporate control measures. PEP set up for all project but kept short make it readable for everyone.
Opinion on how well the project team worked together	Good through teambuilding workshops with overnight stays. Only possible budget-wise because of large project.

	Interviewee E
Improvement/innovation encouragement	Innovation encouraged but limited because of late appointment of parties. Pain/gain share on ground conditions proved beneficial.
Buildability	Most of the design was undertaken before contractor involvement ⇨ lack of buildability consideration
Suggested improvement on buildability	Earlier appointment of parties.
Feedback and feedforward on the project	Regular meetings and workshops, including Critical Success Factors
Monitoring: who and for how long	BMS for monitoring. Did an early performance review due to complaints on temperatures
Delivered Lessons Learnt	Immediate internal implications. External at handover and after one year.
Handover process	Post-project review with assessment of the Critical Success Factors Long commissioning period planned in programme, with support of NEC supervisor, including training of estates department (FM) although it got delayed.
Measures for user understanding	A lot of user-education needed for them to understand heating/ventilation system. Education to facilitate cultural change of open space.
Presence on site after handover	1 year after handover meeting with all main bodies to evaluate performance.

	Interviewee F
Company	Company F
Role	Contractor (also supplier, Passivhaus Certified Consultant, and trained QS)
Project type	Domestic building
Project size & duration	118m² £180,000 June 2009 – April 2010
Certifications	Passivhaus Code of Sustainable Homes Level 3 (despite being one of the best performing buildings it could only reach a 3. Code does not put enough emphasis on fabric)
Understanding of low-carbon requirements	Fabric first for low energy consumption (is the cheapest solution to reduce carbon)
Difference made between low-carbon and low-energy	Careful design with detailed drawings (methodology according to PHPP is very prescriptive) Evidence of materials Airtightness ⇨ entails cultural change and training
Implementation measures for low-energy	A methodology similar to PHPP (design and prove achieved performance) Design: junctions and MVHR Function before form Many drawings with buildability considerations Involvement of builder with trained personnel Two-way communication Appropriate college education on low-energy for project members

	Interviewee F
Assessment of M&E equipment	M&E ⇨ MVHR! Qualitative MVHR system from Germany Rigid ducts, preventing any “shortcuts” in design and construction Early design decisions
Thermal comfort in the project	Services at 17°C when it is -10°C outside. Difficulties of finding gas heating boiler small & cheap enough. Central hearting with hybrid system: wet heating through supply duct of MVHR and 3 radiators Weather compensator to improve initial boiler performance
Impact on schedule	Used cavity wall to allow for traditional methods. Only additional milestones dictated by PHPP methodology.
Energy estimation tool	PHPP & SAP (to comply with building regulations)
Definition of value	What you get for your money. Consideration of resale, long-term, short-term, comfort, re-sale price, aesthetics, how the project fits into the community. Usually it would be upfront cost.
Definition of client priorities	Client gave a budget and was told what he could do with it. Used value engineering to improve client value. Some decisions lead by building regulations: planning authority required natural stone, which lead to the cavity wall choice.
Implementation of client priorities	Client needs a strong QS to be able to counteract on the offered solutions. Client’s perception of sustainable was PVs. After suggestion of Passivhaus by Interviewee F, the client agreed because of he advice of his QS. Interviewee F had a lot of debates on the budget with the client. Cost cut through detailed design by contractor (only general design by architect).
DQI, KPI, earned value, benchmarks	PHPP dictated measures.
Optimisation of supply-chain interdependency	Tendering earlier and less focused on cost Used local labour, mostly even in-house. Project team which often works together. Specialist suppliers not from the UK because of high standards only in Europe. Used a fixed price. Incentive of publicity and pride.
Conflicting demands and change management	Adapted design solutions to what trades are used to for them to accept the contract at a reasonable price and be able to construct it to the required standard. Toolbox talks to insure everyone knew what they had to do and why.
Client/user involvement up to stage D	Very involved: went to Austria to visit a PH Were very adaptable to the project team’s interjections towards the initial demands (e.g. conservatory which had to be adapted to be within the thermal envelope).
Client/user involvement up to stage L	Meeting every 2 weeks from project start to handover with contractor and architect.
FM input	n/a
Lessons Learned from previous projects	Other house built 1991 with BREEAM Excellent where they achieved airtightness of 3 ACH, which helped realise what needed to be done extra to realise 0.6 ACH.
Measurements and testing on project + achieved values	Achieved 0.33 instead of required 0.6 since they tried to reach highest quality possible to secure PH certification – although they only signed for 3 ACH in the contract as it was the 1st cavity wall PH house in the UK!
Quality assurance	Contractors also chosen on the training, their preferred sub-contractors, in-house skills,

	Interviewee F
measures adopted	experience etc. Design to reduce risk of performance loss. Materials looked at in much more detail.
QA specialists	None because the project scale was too small although it has been discussed. They decided to reach highest quality standards possible to cope for it.
Measures to secure close working relationship to suppliers	Used local & familiar suppliers when possible.
M&E commissioning (single components or system)	MVHR commissioning in house, crucial for PH certification
Hierarchy	Project manager, site manager and mostly in-house site workers. Small scale project.
How were project challenged addressed	On a design issue for the roof which was detected late, construction process was stopped until engineer has secured an option. This type of issues was reduced as they had to look much more closely at the design from the start on due to PH.
Process optimisation	*Frown* Except for PH components, suppliers were chosen nearby, which facilitated delivery and lead times, but lead to many unnecessary trips to the suppliers because of easy access.
Opinion on how well the project team worked together	Very good: architect recommended by contractor; client already familiar with the QS; Most labour Company F in-house; team effort achieved through strong leadership, but not necessarily hierarchical; toolbox talks and training increasing knowledge and making the workers feel valued
Improvement/innovation encouragement	Publicity, pride and quality as a driver (price competition limited trough fixed price).
Buildability	Early detailed design Toolbox talks and training
Suggested improvement on buildability	On a bigger project an airtightness champion, adequate site training etc. should be used.
Feedback and feedforward on the project	Was continuous: discussions every time a new element was introduced. On larger project it is down to good QA management.
Monitoring: who and for how long	2 years of monitoring which are to be completed in a few months. Measured temperature, humidity, airtightness, energy demand. Energy for heating, hot water and cooking has not be measured separately, which is regretted.
Delivered Lessons Learnt	Kept close contact: house visits to understand PH are organised with Company F and the client, client write a regular blog on their experience Used Lessons Learnt from this project to support large scheme which failed to comply with PH at early stages, other PH projects. Used for conferences.
Handover process	Interviewee F considers it wasn't good enough: - the MVHR manual was in German - the heating &/MVHR should have been separated
Measures for user understanding	Solar panels & PVs would make operation & maintenance much more complicated. Tight involvement of client in every decision and process, and continuing relationship between Company F and client through blog and house visits
Presence on site after handover	Project team itself was just present for the defects during liability period. Monitoring has been handled by Leeds Metropolitan.

	Interviewee G
Company	Company G
Role	M&E engineer (controlling the main M&E engineer's designs)
Project type	New-built educational building
Project size & duration	420 pupils – no other information disclosed (estimated around 3,000m² compared to the other educational projects studied)
Certifications	Passivhaus BREEAM very good
Understanding of low-carbon requirements	Regulations (Part L) BREEAM
Difference made between low-carbon and low-energy	M&E system chosen (CHP) Footprint reduction PVs
Implementation measures for low-energy	Provide documentation necessary for BREEAM certification. Sustainable specialists (BREEAM assessor & low-carbon consultant like himself)
Assessment of M&E equipment	To comply with Passivhaus
Thermal comfort in the project	Natural ventilation Manually and automatically openable windows; MVHR Electric heaters for one-off heating after holidays, but also controllable from classrooms if needed. Radiator output limited through BMS.
Impact on schedule	Airtightness test
Energy estimation tool	PHPP
Definition of value	From Company G's point of view: - in general: profit; - concerning the project: marketing opportunity and knowledge acquired.
Definition of client priorities	Up to the consulting engineer to find out.
Implementation of client priorities	Up to the consulting engineer.
DQI, KPI, earned value, benchmarks	KPIs for internal QA, checked by Company G's internal QA engineers. Consultant would have the same.
Optimisation of supply-chain interdependency	Work regularly with contractor. Have preferred sub-contractors. Engage early with the design team. Had regular workshops with all the concerned parties to secure buildability and understanding.
Conflicting demands and change management	Give opinion on presented solutions and cost them. Weekly site and progress meetings to address cost changes. Cost variations evaluated by engineering team.
Client/user involvement up to stage D	Doesn't know except for the fact that the client has a book of requirements and specifications for every classroom.
Client/user involvement up to stage L	Soft Landing has been used, so the clients and users where well involved.
FM input	No knowledge on it.
Lessons Learned from	None that Company G was involved in, and didn't have any themselves as it was their

	Interviewee G
previous projects	first Passivhaus project.
Measurements and testing on project + achieved values	Airtightness tests to reach Passivhaus certification.
Quality assurance measures adopted	Manufacture their own M&E products. Otherwise don't know: it's up to the contractor.
QA specialists	Only knows about internal QA engineer.
Measures to secure close working relationship to suppliers	Workshops to secure buildability for specific elements. Preferred subcontractors.
M&E commissioning (single components or system)	Tested both single components and the system.
Hierarchy	*Quite vertical* Line of sub-contracting long because of specialist needs
How were project challenged addressed	Prevented through early engagement of project members (Company G involved from stage F/G on), 3D CAD drawings for better comprehension, buildability workshops to secure airtightness, and good communication between parties.
Process optimisation	Paper waste reduced through electronic drawings, but 75% of the sent information is not relevant (nonetheless looked at to ensure nothing is overlooked). Tools for QA assurance on site, allowing for comments on the right location and drawings automatically.
Opinion on how well the project team worked together	Very well, high involvement of all the parties. No additional challenges for Company G: similar work as usual.
Improvement/innovation encouragement	Internally: innovation forums where best practices are exchanged and knowledge shared throughout the company. Not aware of any external incentives.
Buildability	Workshops will all members to ensure airtightness. Importance of end-user involvement:
Suggested improvement on buildability	n/a
Feedback and feedforward on the project	In buildability workshops on specific systems.
Monitoring: who and for how long	3 years (full Soft Landings process). No monitoring results for now.
Delivered Lessons Learnt	Internally through reports spread through company.
Handover process	Certification of the different processes through a "tick-box" exercise, O&M manual. BREEAM assessment. Passivhaus certification.
Measures for user understanding	Soft Landings process.
Presence on site after handover	Soft Landings process.

	Interviewee H
Company	Company E
Role	Client PM
Project type	Educational buildings framework (for children with behavioural problems)
Project size & duration	350 – 1,100m² £ 0.5 - 5m 2003 - 2007
Certifications	One specific £5m project reached BREEAM very good. No authority requirement for such small buildings.
Understanding of low-carbon requirements	BREEAM: meters to bus stop etc. Critics of criteria validity, and is restricted by some regulations. Carbon reduction is client lead. Movement (PIR) sensor for lightening (difficult in educational environment) Insulation Easy solutions, not necessarily “headline-grabbers” Wood-pellet boiler Embodied energy consideration Fence made from recycled bottles.
Difference made between low-carbon and low-energy	*Frown* High insulation Natural light, big window surfaces with solar reflecting glass to avoid overheating Avoid open-plan area design(ers) causing drafts and smells. Look at energy cost, including signing supply contracts for low price and prediction of the price for the different energy types long-term. Good zoning (only heat parts of building according to usage periods)
Implementation measures for low-energy	It was the client’s wish, in compliance with standards set by funding authorities. Difficulty because of new IT requirements in education. PV panels Managing cost well design vs. sustainable measures Difficulties due to responsibility allocation of monitoring; maintenance demand of equipment; cost of wood pellets which is catching up with gas; contractor (important in D&B) focus on cost rather than quality, and quality depends on contractor. Compliance with regulations. If nobody at project design stage has mobility issues, eliminate access helps such as automatic doors and elevators. However, recommends future-proofing. Adapt use to reduce energy (holiday length adapted to season, reduce possibility of energy usage for pupils through plug reduction etc.)
Assessment of M&E equipment	Left to M&E designer and regulations. Safety and IT in school dictates equipment: underfloor heating instead of hazardous radiators, also increasing thermal comfort. Wood-pellet works better when required around the clock.
Thermal comfort in the project	Underfloor heating. Avoid overheating through solar-reflecting glass. Insulation at regulation levels.
Impact on schedule	Airtightness test for regulations (recommends infrared to see leakage instead of pressure test which only tells you performance without showing weakness). BREEAM: only paperwork evidence.
Energy estimation tool	Some calculations needed for M&E council approval, but doesn’t know what type of calculation.
Definition of value	Initial purchase vs. life-cycle cost

	Interviewee H
	Educational value for the future Psychological impact of sustainability (healthier & recognised environment leading to increase of user performance/productivity)
Definition of client priorities	Client asked for BREEAM rating but gave freedom on how to reach this. Operational costs and frequency of maintenance were high priority because of very high running costs until now.
Implementation of client priorities	Determination of the team to avoid ‘loss of faith’ when setbacks occur due to failing first attempts. In D&B, management is mostly the contractor’s responsibility.
DQI, KPI, earned value, benchmarks	No.
Optimisation of supply-chain interdependency	Local suppliers. Partnering contract Recommends open book policy, although not always successful.
Conflicting demands and change management	Don’t install measures not necessary at the project creation time if not required at the time (elevators, automatic doors etc.). Reactive process.
Client/user involvement up to stage D	Some buildings of the framework had the brief already set, which were then used for the other projects. Complicated client structure lead to little involvement of the parties. 1 consultation workshop per project.
Client/user involvement up to stage L	One site visit of the staff at 60-70% completion.
FM input	Not the concern of Interviewee H. Very late consultation process, although client has a preferred list of FMs.
Lessons Learned from previous projects	Only own experiences.
Measurements and testing on project	Only required tests for regulations or BREEAM and infrared.
Quality assurance measures adopted to reduce carbon & energy	Clerk of works and building control.
QA specialists	BREEAM assessor for the BREEAM project.
Measures to secure close working relationship to suppliers	Contractor’s responsibility.
M&E commissioning (single components or system)	Both. Some equipment testes by supplier.
Hierarchy	Typical D&B hierarchy.
How were project challenged addressed	Reactive.
Process optimisation	Chosen wood-pellet supplier close. Insufficient labour and incomplete brief.
Opinion on how well the project team worked together	Very good relationship through good face-to-face communication and personal relationships.
Improvement/innovatio	None. Pride in the job. Builder wanted to use the project as a showcase of their work.

	Interviewee H
n encouragement	
Buildability	Modular building with pre-fabrication elements.
Suggested improvement on buildability	n/a
Feedback and feedforward on the project	Weekly meeting between clerk of work and PM. Every 3-4 weeks workshops with all the team.
Monitoring: who and for how long	Client's own energy team suspected to do some monitoring.
Delivered Lessons Learnt	None.
Handover process	Handover process often over longer period. Handover session with large amount of team members and client & staff.
Measures for user understanding	Visible sustainable measures: Some parts of the walls glassed for users to understand the structure, rain-water harvesting tank visible, energy production and consumption counter for everyone to read etc.
Presence on site after handover	Only clerk of works if there is a problem.

	Interviewee I
	Company I
Role	Client PM/representative
Project type	New-built prison next to existing and operating one.
Project size & duration	2,000m² (180 prisoners – 90 cells) £22m 2007 – June 2010
Certifications	None as there was no requirement for a BREEAM rating, but used rainwater harvesting system.
Understanding of low-carbon requirements	Material choices Sustainable techniques such as plants and services Life-cycle costing (15-20 years) Long building lifespan
Difference made between low-carbon and low-energy	A lot of cross-over with low-carbon. Sustainable techniques on how the building runs such as system, plant. PVs
Implementation measures for low-energy	Client understanding: he has to "buy in" the sustainable agenda as heir priority is generally profit: PM spent a lot of time consulting. Need for a good and trained architect and design team.
Assessment of M&E equipment	Certain standards set for prisons. Finer choices up to the M&E consultant, who had good knowledge in rainwater harvesting. Depends on the building function.
Thermal comfort in the project	Reviewed frame options, but security sets standards of concrete and steel. Radiant panels which cannot be taken off, in the length of the house block using the circulation.
Impact on schedule	Consideration for airtightness and watertightness for the external envelope. Holistic consideration of the building. Allow for sufficient handover time, including testing and commissioning, and training

	Interviewee I
	of the client/users for the BMS and rainwater harvesting system.
Energy estimation tool	Doesn't know, probably calculated by M&E engineer.
Definition of value	Has to be considered from the client's perspective: what they want and need.
Definition of client priorities	Strong communication and meetings with the client to understand and know them.
Implementation of client priorities	The priorities are mapped in a document and used as benchmarks, with monitoring of their progress and achievement. OGC approved.
DQI, KPI, earned value, benchmarks	Priorities of the client mapped in a document, matched, assessed, evaluated, monitored and reviewed in a post-project review. KPIs set by a third party on the client side and Constructing Excellence: time, delivery, forecast, recycling materials, wastage, completeness of construction etc.
Optimisation of supply-chain interdependency	Wasn't optimised then, but improved according to the Lean concept based on this project experience. Early involvement of all parties: implies additional investment at the design stages, but ten-fold return.
Conflicting demands and change management	Difficulties to reconcile all the different stakeholder agendas (estates department, security, residential, governor, client/sponsor and design team) were reconciled by the partnering contract chosen (PPC 2000), many meetings, mapped out timescale, strong communication, early notices of danger through (possible) issues being raised by the whole team. A core group has been formed by a client 3rd party to assess the solution in case of conflict.
Client/user involvement up to stage D	Client wanted to be informed about everything, but left decisions to project team. Estates department and governor highly involved in the whole project through meetings, design reviews, workshops on how the building functions, the design implications etc.
Client/user involvement up to stage L	Between E and L client was mostly involved in the construction through meetings and site visits to be aware of the building and its function. The contract provided a direct link between the contractor and stakeholder to avoid escalation of issues.
FM input	Covered by the estates department who was very involved from pre-contract until operation with heavy design input.
Lessons Learned from previous projects	No. This was the whole project team's first new-built prison.
Measurements and testing on project	Probably some pressure testing.
Quality assurance measures adopted to reduce carbon & energy	Probably some pressure testing. Nothing else.
QA specialists	None. QA by individual contractors.
Measures to secure close working relationship to suppliers	Partnership contract and getting to know everyone professionally and personally.
M&E commissioning (single components or system)	Probably system.
Hierarchy	Reporting centred on the client PM/representative, with sub-contractors contractually under a main contractor, from a agreed supply chain in compliance with security standards.
How were project challenged addressed	Early waning and notification system when risks appear. Risk log updated monthly with responsible and actions.
Process optimisation	Not much done at pre-contract. Used the lean 'Kan-Ban' where on site things are located where needed to reduce

	Interviewee I
	transportation and movement, but has been limited by the project type restrictions.
Opinion on how well the project team worked together	Very well because of getting to know each other, although it was difficult at first because of the numerous stakeholders. It has been facilitated by the central reporting position of the PM. Need for a strong leader and manager.
Improvement/innovation encouragement	Innovation encourage within Company I through implementation of the lean concept and internal use of Lessons Learnt based on this project. No further incentive than possibility of further projects, pride and experience.
Buildability	Question on what is meant by buildability. Workshops for the different elements. Standardised guideline from the client's technical department, which however wasn't up to date (1995).
Suggested improvement on buildability	Updated client specifications (regulations, new technologies etc.)
Feedback and feedforward on the project	Only informal through numerous workshops with brainstorming approach. Used to understand the design requirements for the client better.
Monitoring: who and for how long	Only testing for commissioning and presence for the liability period (1 year) with defects meetings on a 3-monthly, 6-monthly and 9 monthly basis.
Delivered Lessons Learnt	Probably internal Lessons Learnt. Own Lessons Learnt on Lean. No update of the specifications handbook has been given to the client: there isn't any time after handover, project team members are on other projects.
Handover process	Working backwards from completion to test all the delivered sections, which were then logged.
Measures for user understanding	Presence of governor and estates department during construction. Estates department was trained on how to use the BMS and plant, they received the H&S files and O&M manual.
Presence on site after handover	None except for liability period.

	Interviewee J
Company	Company J
Role	Environmental Manager
Project type	Educational
Project size & duration	2,600m² 5.1m October 2010 – October 2011 Demolishing & external works finished by February 2012
Certifications	Passivhaus BREEAM very good
Understanding of low-carbon requirements	But low-carbon doesn't have to be efficient; you can use a lot of carbon-reducing technology (waste of money). Energy consumption reduction first Renewable energy
Difference made between low-carbon and low-energy	Having a clear target of what should be achieved and what the issues are with it. Energy efficiency Type of materials chosen Construction methodology Location Orientation Use specialists
Implementation measures for low-energy	Talk to client, sponsor or other key roles (M&E engineer). Tell them the difference between low-carbon and low-energy. Airtightness could have been improved, but would have delayed delivery of project and increased budget. Could have improved lighting, heating…
Assessment of M&E equipment	PH requires very low energy consumption: equipment which is at that standard from Germany and Austria. PHPP helps to decide based on calculations.
Thermal comfort in the project	Done by design team. Target temperature of 20°C has been modelled. Well insulated. Ventilation strategy (cross-flow ventilation)
Impact on schedule	Air-testing programme. Did an air-test sampling o a room to see how it would work to then adapt the design for the whole project. Resulted in 0.69. Changed details of windows. June: pressure test, smoke test and thermal imaging. Result: 0.34 First create the whole building shell before installing services. Then test before any plasterboard to be able to improve on defects. Final test in October of 0.48.
Energy estimation tool	PHPP SBEM for Building Regulations and to get Energy Estimate Certificate
Definition of value	Should be cost, time, quality, ecological/environmental impact. Often only cost and time. Value of client and user. Cashable and non-cashable benefits.
Definition of client priorities	PH was a priority for the client: put a good learning environment to work in. They also wanted to have a quick delivery. PH was in the contract.

	Interviewee J
Implementation of client priorities	Intense workshops and training before construction
DQI, KPI, earned value, benchmarks	Passivhaus standards = DQIs BREEAM as base for energy use monitoring Energy use on site monitored, waste etc. according to internal targets ⇨ Constructing Excellence KPIs
Optimisation of supply-chain interdependency	A lot of effort to work with supply chain before construction itself: Workshops with suppliers demonstrating methods on site Using same supply chain for next project and involved even earlier
Conflicting demands and change management	PH set as quality standard in the contract ⇨ reduced conflicts. Discussed problems in a cordial manner. Collaborative working Big conflicts were therefore avoided
Client/user involvement up to stage D	Teachers involved in design. Learning/teaching what PH is. Their involvement is crucial
Client/user involvement up to stage L	Kept very involved in supply-chain through workshops. Staff and students shown around and taught about the building. Weekly meeting and monthly site visit
FM input	Caretaker with only little involvement because of limited expertise. Encouraged them to use Company J's FM.
Lessons Learned from previous projects	Used supply-plain chain from 2 previous similar projects. Previous project had delay on delivery of specialist components from Europe: this time Company J stored them earlier to avoid this.
Measurements and testing on project	Several airtightness tests: 0.69, 0.34 and 0.48 final. Thermal imaging etc.
Quality assurance measures adopted to reduce carbon & energy	Company J internal QA system PHPP
QA specialists	Interviewee J himself - Environmental manager PH assessor Airtightness champion
Measures to secure close working relationship to suppliers	Workshops Open discussions Presence on site to demonstrate installation and product
M&E commissioning (single components or system)	Both. Individual components tested by suppliers.
Hierarchy	Traditional with limitation of sub-sub-contracting to specialists.
How were project challenged addressed	No special challenge because of QA system and Lessons Learnt used.
Process optimisation	Lean methodology Collaborative working Coordination meetings Workshops Early supply-chain involvement
Opinion on how well the project team	Some strain put on the construction team because of changed construction approach (no overlapping).

	Interviewee J
worked together	Great work together thanks to very good communication
Improvement/innovation encouragement	No special penalties. Incentive through pride, publication etc.
Buildability	Workshops on installation. Design meetings involving everyone.
Suggested improvement on buildability	n/a
Feedback and feedforward on the project	Workshops and meetings
Monitoring: who and for how long	Soft Landings but not for the full 3 years due to budget limitation.
Delivered Lessons Learnt	LL workshops with design and construction team, Going to use this for next PH school project. E.g. how windows are controlled etc.
Handover process	Limited time – wants to improve on it.
Measures for user understanding	User involvement in design and construction: workshops and presentations. User guides etc.
Presence on site after handover	Weekly visit from architect and environmental manager. Site manager there every day.

	Interviewee K
	Company K
Role	Developer: contractor's PM
Project type	Accommodation for elderly
Project size & duration	6,000m² £4-5m Construction start 07.2010 – Occupation 09.2011
Certifications	None required
Understanding of low-carbon requirements	Follow regulations requirements in the most cost-effective way
Difference made between low-carbon and low-energy	Same as low-carbon. More requirements could mean less profit, so not looked at. Understanding of MVHR.
Implementation measures for low-energy	As developer, they are their own client, and do not look at higher requirements than the regulatory.
Assessment of M&E equipment	Adapted to elderly usage. Choices according to regulation.
Thermal comfort in the project	23°C (higher than usual because of elderly) Regulation system in each flat
Additional understanding of thermal comfort	n/a
Impact on schedule	Airtightness test close to the finishing of the building – high risk for reaching the set value in time

	Interviewee K
Energy estimation tool	SAP for residential part SBEM for commercial part
Definition of value	It's not the product quality as such, but which fulfils the best the need to the lowest price.
Definition of client priorities	Usage of the building. Financial viability of the project, which depends a lot on the construction cost.
Implementation of client priorities	Private sector targeted. Use the traditional construction methods and only adapt to new regulatory requirements.
DQI, KPI, earned value, benchmarks	Earned value and KPIs are a good concept but require too many measurements, which are costly & time-consuming, so not used.
Optimisation of supply-chain interdependency	Keep same supply-chain. Have knowledgeable site management with strong technical specialist support. Visual presentations to the sub-contractors (suggested the use of infrared and smoke to show airtightness issues)
Conflicting demands and change management	
Client/user involvement up to stage D	No direct involvement of users, but knowledge about the user interest and individual requirements. Created a programme specifically for group of very high age.
Client/user involvement up to stage L	As little as possible due to H&S
FM input	Maintenance by FM branch of the same group as Company K Staff present 24h/day for the day-to-day operation. Involvement of external FM very late – only for takeover, although Interviewee K says it would limit risks at tendering if they had more design input.
Lessons Learned from previous projects	Always with the same supply-chain, so already knowledgeable, but no official knowledge transfer.
Measurements and testing on project	Airtightness: requirement = 5; Aim = 3; Achieved = 4.95 ACH.
Quality assurance measures adopted to reduce carbon & energy	Low quality assurance beyond the planning because of low regulation requirements under 2006 regulations.
QA improvement measures	Air-source heat pump instead of gas boiler. Increase centralised heating capacity to limit individual electrical heaters. Wet circuit underfloor heating, also increase space usage. CHP systems although seen as quite expensive. Solar panels for hot-water heating, seen as "eco-bling" Increase control on the execution of site works
QA specialists	Internal QA processes as checklist based on experience
Measures to secure close working relationship to suppliers	Worked with them for decades. Entails the risk of the suppliers acting as the usually would instead of respond to specific brief.
M&E commissioning (single components or system)	Whole system during a commissioning of several weeks.
Hierarchy	Traditional D&B but simplified client/contractor due to developer situation
How were project	Reactive approach.

	Interviewee K
challenged addressed	
Process optimisation	Waste management plan according to regulations. 80% of material waste recycled
Opinion on how well the project team worked together	Well because consistent supply chain
Improvement/innovation encouragement	n/a
Buildability	Traditional construction methods used
Suggested improvement on buildability	n/a
Feedback and feedforward on the project	No formal feedbacks, internal knowledge
Monitoring: who and for how long	No monitoring (expensive)
Delivered Lessons Learnt	No formal Lessons Learnt, but gathered user feedback especially since it is a new target for Company K
Handover process	FM rep at commissioning to comment on improvements necessary before handover.
Measures for user understanding	Basic training on the building to the FM.
Presence on site after handover	Presence of team for 4 weeks after handover because the next project they were allocated to did not start until then. Was very useful.

A 8 APPENDIX 8: EVALUATION OF PROCESS COMPETENCY

A 8.1 Case Study B (Contractor; BREEAM very good; Educational)

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	53%					
	Consideration for fabric first				x		
	Lucidity on "eco-bling"	x					
	FM involvement [in all phases]						x
	Planning	40%					
	Early involvement of project team members		x				
	Certification milestones included						x
	Different planning approach to achieve standard	x					
	Buildability	25%					
	Design understandable by construction team		x				
	Involvement of subcontractors in construction					x	
	Involvement of suppliers in construction	x					
	Materials or techniques facilitating construction	x					
Construction	Construction QA	20%					
	Training of contractor	x					
	Training of sub-contractors	x					
	Use of carbon/energy specialists					x	
	KPIs, DQIs etc. independent from certification tools	x					
	Process optimisation	73%					
	Work with preferred supply-chain				x		
	Proactive change management				x		
	Reduction of unnecessary movement or documentation						x
	Collaboration	60%					
	Flat hierarchy				x		
	Integrative communication				x		
	Regularity of meetings				x		
Operation	Client/user involvement	80%					
	Client involved in design [stages A to D]						x
	User involved in design [stages A to D]						x
	Client involved [stages E to L]						x
	User involved [stages E to L]						x
	Site visits	x					
	Handover & Monitoring	33%					
	User training	x					

		Level					
		0%	20%	40%	60%	80%	100%
	Commissioning of separate elements						x
	Commissioning of system						x
	Measurement of as-built performance[1]	x					
	Long-term monitoring	x					
	Lessons Learnt involving client and whole supply chain	x					

Average: 48%

[1] Excluding airtightness measurement required by regulations

A 8.2 CASE STUDY C (ARCHITECT; PH & BREEAM VERY GOOD; EDUCATIONAL)

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	100%					
	Consideration for fabric first						x
	Lucidity on "eco-bling"						x
	FM involvement [in all phases]						x
	Planning	87%					
	Early involvement of project team members				x		
	Certification milestones included						x
	Different planning approach to achieve standard						x
	Buildability	80%					
	Design understandable by construction team						x
	Involvement of subcontractors in construction				x		
	Involvement of suppliers in construction				x		
	Materials or techniques facilitating construction						x
Construction	Construction QA	30%					
	Training of contractor	x					
	Training of sub-contractors	x					
	Use of carbon/energy specialists				x		
	KPIs, DQIs etc. independent from certification tools				x		
	Process optimisation	0%					
	Work with preferred supply-chain	x					
	Proactive change management	x					
	Reduction of unnecessary movement or documentation	x					
	Collaboration	40%					
	Flat hierarchy				x		
	Integrative communication	x					
	Regularity of meetings				x		

		Level					
		0%	20%	40%	60%	80%	100%
Operation	**Client/user involvement**	64%					
	Client involved in design [stages A to D]					x	
	User involved in design [stages A to D]					x	
	Client involved [stages E to L]					x	
	User involved [stages E to L]					x	
	Site visits	x					
	Handover & Monitoring	67%					
	User training					x	
	Commissioning of separate elements						x
	Commissioning of system						x
	Measurement of as-built performance[1]						x
	Long-term monitoring		x				
	Lessons Learnt involving client and whole supply chain	x					
	Average:	58%					

[1] Excluding airtightness measurement required by regulations

A 8.3 Case Study D Architect NHS sustainable certificate Health

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	**Design**	80%					
	Consideration for fabric first						x
	Lucidity on "eco-bling"					x	
	FM involvement [in all phases]				x		
	Planning	60%					
	Early involvement of project team members				x		
	Certification milestones included						x
	Different planning approach to achieve standard		x				
	Buildability	40%					
	Design understandable by construction team					x	
	Involvement of subcontractors in construction		x				
	Involvement of suppliers in construction		x				
	Materials or techniques facilitating construction					x	
Construction	**Construction QA**	35%					
	Training of contractor		x				
	Training of sub-contractors	x					
	Use of carbon/energy specialists					x	
	KPIs, DQIs etc. independent from certification tools						x

		Level					
		0%	20%	40%	60%	80%	100%
	Process optimisation	20%					
	Work with preferred supply-chain	x					
	Proactive change management				x		
	Reduction of unnecessary movement or documentation	x					
	Collaboration	60%					
	Flat hierarchy	x					
	Integrative communication					x	
	Regularity of meetings						x
Operation	Client/user involvement	40%					
	Client involved in design [stages A to D]					x	
	User involved in design [stages A to D]	x					
	Client involved [stages E to L]		x				
	User involved [stages E to L]				x		
	Site visits			x			
	Handover & Monitoring	80%					
	User training					x	
	Commissioning of separate elements						x
	Commissioning of system						x
	Measurement of as-built performance[1]					x	
	Long-term monitoring				x		
	Lessons Learnt involving client and whole supply chain				x		
	Average:	52%					

[1] Excluding airtightness measurement required by regulations

A 8.4 Case Study E (Project Manager; BREEAM very good; Educational)

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	47%					
	Consideration for fabric first	x					
	Lucidity on "eco-bling"			x			
	FM involvement [in all phases]						x
	Planning	33%					
	Early involvement of project team members	x					
	Certification milestones included						x
	Different planning approach to achieve standard	x					

		Level					
		0%	20%	40%	60%	80%	100%
	Buildability	50%					
	Design understandable by construction team			x			
	Involvement of subcontractors in construction					x	
	Involvement of suppliers in construction					x	
	Materials or techniques facilitating construction	x					
Construction	Construction QA	45%					
	Training of contractor	x					
	Training of sub-contractors	x					
	Use of carbon/energy specialists					x	
	KPIs, DQIs etc. independent from certification tools						x
	Process optimisation	73%					
	Work with preferred supply-chain			x			
	Proactive change management						x
	Reduction of unnecessary movement or documentation					x	
	Collaboration	80%					
	Flat hierarchy			x			
	Integrative communication						x
	Regularity of meetings						x
Operation	Client/user involvement	100%					
	Client involved in design [stages A to D]						x
	User involved in design [stages A to D]						x
	Client involved [stages E to L]						x
	User involved [stages E to L]						x
	Site visits						x
	Handover & Monitoring	73%					
	User training						x
	Commissioning of separate elements					x	
	Commissioning of system		x				
	Measurement of as-built performance[1]						x
	Long-term monitoring				x		
	Lessons Learnt involving client and whole supply chain					x	
	Average:	63%					

[1] Excluding airtightness measurement required by regulations

A 8.5 Case Study F (Contractor; PH & Code of Sustainable Homes level 3; Domestic)

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	100%					
	Consideration for fabric first						x
	Lucidity on "eco-bling"						x
	FM involvement [in all phases]	not applicable [single house]					
	Planning	100%					
	Early involvement of project team members						x
	Certification milestones included						x
	Different planning approach to achieve standard						x
	Buildability	85%					
	Design understandable by construction team						x
	Involvement of subcontractors in construction						x
	Involvement of suppliers in construction			x			
	Materials or techniques facilitating construction						x
Construction	Construction QA	87%					
	Training of contractor						x
	Training of sub-contractors						x
	Use of carbon/energy specialists				x		
	KPIs, DQIs etc. independent from certification tools	x					
	Process optimisation	53%					
	Work with preferred supply-chain						x
	Proactive change management			x			
	Reduction of unnecessary movement or documentation		x				
	Collaboration	100%					
	Flat hierarchy						x
	Integrative communication						x
	Regularity of meetings						x
Operation	Client/user involvement	100%					
	Client involved in design [stages A to D]						x
	User involved in design [stages A to D]						x
	Client involved [stages E to L]						x
	User involved [stages E to L]						x
	Site visits						x
	Handover & Monitoring	100%					
	User training						x
	Commissioning of separate elements	not applicable [single house]					
	Commissioning of system	not applicable [single house]					

		Level					
		0%	20%	40%	60%	80%	100%
	Measurement of as-built performance[1]						x
	Long-term monitoring						x
	Lessons Learnt involving client and whole supply chain						x
	Average:	91%					

[1] Excluding airtightness measurement required by regulations

A 8.6 Case Study G Engineer PH & BREEAM very good Educational

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	0%					
	Consideration for fabric first	x					
	Lucidity on "eco-bling"	x					
	FM involvement [in all phases]	not known					
	Planning	60%					
	Early involvement of project team members					x	
	Certification milestones included						x
	Different planning approach to achieve standard	x					
	Buildability	70%					
	Design understandable by construction team					x	
	Involvement of subcontractors in construction						x
	Involvement of suppliers in construction			x			
	Materials or techniques facilitating construction				x		
Construction	Construction QA	25%					
	Training of contractor	x					
	Training of sub-contractors	x					
	Use of carbon/energy specialists	x					
	KPIs, DQIs etc. independent from certification tools						x
	Process optimisation	80%					
	Work with preferred supply-chain						x
	Proactive change management					x	
	Reduction of unnecessary movement or documentation				x		
	Collaboration	60%					
	Flat hierarchy		x				
	Integrative communication				x		
	Regularity of meetings						x
Oper	Client/user involvement	100%x					
	Client involved in design [stages A to D]						x

		Level					
		0%	20%	40%	60%	80%	100%
	User involved in design [stages A to D]						x
	Client involved [stages E to L]						x
	User involved [stages E to L]						x
	Site visits						x
	Handover & Monitoring	83%					
	User training						x
	Commissioning of separate elements						x
	Commissioning of system						x
	Measurement of as-built performance[1]						x
	Long-term monitoring						x
	Lessons Learnt involving client and whole supply chain			x			
	Average:	60%					

[1] Excluding airtightness measurement required by regulations

A 8.7 Case Study H (Project Manager; None & BREEAM; Educational Framework)

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	27%					
	Consideration for fabric first			x			
	Lucidity on "eco-bling"		x				
	FM involvement [in all phases]		x				
	Planning	33%					
	Early involvement of project team members	x					
	Certification milestones included						x
	Different planning approach to achieve standard	x					
	Buildability	10%					
	Design understandable by construction team			x			
	Involvement of subcontractors in construction	x					
	Involvement of suppliers in construction	x					
	Materials or techniques facilitating construction	x					
Construction	Construction QA	0%					
	Training of contractor	x					
	Training of sub-contractors	x					
	Use of carbon/energy specialists	x					
	KPIs, DQIs etc. independent from certification tools	x					

		Level					
		0%	20%	40%	60%	80%	100%
	Process optimisation	0%					
	Work with preferred supply-chain	x					
	Proactive change management	x					
	Reduction of unnecessary movement or documentation	x					
	Collaboration	60%					
	Flat hierarchy			x			
	Integrative communication				x		
	Regularity of meetings					x	
Operation	Client/user involvement	4%					
	Client involved in design [stages A to D]	x					
	User involved in design [stages A to D]	x					
	Client involved [stages E to L]	x					
	User involved [stages E to L]	x					
	Site visits		x				
	Handover & Monitoring	43%					
	User training		x				
	Commissioning of separate elements						x
	Commissioning of system						x
	Measurement of as-built performance[1]	x					
	Long-term monitoring			x			
	Lessons Learnt involving client and whole supply chain	x					
	Average:	22%					

[1] Excluding airtightness measurement required by regulations

A 8.8 Case Study I (Project Manager; None; Prison)

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	53%					
	Consideration for fabric first				x		
	Lucidity on "eco-bling"	x					
	FM involvement [in all phases]						x
	Planning	53%					
	Early involvement of project team members						x
	Certification milestones included	x					
	Different planning approach to achieve standard				x		
	Buildability	50%					
	Design understandable by construction team						x

		Level					
		0%	20%	40%	60%	80%	100%
	Involvement of subcontractors in construction					x	
	Involvement of suppliers in construction		x				
	Materials or techniques facilitating construction	x					
Construction	Construction QA	25%					
	Training of contractor	x					
	Training of sub-contractors	x					
	Use of carbon/energy specialists	x					
	KPIs, DQIs etc. independent from certification tools						x
	Process optimisation	83%					
	Work with preferred supply-chain					x	
	Proactive change management						x
	Reduction of unnecessary movement or documentation					x	
	Collaboration	80%					
	Flat hierarchy			x			
	Integrative communication						x
	Regularity of meetings						x
Operation	Client/user involvement	60%					
	Client involved in design [stages A to D]						x
	User involved in design [stages A to D]	x					
	Client involved [stages E to L]						x
	User involved [stages E to L]	x					
	Site visits						x
	Handover & Monitoring	37%					
	User training						x
	Commissioning of separate elements	x					
	Commissioning of system						x
	Measurement of as-built performance[1]	x					
	Long-term monitoring		x				
	Lessons Learnt involving client and whole supply chain	x					
	Average:	56%					

[1] Excluding airtightness measurement required by regulations

A 8.9 Case Study J (Environmental Manager; PH & BREEAM very good; Educational)

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	73%					
	Consideration for fabric first						x
	Lucidity on "eco-bling"						x
	FM involvement [in all phases]		x				
	Planning	100%					
	Early involvement of project team members						x
	Certification milestones included						x
	Different planning approach to achieve standard						x
	Buildability	90%					
	Design understandable by construction team						x
	Involvement of subcontractors in construction						x
	Involvement of suppliers in construction						x
	Materials or techniques facilitating construction				x		
Construction	Construction QA	100%					
	Training of contractor						x
	Training of sub-contractors						x
	Use of carbon/energy specialists						x
	KPIs, DQIs etc. independent from certification tools						x
	Process optimisation	100%					
	Work with preferred supply-chain						x
	Proactive change management						x
	Reduction of unnecessary movement or documentation						x
	Collaboration	87%					
	Flat hierarchy				x		
	Integrative communication						x
	Regularity of meetings						x
Operation	Client/user involvement	100%					
	Client involved in design [stages A to D]						x
	User involved in design [stages A to D]						x
	Client involved [stages E to L]						x
	User involved [stages E to L]						x
	Site visits						x
	Handover & Monitoring	100%					
	User training						x
	Commissioning of separate elements						x
	Commissioning of system						x

		Level					
		0%	20%	40%	60%	80%	100%
	Measurement of as-built performance[1]						x
	Long-term monitoring						x
	Lessons Learnt involving client and whole supply chain						x

Average: 94%

[1] Excluding airtightness measurement required by regulations

A 8.10 Case Study K (Contractor [in a Developer structure]; None Large; Domestic)

		Level					
		0%	20%	40%	60%	80%	100%
Design & Planning	Design	7%					
	Consideration for fabric first	x					
	Lucidity on "eco-bling"	x					
	FM involvement [in all phases]		x				
	Planning	0%					
	Early involvement of project team members	x					
	Certification milestones included	x					
	Different planning approach to achieve standard	x					
	Buildability	45%					
	Design understandable by construction team			x			
	Involvement of subcontractors in construction			x			
	Involvement of suppliers in construction			x			
	Materials or techniques facilitating construction				x		
Construction	Construction QA	5%					
	Training of contractor	x					
	Training of sub-contractors	x					
	Use of carbon/energy specialists	x					
	KPIs, DQIs etc. independent from certification tools		x				
	Process optimisation	40%					
	Work with preferred supply-chain						x
	Proactive change management	x					
	Reduction of unnecessary movement or documentation		x				
	Collaboration	33%					
	Flat hierarchy			x			
	Integrative communication			x			
	Regularity of meetings		x				

		Level					
		0%	20%	40%	60%	80%	100%
Operation	Client/user involvement	20%					
	Client involved in design [stages A to D]				x		
	User involved in design [stages A to D]	x					
	Client involved [stages E to L]		x				
	User involved [stages E to L]	x					
	Site visits		x				
	Handover & Monitoring	23%					
	User training		x				
	Commissioning of separate elements	x					
	Commissioning of system						x
	Measurement of as-built performance[1]	x					
	Long-term monitoring	x					
	Lessons Learnt involving client and whole supply chain		x				
	Average:	22%					

[1] Excluding airtightness measurement required by regulations

A 9 APPENDIX 9: DETAILED GRAPHICAL REPRESENTATIONS

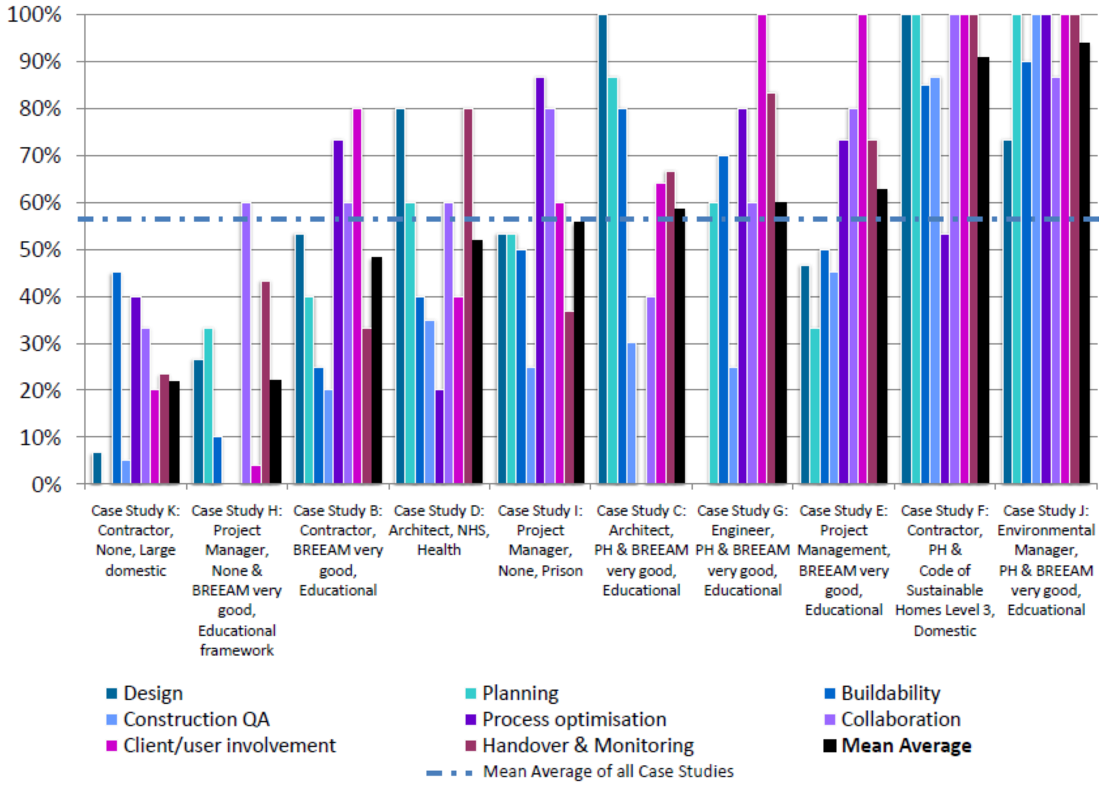

Figure 5.9: Process competency of the different case studies in all performance gap categories; in increasing performance order (researcher's own)

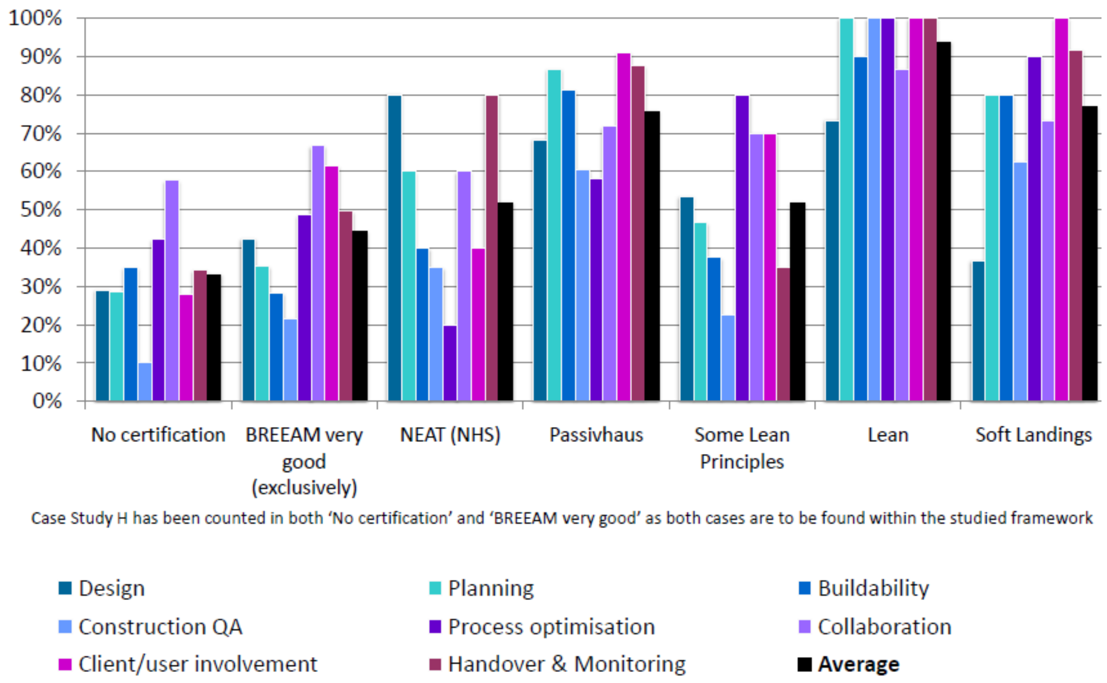

Figure 5.10: Process competency of the projects according to certification tools and processes (researcher's own)