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Exploring a Best Practice Approach to Operability and Maintainability of Low Carbon Buildings in the UK

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Abstract

Growth in technological advancement was to humanity a mixed blessing. While it provided comfort and improved quality of life, it also increased the demand for energy to drive them. This increase in energy usage, particularly from fossil fuel sources is widely understood to be responsible for the critical environmental problems in the world (Climate Change). Mitigating and adapting to this anthropogenic induced consequence created the need for varying innovative and new low carbon and renewable technologies which are gradually replacing the traditional high fossil fuel driven systems in buildings.

Presently in the UK, every new building is expected to be low carbon and energy efficient; operated in such a manner as to use no more fuel and power than is reasonable in the circumstances. However, it is widely believed that construction underperforms in terms of capacity to deliver value. Clients and end-users of these buildings appear not to be getting long term value for their investments. Much attention has also not been given to how these new and innovative technologies can be operated and maintained long into the future. Recent researches also underpin the fact that the wide information gap existing between designers and building end-users is one of the factors responsible for the underperformance.

This research therefore sought to explore a best practice approach that could bridge this information gap, and ensure that low carbon buildings are efficiently operated and maintained long into the future, particularly as the UK built environment moves closer to its zero carbon targets of 2016 and 2019. The research methodology involved triangulation (a mixed-method research approach), thus maximising the chances of benefiting from the strength of each of qualitative and quantitative methods. Interviews, surveys and case studies were employed. Post occupancy evaluation method was also used for the key case study.

Findings indicate that there is a need for change in the way low carbon buildings are delivered to the end-users; that a properly prepared operation and maintenance (O&M) manual is indispensable in the effective and efficient operation and maintenance of low carbon buildings, and that it will be good practice to bring in the O&M team early to the design process. The study also suggested that designers be required to prove 'life-cycle operability and maintainability' of their designs before they are constructed. To ensure this desired cultural and process change in project delivery, a Maintainability and Operability Integrated (OMI) Design and Construction Process Model is proposed. The model was developed using the proposed RIBA 2013 revised Outline Plan of Work and drawing lessons from the New Product Development (NPD) process used by the manufacturing sector and other construction industry models.

A validation test was conducted by means of a focus group, populated by top management officials of the University of Nottingham Estates Office, which has been actively involved in the procurement and management of myriads of low carbon buildings. Feedbacks from the validation test indicate that the proposed OMI Process Model was a well thought out idea which is practicable and capable of addressing the shortfall within the existing processes to deal with the O&M issues raised by the use of new and innovative low carbon technologies.

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The entire research exercise has been very challenging. Success would have been a 'far-cry' but for the many persons God Almighty brought my way and who allowed me '*climb their backs'* to see '*the glory at the end of the tunnel'*.

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Above all, to God Almighty, the invisible and only wise, who '*makes all things work together for the good of those who love Him; making them beautiful in His time'*, be all the glories, honour and splendour for the inspiration, grace and courage through these nearly 4 years! He has been my help in ages past and remains my hope for the years to come.

O L Frank

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Glossary: Acronyms

3D – Three Dimension(al)

ABE – Association of Building Engineers

ACA – Association Consultant Architects

ACE – Association for Consultancy and Engineering

ACoP – Approved Code of Practice

ADP – Ad Hoc Working Group on the Durban Platform for Enhanced Action

BCIS – Building Cost Information Service

BedZED – Beddington Zero Energy Development

BIFM – British Institute of Facilities Management

BIM – Building Information Modelling

BM – Building Manual

BMS – Building Management System

BOO – Build, Operate and Own

BOOT – Build, Own, Operate and Transfer

BOT – Build, Operate and Transfer

BPE – Building Performance Evaluation

BPR – Business Process Management

BQ – Bill of Quantities

BRE – Building Research Establishment

BREDEM – Building Research Establishment Domestic Energy Model

BREEAM – BRE Environmental Assessment Method

BS – British Standards

BSI – British Standards Institution

BSRIA – Building Services Research and Information Association

BT – Build and Transfer

Building Regs. – Building Regulations

BUS – Building Use Studies

C&C – Contraction and Convergence

C21 – 'Construction 21' – a strategic blueprint spelling out the vision and strategies to re-invent Singapore´s construction industry

C60 – 'Carbon 60' – UK's aspirational target of cutting carbon emission by some 60% by 2050

CABE – Commission for Architecture and Built Environment

CCL – Climate Change Levy

CDM – Construction Design and Management

CEN – European Committee for Standardisation

CERT – Carbon Emission Reduction Target

CFC – Chlorofluorocarbon

CHP – Combine Heat and Power

CIBSE – Chartered Institute of Building Services Engineers

CIC – Construction Industry Council

CIOB – Chartered Institute of Building

CIRIA – Construction Industry Research and Information Association

CMP – Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol

CO_2 – Carbon dioxide

COP – Conference of the Parties

CSNP – Construction Supply Network Project

D&B – Design and Build

DBFO – Design, Build, Finance and Operate

DBFT – Design, Build, Finance and Transfer

DECC – Department for Energy and Climate Change

DECC – Department of Energy and Climate Change

DEFRA – Department for Environment, Food and Rural Affairs

DFD – Design for Deconstruction

DLP – Defects Liability Period

DPM – Deconstruction Process Model

DQI – Design Quality Indicator

EC – European Commission

EIA – Energy Information Administration (of United States)

EN – European Standards

ENVEST – A Software tool designed by Edge Environment for life-cycle Assessment

EPBD – Energy Performance of Buildings Directives

EPC – Energy Performance Certificate

EPSRC – Engineering and Physical Sciences Research Council

ESD – Energy Services Directives

ESRC – Economic and Social Research Council

EST – Energy Saving Trust

EThOS – Electronic Theses Online Service of the British Library

EU – European Union

FEES – Fabric Energy Efficiency Standard

FM – Facilities Management

FMs – Facilities Managers

GCI – Global Commons Institute

GDCPP – Generic Design and Construction Process Protocol

GMP – Guaranteed Maximum Price

GSHP – Ground Source Heat Pump

H&S – Health and Safety

H_2O – Water

HC – House of Commons

HSC – Health and Safety Commission

HVAC – Heating, Ventilation and Air Conditioning

IAQ – Indoor Air Quality

ICE – Institution of Civil Engineers

IEQ – Indoor Environment Quality

ILL – Inter-Library Loan

IMI – Innovative Manufacturing Initiative

IPCC – Intergovernmental Panel on Climate Change

IT – Information Technology

JCT – Joint Contracts Tribunal

KPI – Key Performance Indicators

k-value – Thermal Conductivity

LC – Low Carbon

LCA – Life-Cycle Analysis

LCB – Low Carbon Building

LCBP – Low Carbon Building Programme

LCC – Life-Cycle Costing

LCCA – Life-Cycle Cost Analysis

LCTs – Low Carbon Technologies

LEED – Leadership in Energy and Environmental Design

LPG – Liquid Petroleum Gas

M4I – Movement for Innovation

Met Office – Meteorological Office (UK's National Weather Service)

MEV – Mechanical Extract Ventilation

MSS – Maintainability Scoring System

MVHR – Mechanical Ventilation with Heath Recovery

NASA – National Aeronautics and Space Administration

NBS – National Building Specification

NCF – Nottinghamshire Construction Forum

NDLTD – Network of Digital Library Theses and Dissertations

NEDO – National Economic Development Office

NEMS – National Energy Modelling Systems (of United States)

NHS – National Health Service

No.1 – No.1 Nottingham Science Park

NPD – New Product Development

O&M – Operation and Maintenance

OGC – Office of Government Commerce

OMI – Operability and Maintainability Integrated

OMI Process Model – Operability and Maintainability Integrated Design and Construction Process Model

PCT – Primary Care Trust

PFI – Private Finance Initiatives

POE – Post Occupancy Evaluation

PPP – Public Private Partnership

ProjectCo – Consortium of Main Contractor and Private Sector Funders in PFI Contracts

PV – Photo-Voltaic

PVs – Photo-Voltaic panels

R.A. – Rating Average

RCM – Reliability Centred Maintenance

RIBA – Royal Institute of British Architects

RICS – Royal Institute of Chartered Surveyors

SAP – Standard Assessment Procedure

SBS – Sick Building Syndrome

SDC – Sustainable Development Committee

SME – Small and Medium Enterprise

Spec. – Specification

SRB – Sustainable Research Building, University of Nottingham

SUDS – Sustainable Urban Drainage System

TER – Target Emission Rate

ThinkFM – Annual conference of the British Institute of Facilities Management

UBT – Usable Building Trust

UBT – Usable Building Trust

UK – United Kingdom

UKGBC – UK Green Building Council

UN – United Nations

UNEP – United Nations Environmental Programme

UNFCCC United Nations Framework Convention on Climate Change

UNLOC – University of Nottingham Library Online Catalogue

UoN – University of Nottingham

US – United States of America

USGBC – US Green Building Council

U-value – Thermal Transmittance

VfM – Value for Money

WBDG – World Building Design Guide

WCC – World Climate Conference

WHO – World Health Organisation

WLC – Whole-Life Costing

WMO – World Meteorological Organisation

Chapter 1:

INTRODUCTION

1.0: INTRODUCTION

This chapter introduces the context of the research, beginning with the background information; highlighting the gaps in knowledge and practices that justify the research. The chapter also discusses the research aim, objectives, methodology and the steps taken to prosecute the research as well as a summary of the thesis structure.

1.1 BACKGROUND TO RESEARCH

With the realities of climate change confronting us, building designers all over the world are being called upon to create buildings that are sustainable; energy efficient, functional, economical, comfortable and safe, with reduced or no harm to the macro environment and the future generation. Consequently, the past few decades have witnessed a substantial rise in technology which has been a mixed blessing to humanity. Whereas technology provides us with comfort, it has also increased the amount of energy required to drive these technologies (Hensen and Lamberts, 2011). It is also widely understood that this increased energy usage has led to critical environmental problems (Ibid) such as increased CO_2 and other greenhouse gasses emission (RIBA, 2009f). Globally, efforts are being made to cut down on the use of fossil fuel in driving these technologies. Joe Clarke in Hensen and Lamberts (2011) noted some of these efforts to be the deployment of energy efficiency measures and a switch to new and renewable sources of energy, among others.

In the building industry, this has given rise to varying low carbon and renewable technologies, also referred to as sustainable technologies, green technologies or energy efficient technologies gradually replacing the traditional high fossil fuel driven technologies in buildings. These measures are adopted to meet up with the World scientific consensus on a Carbon emissions target of 80% reduction by the year 2050 (Avis, 2011).

However, in all these strategies, little or no emphasis is being made on how these buildings will continue to perform their required functions and maintain their good aesthetic appeal in the face of natural forces such as wear & tear and aging. Artificial forces like misuse or mishandling, accidents and change of taste through the operating and maintenance phase of the building life, also to be considered.

As stated in literature, for a building of about 30 – 50 year life span, the operation and maintenance phase which is the longest phase of the building life accounts for 50 – 80% of the real cost spent over the life of the building (Bokalders and Block, 2010; Silver et al, 2004). Unfortunately, reasonable attention has not been given to research concerning how the new components provided in buildings could be effectively maintained long into the future (Seeley, 1987; RICS, 2000 and Wood, 2009).

Low carbon buildings (LCB) are energy efficient buildings; which are not only those fitted with energy efficient technologies, but are also required to adopt materials and processes that are environmentally responsible and resource-efficient throughout the buildings' life-cycle: from siting to design, construction, operation, maintenance and disposal (from cradle to grave). They are also referred to as green buildings, energy efficient buildings or sustainable buildings. In the UK there are concerted efforts by government to ensure that all new domestic buildings are Zero net Carbon by 2016 and 2019 for the non-domestic (DCLG, 2007; BRE, n.d.).

The driving objective of LCB building designs is to reduce the overall impact of the built environment on human health and the natural environment by (EPA, 2012):

- Efficiently using energy, water and other resources
- Protecting occupants health and improving employee productivity
- Reducing waste, pollution and environmental degradation.

Literature reviews indicate that buildings and associated uses account for a substantial part of the environmental load caused by humanity (U.S.DOE, 1999; Szokolay, 2008; BRE, n.d.). The United States Department Of Energy (DOE),1999 reports that buildings in the U.S alone consume roughly:

- 37% of the nation's primary energy
- 67% of the total electricity used each year

- 35% of CO_2 emission in the US
- 9% global CO_2 emission

Former CIBSE President, Mike Simpson, in his forward to Cinquemani and Prior (2010) noted that about half of the CO_2 emission in the UK are attributed to buildings. Szokolay, 2008 looks at the figures from a global perspective; reporting that buildings and associated uses are responsible for:

- 42% of all energy consumption
- 40% of all atmospheric emissions
- 30% of all raw material usage
- 25% of solid wastes
- 25% of water usage
- 20% of liquid wastes

Szokolay also added that all these can be strongly influenced by architects and designers. The question is how? Some of the common answers in literature are:

1. To ensure that the buildings they design are energy efficient and meet the nation's standards for zero carbon designs (U.S.DOE, 1999)
2. Address the issue (of ensuring zero carbon) from all the stages of the building life; from early sketch design, via detailed design to construction, commissioning, operation, control and maintenance of new builds and existing one (Hensen and Lamberts, 2011).
3. Similar to point 2 above is advocacy for whole-life assessment concept (Edwards, Bartlett and Dickie, 2000). However, RIBA (2009f) has criticised the conventional concept of Whole life Assessment termed life-cycle costing (LCC) or whole-life costing (WLC), noting that this is a money-based measurement. It further explained that whereas the initial construction cost could be estimated with reasonable accuracy, the cost-in-use could be more difficult to estimate due to future uncertainty.

RIBA further advocates for life-cycle analysis (LCA) which is based on the whole life assessment of its environmental impact.

However, some researchers have raised concerns in line with current practices of zero carbon designs. Joe Clarke questioned in his forward to Hensen and Lamberts (2011); *"should the widespread deployment of micro-CHP* (combined Heat and power) *within the urban environment be acceptable if the global carbon emission reduction target is attained at the expense of reduced local air quality and increased maintenance cost?"* This implies that the cost implication of running a building cannot be divorced from the environmental impact globally and locally, within the building.

From the foregoing, it seems proper to conclude that whereas it is difficult to calculate near-actual operating and maintenance cost from inception, it is possible to put forward a rough guide in the form of maintenance needs of the design from the very early stage of the project. It is also clear that the design of a building is just the beginning of the building's environmental impact (Cassidy & Pinkard, n.d.). So if the environment must be safe guarded, demand is placed not only for a reduction in new-build activities, but also in repair/restoration (corrective maintenance) works.

1.2 PROBLEM STATEMENT

The issue of building operation and maintenance has become a growing concern not only to researchers but to government bodies and practitioners. This has led to the adoption of various procurement routes in the industry. Until the recent introduction of the new Government Construction Strategy in the UK, the Design & Build (or Develop and Build) and the Design, Build & Operate (PFI) systems seem to be highly ranked on the preferred list by public or corporate clients. However, studies show that no procurement route can adequately ensure maintainability or sustainable maintenance of buildings, if a deliberate attempt at ensuring maintainability is not considered at the design stage of the project (Frank, 2011). John Edwards, Chair of the expert panel in building maintenance at the Chartered Institute of Building said; *"Maintenance and repair is estimated at 47% of the construction industry's output, so if we really want to reduce greenhouse gas output by 80% by 2050, we cannot afford to ignore building maintenance"* (UWIC 2009). UWIC (2009) noted also that *"Proper maintenance will help buildings survive through climate change …",* and that *"building maintenance is the most essential ingredient in both tackling and coping with climate change".*

Malekzadeh et al. (2011) stated that the need for constant communication between building designers with operators/managers and users of buildings has been identified as a possible factor in preventing building failure in its in-use performance and ensuring sustainability in energy efficient buildings; geared towards achieving zero carbon.

This research has therefore identified the building operation and maintenance (O&M) manual and other building documents as sources of communication between the designers and operators of buildings and seeks to explore a more effective approach to the drafting of O&M manuals for low carbon buildings.

However, BSRIA (2011) decried the fact that the construction industry has a poor reputation when it comes to O&M manuals in terms of quality and timeliness of delivery. However, low carbon buildings are unconventional buildings; hence the need for an effective guidance on how they should be operated and maintained cannot be over emphasised if the building and its operation and maintenance processes must remain energy and resource efficient.

1.3 JUSTIFICATION/RELEVANCE OF THE RESEARCH

The need for this research is reflected in the views of several authors who have decried the dearth of sufficient research on the subject of building operation and maintenance (Lewis et al, 2011; Edmond et al, 2010; Wood, 2005). It becomes more compelling when one understands that *"no matter how sustainable a building may have been in its design and construction, it can only remain so if it is operated responsibly and maintained properly"* (National Institute of Building Science, 2010). RICS, 2000 also sees building maintenance as the "*key to sustaining the built environment*". This research is built upon this foundation and also based on the fact that buildings are not designed and built just for today but for the future as well (Ruskin, 1895).

> *"When we build, let us think that we build forever. Let it not be for present delight, nor for present use alone; let it be such work as our descents will thank us for, and let us think, as we lay stone on stone, that a time is to come when those stones will be held sacred... For indeed the greatest glory of a building is not in its stones, nor its gold. It is in its Age".* - (John Ruskin*1895*)

Also, Communities Minister Andrew Stunell was quoted in his keynote address at a UK Liberal Democrat Party conference to have said;

> *"zero-carbon homes were in the danger of becoming an 'empty slogan' because of the industry's failure to build to required standards... But it is essential in the fight against climate change…"* (Rudi.net, 2012a).

Dr David Strong who is the 2007 Sustainability Leadership Award winner and also a founding member on the UK Green Building Council was also quoted to say;

> *"If we end up with zero carbon Code Level 6 homes that are uneconomical to maintain … poor indoor air quality or other unintended consequences, then we have created a generation of homes that are unfit for people. We can't call this sustainability. The so-called 'best' are in real danger of becoming the enemy of good"* (Rudi.net, 2012b).

David Strong also noted that

> "*The danger of the Zero carbon agenda that has gripped the UK property industry is that it ignores social and economic sustainability and could result in highly perverse outcome……"* (Ibid).

Andrew Stunell was also quoted to say that

> *"many processes and cultures within the industry and its supply chain need to change if Zero Carbon Homes is to be more than an empty slogan" (Rudi.net, 2012a).*

These statements suggest that clients/users of LCBs may not be receiving long-term value for their investments, and/or that the current processes of LCB delivery do not deliver satisfactory results and therefore may warrant a change in the way we; as 'trusted professionals' deliver LCBs to the end-users.

Many government reports on the construction industry such as the Latham 1994 and Egan 1998 have emphasised the need to improve construction. The reports identified poor co-ordination and communication, minimal research and development and lack of customer focus, among others as key inhibitors to the industry's performance (Cahill & Puybaraud, 2003; Murray, 2003). Recent researches have also shown that significant differences are often found between the design and measured performance of buildings (Birchall, 2011). Also, research on 2016 emissions targets for zero carbon homes suggests that action is needed by Government and industry to investigate and tackle the perceived gap between the calculated energy performance of new buildings at the design stage and the as built performance of same buildings (DCLG, 2012). Many factors could be responsible for this disparity, however, it had been argued that the information gap between the design team and the end users of the building is one (Malekzadeh et al., 2011). Within the current building delivery and management system, the building documentations, if properly harnessed is likely to be a good bridge.

This Research therefore was set out to investigate how operation and maintenance consideration could be embedded into the delivery process of low carbon buildings, as a way of improving the build quality and enhancing client/end-users satisfaction. At the start, it was not clear how this could be achieved, however, in concluding, an innovative design and construction process model that integrates operation and maintenance considerations into the design and construction process was proposed. Most importantly, a stage requiring 'Proof of Life-Cycle Operability and Maintainability' was incorporated in the proposed model.

Lastly, the relevance of this research cannot be overemphasised as it is most needful in the UK building industry at present. In 2011, the Government Construction Strategy was launched; aiming to achieve efficient construction delivery. By 2012, the RIBA proposed a review to her 50 year old Plan of Work with a view to improve building delivery processes. By June 2013, when this research was concluding its writing-up phase, a revised version of the RIBA's model was launched. The revised version of the RIBA Model incidentally created room for the integration of operation and maintenance considerations as *'Suggested Key Support Tasks'*, but did not however provide details. The model proposed by this research provided the details to fill the gap.

1.4 RESEARCH AIM AND OBJECTIVES

The aim of this research is to explore how best the operation and maintenance challenges of low carbon buildings can be minimised with the use of an effective building operation and maintenance manual regime within the current practices in the building delivery process in the UK.

To achieve this aim, the following objectives have been outlined:

1. Review the operation and maintenance challenges that exist in selected low carbon technologies and their impacts on the users well-being and the environment

2. Evaluate prevalent delivery processes of low carbon buildings in the UK, and the operation and maintenance challenges that exist there in.
3. Explore the barriers and enablers for O&M manuals as an effective tool for maintainability and operability of low carbon building design.
4. Explore a best practice approach to drafting and use of the O&M manual in a manner capable of bridging the information gap identified between building designers and users cum operators of low carbon buildings.

1.5 RESEARCH PROCESS

To achieve the research objectives outlined in section 1.4, a multi-method research approach was employed. The multi-method approach was adopted because the conclusions reached in a research project are more convincing and accurate when they are based on several sources (Yin, 2009). Table 1.1 explains how each objective was pursued; the methods used and subjects involved. The table also acted as a guide in determining the purpose and consequently questions for the interviews and surveys.

The research began with trying to establish relevance and identifying gaps in knowledge through a review of literature on relevant topics within the research domain from journal papers, conference proceedings, textbooks and archival records. The main sources of data were the University of Nottingham library, Nottingham City library, the British library (including Inter-Library Loan Service and the Electronic Theses Online Service – EthOS). Other sources included the British Standards Institution (BSI) Knowledge Centre, Papers from Professional Public Debates, Consultations and Exhibitions and the world-wide-web searches.

Table 1.1: Research Plan

S/n.	Research Objectives	Research Method	Subjects
1	Review the operation and maintenance challenges that exist in selected low carbon technologies and their impacts on the users well-being and the environment.	**Secondary data (literature/archives)**	
		Interviews	Clients, Designers, Facilities Managers, Other Built Environment Professionals and researchers
		Structured Questionnaire	
		Case Studies	Exemplar low carbon buildings
2	Evaluate prevalent delivery process of LCBs in the UK and the operation and maintenance challenges that exist there in	**Secondary data (literature/archives)**	
3	Explore the barriers and enablers for O&M manuals as an effective tool for maintainability and operability of low carbon building design.	**Secondary data (literature/archives)**	
		Interviews	Clients, Designers, Contractors, Built Environment Professionals – practitioners and researchers
		Semi-Structured Questionnaire	
		Case Studies	Exemplar low carbon buildings
4	Explore a best practice approach to drafting and use of the O&M manual in a manner capable of bridging the information gap identified between building designers and users cum operators of low carbon buildings.	**Secondary data (literature/archives)**	
		Interviews	Clients, Designers, Contractors, Built Environment Professionals – practitioners and researchers
		Semi-Structured Questionnaire	

Preliminary exploratory pilot study was also carried out with a view to test some of the data collection and analysis tools; it involved interviews, questionnaire survey and physical evaluation with photographic evidences. A pool of contacts was also built up from professional and industrial conferences, exhibitions and debates, such as; Ecobuild, ThinkFM and ACA Debate.

1.6 THE THESIS STRUCTURE

The thesis is divided into nine (9) chapters as illustrated in figure 1.1 and a brief content description of each chapter outlined.

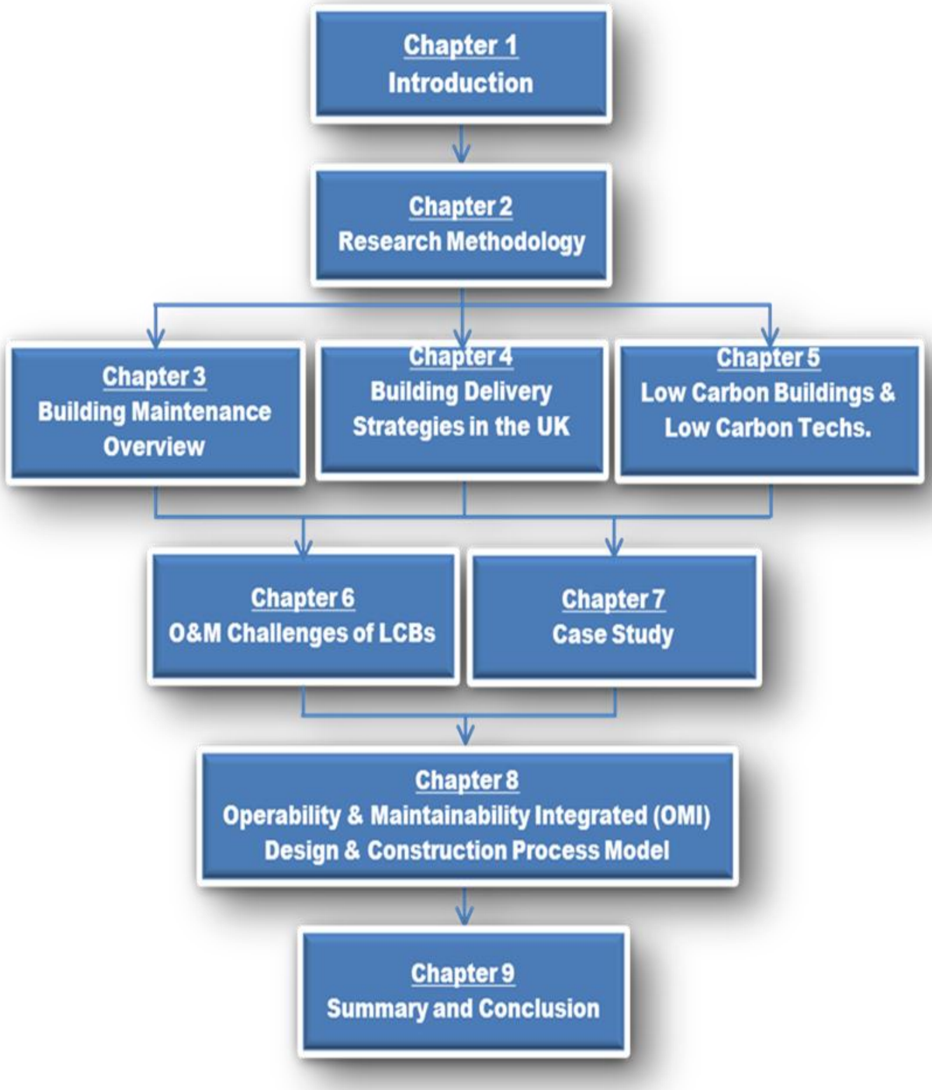


Figure 1.1: The Thesis layout

Chapter 1 introduces the context of the research, beginning with the background information; highlighting the gaps in knowledge and practices that justifies the research. The chapter also discusses the research aim/objectives, method and a summary of the thesis structure.

Chapter 2 examines the generic research concepts and delineates the strategies adopted for this research to facilitate the achievement of the aim and objectives set for this research. It discusses also how the data were analysed.

Chapter 3 presents an overview of relevant literature on the subject building maintenance; objectives, impacts on national growth, etc. It also reviews the concepts of maintainability, operability and sustainability in operation and maintenance of buildings, and the impacts on the environment. It also discusses the Principle of Duty of Care, seeing building designers as owing a duty to take reasonable care to ensure that their clients or third party users do not incur any foreseeable physical injury or economic loss as a consequence of their negligence.

Chapter 4 continues with literature review, presenting a retrospective survey of building procurement strategies in the UK and how they impact on operation and maintenance of buildings, from pre-1939 to PFI and the current Government's Construction Strategy vis-à-vis the efforts of the industry to prosecute the strategy. It also reviewed the 2010 RICS Contract in Use data

Chapter 5 also discusses relevant literature on the concept of low carbon buildings, and low carbon technologies. It looks at its antecedents; Climate Change and Sustainable development, the UK zero carbon policy and the government's strategy and progress so far in achieving the zero carbon target.

Chapter 6 presents the analysis of results of interviews and survey conducted with professionals who have been involved in design, construction, management and research of low carbon buildings, and highlighting the various challenges associated with their operation. The chapter also discusses the results of the hard copy survey circulated principally among facilities managers in the UK, who are the professionals directly involved with the day to management of buildings, trying to understand their perspective about the O&M regime in the UK. Related archival and recent Government documents are also examined. Detailed procedures of how these data were collected were also discussed.

Chapter 7 discusses results of case studies undertaken with the aim of understanding operation and maintenance challenges of selected low carbon technologies, how they impact on the comfort and well-being of users. The case studies also focused on assessing how the O&M manual and other building documentations impact on the effective operation and maintenance of buildings studied. The No.1 Nottingham Science Park was selected from 20 exemplar low carbon buildings identified, for the case study, through an information oriented selection process.

Chapter 8 draws from the conclusions reached in chapters 6 and 7, which shows that there was need to propose a new design and construction process model that will integrate operability and maintainability into the delivery process of low carbon buildings. The purpose was to make designers think through operation and maintenance by bringing in facilities management skills and O&M drafting process early in the design process of LCBs. It discusses how the process model was developed as well as the steps taken to validate it.

Chapter 9 summarises the findings of this research and assessing how the research aim and objectives were achieved. The chapter also discusses the conclusions reached and how this research contributes to knowledge as well as the opportunities for future research work.

Chapter 2:

RESEARCH METHODOLOGY

2.0 INTRODUCTION

This chapter examines the generic research concepts and methodologies common in literature, which are used in built environment researches and also delineates the strategies adopted for this research to facilitate the achievement of the aim and objectives. It discusses also how the data were analysed. It begins by examining the various concepts or world view of research, then discusses and differentiates between the Qualitative and Quantitative research methods and their traditions. The chapter also gives explanations on why the Mix Methodology also known as Triangulation was adopted for the construction of this research design, and the actual techniques used in prosecuting the research.

2.1 CONCEPT OF RESEARCH AND RESEARCH PHILOSOPHY

Research means different things to different people however common phrases used to describe research include detailed enquiry; solution seeking in a methodical manner; aimed at making discoveries that will add to knowledge (Fellow and Liu, 2008; ESRC, 2010). The Chambers 21st Century Dictionary describes research to mean; "detailed and careful investigation into some subject or area of study with the aim of discovering and applying new facts or information.

Grinnell (1993) in Kumar (2011) also describes research as a structured inquiry that utilises acceptable scientific methodology to solve problems and create new knowledge that is generally applicable. This implies that there are varying methodologies, and the methodology to be used for any research must be fitting and acceptable.

However, irrespective of the methodology chosen, good research must be rigorous, systematic, integrated and focused (Peters and Howard, 2001). It should also aim at either developing or enhancing a theory (pure research) or problem solving (applied research) (Holt, 1998).
The concept of pure research and applied research can be explained clearly on Table 2.1.

Within the research community, there exist several perspectives on the suitable paradigm (Fellows and Liu, 2008) or worldview (Creswell, 2009) for understanding the philosophical position and conducting a research. The two major philosophical schools of thought or worldview in social science research, and by extension the social science or management aspect of built environment research, are Ontological and Epistemological considerations (Bryman, 2004).

Table 2.1: Difference between Pure and Applied Research

Characteristics	Pure Research	Applied Research
Purpose	Focused on developing or enhancing theory, development of knowledge and to aid search for the 'truth'	Conducted to solve practical and current problems. Here addition to knowledge is more 'incidental' than being the main purpose.
Reasoning Method	Research is carried out for the advancement of knowledge, without working for long-term economic or social benefits and with no positive efforts being made to apply the results to practical problems or to transfer the results to sectors responsible for its application. Pure research asks questions like, 'is it true?'	Research is original investigation undertaken in order to acquire new knowledge. It is however, directed primarily towards a specific practical aim or objective. Applied research asks questions like, 'does it work?'
Hypothesis	Pure research is for the sake of curiosity and functions to advance knowledge for its own sake.	Applied research is for the sake of technological advancements. The research anticipates that the results will lead to the development of a commercially viable goods or processes

(Source: Adapted from Fellows and Liu, 2008)

While ontology concerns the nature of social entities and how they exist within a structure of reality, epistemology is concerned about the question of what is (or should be) the acceptable knowledge in a discipline and the methods used to investigate the development of this knowledge (Bryman, 2004). Fitzgerald and Howcroft (1998) highlighted the two broad ontological positions as: Realist and Relativist positions, while the epistemological positions are grouped as Positivist and Interpretivist. Table 2.2 summarises the nature and characteristics of these philosophical assumptions.

Table 2.2: Summaries of Philosophical Assumptions

Ontological Considerations	Epistemological Considerations
REALIST ❖ External world comprises pre-existing hard and tangible structures. ❖ Structures exist independent of individual's ability to acquire knowledge.	**POSITIVIST** ❖ Social world exists externally and is objective in nature. ❖ Advocates application of the methods from natural sciences. ❖ Quantifiable observations are measured with statistical analysis to draw inferences about a phenomenon.
RELATIVIST ❖ Existence of multiple realities is a subjective construction of the mind ❖ Perception of reality is directed by varying socially transmitted terms	**INTERPRETIVIST** ❖ Reality is constructed by researcher's understanding and interpretation of real world. ❖ Concerned with meanings and experiences people associate with the real world. ❖ Alternative to the positivist orientation

Source: Love et al, 2002

2.1.1 Philosophical Positioning of this Research

The research was based on the belief or assumption that an improved information system from designers to the building end users is capable of bridging the information gap that exists between these two parties. It is also assumed that the improved information system will improve the in-use performance of new and innovative low carbon technologies which are fast replacing the fossil fuel driven equipment in buildings. Therefore the following ontological and epistemological considerations were assumed:

i) The realist position of Ontology was assumed from a theoretical standpoint because it was possible to explore real life experiences of end users and professionals involved in designing, constructing, managing and/or researching about low carbon buildings in the UK.

ii) The research also acknowledges that there are studies, though very limited, that have identified the need to bridge this gap and offered useful suggestions, which form the pivot for this study.

2.2 REVIEW OF RESEARCH METHODS

Yin (2009) posits that the choice of an appropriate research method should be influenced by the following factors:

❖ the nature of the inquiry and the type of questions being posed,

❖ the extent of the researcher's control over the actual behavioural event,

❖ the degree of focus on contemporary events.

The research approaches common in literature are basically Quantitative and Qualitative (Hussey and Hussey, 1997). There is also a combination of methods commonly referred to as Triangulation (Neuman, 2006). An overview of the characteristics of the quantitative and qualitative methods is shown Table 2.3.

Table 2.3: Overview of Quantitative and Qualitative Research Methods

Characteristics	Quantitative Research (Analytical)	Qualitative Research (Interpretative)
Philosophical assumptions	Positivism/empiricism	Subjectivism, interpretivism, constructivism and advocacy/ participatory knowledge claims
Strategy of inquiry	Scientific method; surveys and experiments, hypothesis – driven, deductive, reliable, valid, reproducible, objective and generalizable	Grounded theory, phenomenology, ethnography, case study, inductive, subjective, idiographic and intuitive
Purpose	To generalize about or control phenomena	To provide in-depth descriptions of settings and people
Reasoning Method	Primarily deductive: specific predictions based on general observations, principles or experiences	Primarily inductive: generalization based on specific observations and experiences.
Hypothesis	Identified prior to research; purpose of research is to test it	Begins with guiding research questions which will be refined during data collection and analyses.
Nature	More narrowly focused and outcome oriented	Holistic and process oriented
Design	Clear, well-oriented sequence of steps	Flexible and changeable in the process of research
Interaction with context	Tries to eliminate the influence of contextual variables	Tries to capture the richness of the context of the subjects and their perspectives
Data Collection	Primarily numerical data through paper-and-pencil, Non-interactive instruments (Can also include narrative data)	Primarily narrative data collected from field work
Methods/ Samples	Large-scale, generally surveying randomly selected respondents	Small-scale, interviewing, observation, document analysis with respondents selected to fulfil a given quota or requirement
Data Type	Self-administered questionnaires, experiments, structured observation and structured interview – closed-ended questions, predetermined approaches	Conversation and analysis, focus groups, and unstructured and semi- structured interviews – open-ended questions, emerging approaches, text or image data
Common practices	Tests or verifies theories or explanations, identifies variables to study, relate variables in questions or hypotheses, use standards of validity and reliability, observes and measures information numerically, and uses unbiased approaches and statistical procedures.	Collect participant meanings, focus on single concept, brings personal values into the study, studies the context or setting of participants, makes interpretations of data, creates an agenda for change or reform, and collaborate with the participants.
Outcome/ Analysis	Content analysis/statistical analysis and recommended final course of action	Non-statistical, thematic exploration, with findings being generalized
Final Written Report Structure	Set structure consisting of: introduction, literature and theory, methods, results and discussion	Flexible structure; inductive style

Adapted from: Isiadinso, 2010; Creswell, 2009

2.2.1 Quantitative Research

Quantitative research method is used in testing objective theories by examining the relationship among variables, which in turn can be measured, typically with instruments so that the data generated; usually numbers can be analysed by statistical procedures (Creswell, 2009). Fellows and Liu (2008) noted that quantitative research uses 'scientific method' in which initial study of theory and literature yields precise aims and objectives with proposition(s) and hypotheses to be tested. Sarantakos (1998) argued that quantitative method is objective in nature and capable of providing explanations for social phenomena or process such as standardization. Quantitative research could be in the form of Experimental or Survey research (McQueen and Knussen, 2002). See Table 2.4 for a comparative merit/de-merits of each of the quantitative processes.

Table 2.4: Overview of the Quantitative Research Method

Quantitative Methods	Advantages	Disadvantages
Surveys	Very good for factual information gathering	Subjective responses
	Low cost of execution compared to other methods	Not entirely effective with complex and sensitive data
	Reduced limitations on geographical reach, especially with e-mails	Questions often misinterpreted and no chance for clarification, especially when mailed
Experiments	Ability of the researcher to control the variables	Difficult to use when studying people-related issues
	Ability to measure the extent of change	Often done in controlled environment without external factors
	Evaluates the cause-and-effect relationship	Time consuming

Source: McQueen and Knussen, 2002

2.2.2 Qualitative Research

Qualitative research method is adopted for exploring and understanding the meaning individuals or groups attribute to a social or human problem (Creswell, 2009). Qualitative approaches, according to Fellows and Liu (2008) seeks to uncover why things happen as they do; to determine the meanings which people give to events, processes, structures, etc. Fellows and Liu also added that; many qualitative works use data relating to people's perceptions to investigate aspects of their social world; some address people's assumptions, prejudices, etc., to understand their impacts on behaviour and, thence, (organizational/project) performance. Denzin and Lincoln (2000) and Creswell (1998) describe qualitative research as being multi-method in focus, involving an interpretive and naturalistic approach to the subject in question. This research approach emphasises words (rather than numbers), and observations to express reality and attempts to describe people in natural situation (Amaratunga et al, 2002; Bryman and Bell, 2007). In a nutshell, qualitative research involves the collection, organization and interpretation of textual data gathered from talks or observations; used in exploration of meanings of social phenomena as experienced by individuals, in their natural context (Malterud, 2001).

One attribute of this research method is that of flexibility in the overall research process as the questions and procedure are emerging (Creswell, 2009), not usually pre-determined. Data analysis are usually inductive; building from particular to general themes, and the researcher makes interpretations of the meaning of the data (Ibid). Qualitative research is many things and can be applied in researches within every discipline. It is interdisciplinary, trans-disciplinary and sometimes counter-disciplinary field, which crosses the humanities, social and physical sciences (Nelson et al, 1992). It is also argued that the qualitative methodology has replaced the pre-eminence and predominance of the quantitative methodology in British sociology (Bryman and Burgess, 2002).

Qualitative research could be viewed from 5 different perspectives referred to as; "tradition of inquiry" (Creswell, 1998) or "strategies of inquiry" (Denzin & Lincoln, 2000). These include:

- *Biography*; a study an individual and the individuals experience as told to the researcher or collected from archival records (Creswell, 1998)
- *Phenomenology*; in literal term, the study of a phenomena (Kakulu et al, 2009). It focuses on things that exist as part of the world in which we live such as events, situations, experiences or concepts (Ibid).
- *Grounded Theory*; aimed at the discovery or generation of a theory (Creswell, 1998).
- *Ethnography*; studies people in their natural settings, their behaviour, culture, etc. (Fellows and Liu, 2008).
- *Case Study*; a study of a single individual, a group or an event/project as a source of insights and ideas or to describe phenomena, project-biography or illustrative anecdotes (Ibid).

Table 2.5 describes further the differences between these 5 traditions.

Table 2.5 Comparing the Five Research Traditions in Qualitative Research

	Biography	Phenomenology	Grounded Theory	Ethnography	Case Study
Focus	+Exploring the life of an individual	+Understanding the essence of experiences about a phenomenon	+Developing a theory	+Describing and interpreting a cultural and social group	+Developing an in-depth analysis of a single case or multiple cases
Discipline Origin	+Anthropology, +Literature +History +Psychology +Sociology	+Philosophy +Sociology +Psychology	+Sociology	+Cultural anthropology +Sociology	+Political Science +Sociology +Evaluation +Urban studies +Other Social Scs.
Data Collection	+Primarily interviews and documents	+Long interviews with up to 10 people	+Interviews with 20- 30 individuals to 'saturate' categories and detail a theory	+Primarily observations and interviews with additional artefacts during extended time in the field	+Multiple sources – documents, archival records, interviews, observations, physical artefacts
Data Analysis	+Stories +Epiphanies +Historical contents	+Statements +Meanings +Meaning themes +General description of experience	+Open coding +Axial coding +Selective coding +Conditional matrix	+Description +Analysis +Interpretation	+Description +Themes +Assertions
Narrative Form	+Detailed picture of an individual's life	+Description of the 'essence' of the experience	+Theory of theoretical model	+Description of the cultural of a group or an individual	+In-depth of a 'case' or 'cases'

Source: Creswell, 1998.

2.2.3 Triangulation

Also commonly referred to in literature as mixed method (Olsen, 2004) or multi-method research (Bryman, 2004b); triangulation is an approach that combines both quantitative and qualitative forms within a study (Fellows and Liu, 2008). In social science triangulation is described as "the mixing of data or methods so that diverse viewpoints or standpoints cast light upon a topic (Olsen, 2004). Bryman (2004b) argues that one reason why researchers adopt triangulation is to enhance confidence in the ensuing findings, and that triangulation is more related with occasions where researchers seek to check the validity of their findings by cross-checking them with another method. Triangulation helps to gain insights and results, to assist in making inferences or drawing conclusions as shown in figure 2.1 (Fellows and Liu, 2008). The basis for triangulating is seeing quantitative and qualitative approaches as being complementary rather than as incompatible (Malterud, 2001).

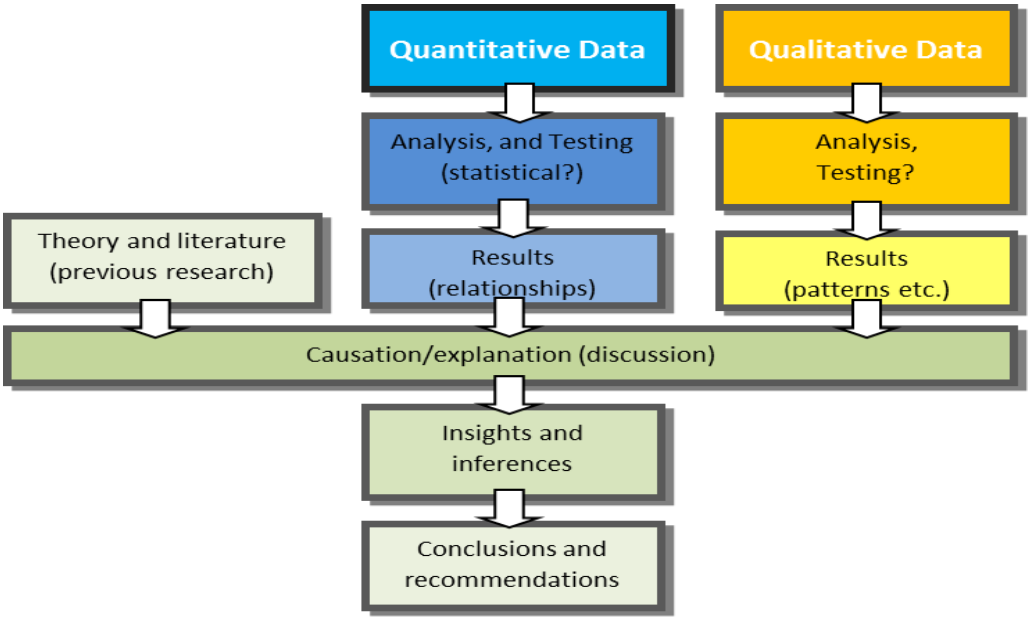


Figure 2.1: Triangulation of Quantitative and Qualitative Data
(Adapted from: Fellows and Liu, 2008)

Triangulation can be viewed from four different stand points (Yin, 2009; Denzin, 1970 in Bryman, n.d.):

- *Data triangulation,* involving the gathering of data through several sampling strategies, e.g., at different times, under different social situations, variety of people, etc.
- Investigator triangulation, involves using more than one researcher to gather and interpret data from their respective perspectives on the same theme
- Theoretical triangulation, involves using more than one theoretical position to interpret the same data
- Methodological triangulation, involves gathering data with more than one method.

Bryman noted that the Methodological triangulation appears to be the most common perspective of triangulation and that this can also be the form known as *'within-method triangulation'* or *'between method triangulation'.* Within-method approach adopts a single method but uses different strategies within that method while the between-method approach also referred to as 'across-method' approach combines more than one method in one study.

Love et al (2002) pointed out two main advantages of combining qualitative and quantitative research approaches as:

- It increases the capability to transmit the knowledge in a tangible form
- Convergent findings can provide greater researcher confidence in the reliability and/or validity of the results, while divergence can also lead to greater definition and theoretical elaboration as the researcher attempts to put the many pieces of complex puzzles into a coherent picture.

More so, a mixed methodology possesses the potential of leading to a better understanding of the phenomena being investigated, when additional information may be revealed that would otherwise remain undiscovered through a single methodological approach. It can also be argued that mixing research methods provide the advantage of benefiting from the strength of each of the methods and complementing the weaknesses inherent in each of the methods as well. Creswell (2009) argued that triangulation is a means for seeking convergence across the qualitative and quantitative methods. Figure 2.2 illustrates some of the opportunities of a mixed methodology research.

However, there may be some challenges in the use of the multi-method research. Yin (2009) noted that it could be more expensive than collecting data from a single source. Secondly, The researcher needs to know how to carry out the whole variety of data collection techniques because an improper use of a technique could hamper the opportunity to address a broader array of issues or to establish converging lines of inquiry.

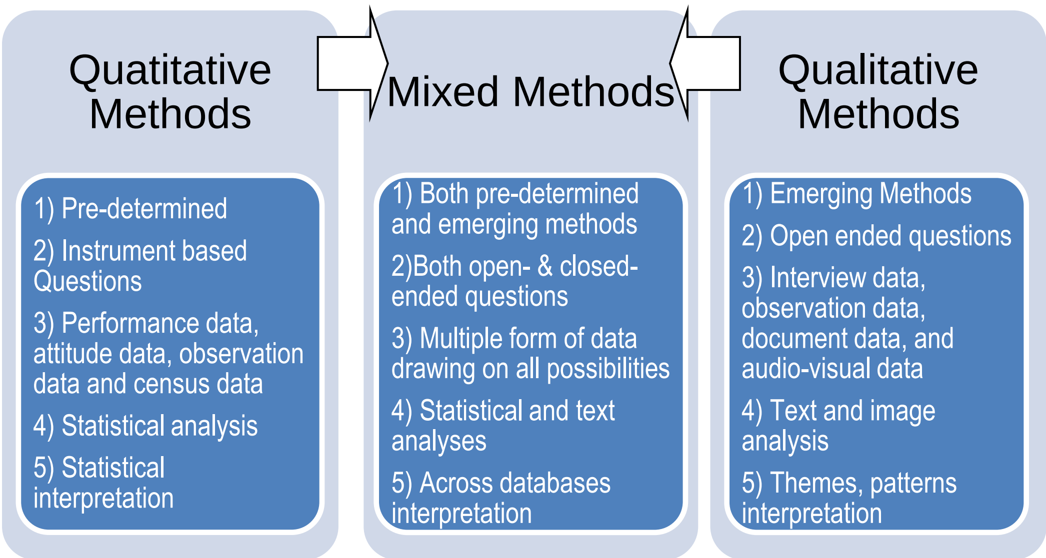


Figure 2.2: A Summarized Overview of Quantitative, Mixed, and Qualitative Methods (Adapted from Creswell, 2009)

2.3 METHOD ADOPTED FOR THIS RESEARCH

The mixed methodology design was chosen for this research in order to maximise the chances of realizing the research objectives in a more empirical way, while benefiting from the strength of each of qualitative and quantitative methods. Table 1.1 in the previous chapter highlights the way triangulation was used in this research; methodological triangulation. It featured both 'between method triangulation' and 'within method triangulation'. Figure 2.3 also shows how the research objectives were investigated and the general outline process of the research.

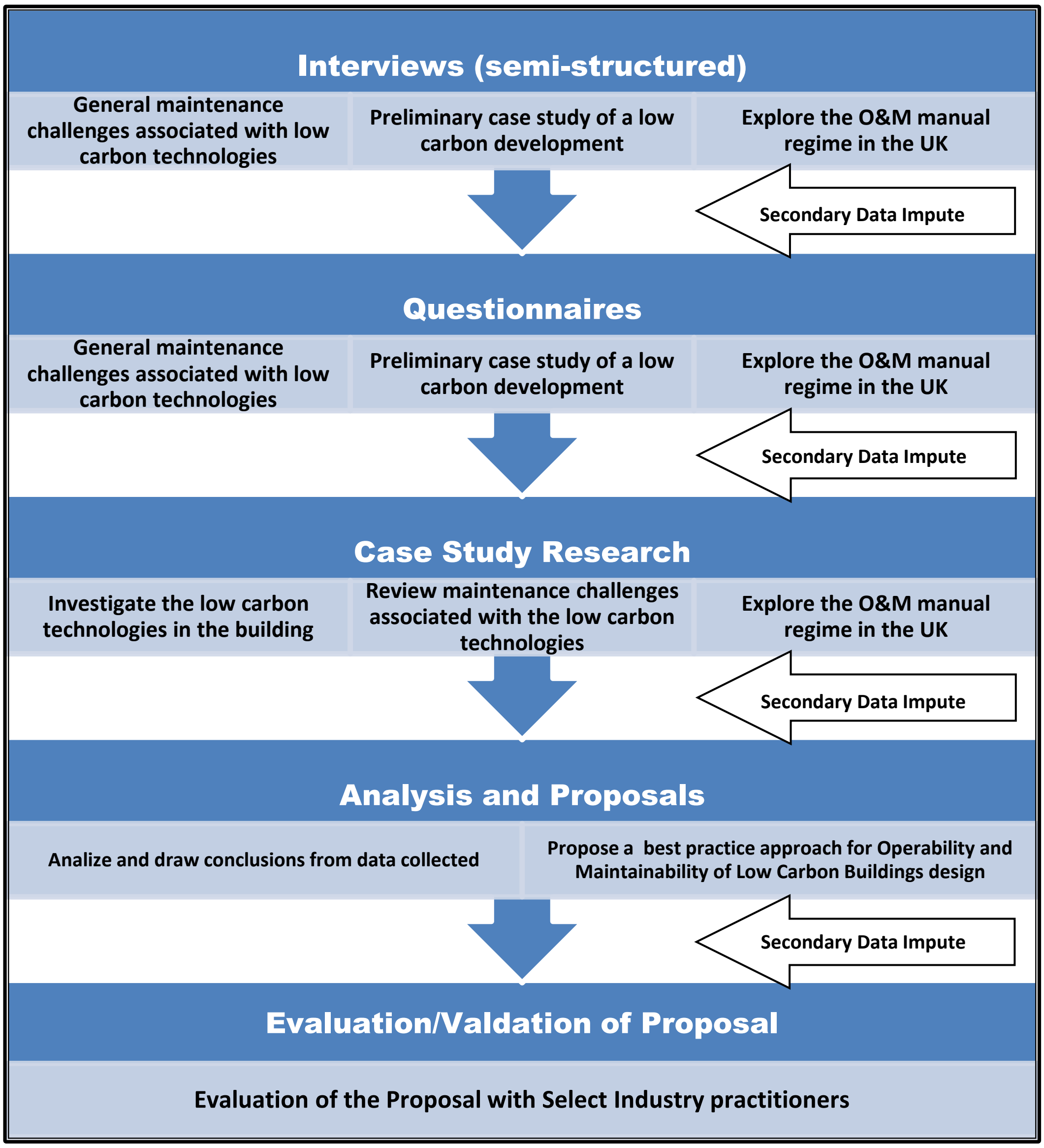


Figure 2.3: Data Collection Process

Firstly, the research started with discussions with relevant stakeholders in a one-on-one interview (Qualitative), after the initial literature review, in order to set the stage for a detailed inquiry. The quantitative survey, besides serving as a continuation of the interview, helped to strengthen the results from the interviews and some of the findings from literature. Case study

(Qualitative) became necessary for in-depth exploration. Within the case study methodology, physical evaluation/observation (Qualitative), interviews (Qualitative) and surveys (quantitative) were also used.

2.3.1 General Precautions to Minimise Error

Care was also taken to minimise the shortcomings identified for each of the research approaches the actions taken are as listed in the following points below.

2.3.1.1 Qualitative Approach:

- *Limited generalisation capability*. Within this research, though the samples for the interviews were relatively small because of in-depth nature of the investigations, but very experienced subjects were involved to obtain quality, diverse and reliable perspectives.
- *Subjectivity*. In order to minimise the subjectivity in the data collection and analysis for this research, a structured set of questions for the interviews was used, although open ended, to allow participants adequate room to express their experienced opinions. There were additional probing to explore or clarify issues further, and the interviews were recorded and documented.
- *Difficulty of replication*. To overcome this weakness, structure was introduced in the interview process.
- *Lack of transparency*. To minimise this limitation, the interviews were recorded in a digital voice recorder. The verbatim transcriptions were sent back to the interviewees for editing and correction.
- *The human element*. One of the weaknesses of the qualitative inquiry is being so heavily dependent on the researcher's skill, training, intellect, discipline, and creativity (Patton, 1988). So the quality of the research will depend heavily on the qualities of that human being. Therefore concerted efforts have been made to develop and improve

the research skills and quality of this researcher through attendance to numerous short training courses mounted by the Graduate School of the University. Training certificates attached as Appendix A.

2.3.1.2 Quantitative approach

- *Sampling limitation*. Although a small sample generally precludes some types of statistical tests of significance, the effective response rates of the surveys used in this study were small, and it is not unusual for this type of survey that has to do with a fairly new area like low carbon buildings where practitioners are also relatively few. For example, similar questionnaire surveys in the UK by Li *et al.* (2005) received a response rate of 12% and Soetanto *et al.* (2004) received a response rate of 18.9%.
- *Non-response limitation*. A variety of precautions were taken in the administration of the questionnaires such as hand delivery, telephone reminders and physical visits to retrieve back in order to maximise the response rate. In some cases, the survey pack also contained the researcher's self-addressed, first class stamped return envelopes.
- *Data collection errors*. To minimise such errors, a pilot study was conducted and the questionnaire was reviewed accordingly before the main survey was administered.
- *Data processing errors*. The data were coded and the data entry and results were double-checked throughout the data processing and analysis to minimise the likelihood of errors and limitations.

2.3.2 Literature Review

Literature review was conducted both at the outset and all through the research process as shown on figure 2.3, on relevant topics within the research domain such as:

- ❖ An Overview of building maintenance covering sub-sections like; terminologies, operability, maintainability and sustainable maintenance, need for sustainable building maintenance, impacts of maintainability on the environment and maintainability optimization.
- ❖ Historical background and legal requirements for the O&M manual in the UK.
- ❖ Building Procurement, historical development in the UK; from pre-1939 World War II through Simeon 1944 to the Latham and Egan Reports of 1994 and 1998 respectively and to present day. Procurement types were also explored; Traditional, Design & Build and Single-Point Procurement like Partnering and Private Finance Initiative (PFI), and how they impacted on maintenance.
- ❖ Climate Change imperatives on the built environment, including Global concerns for Low Carbon environment and the UK Government efforts towards the Zero Carbon target.
- ❖ Low carbon and renewable energy technologies and their operation and maintenance challenges.

The review of relevant literature essentially served three major purposes:

i. Providing a good foundation for the research by clarifying all relevant issues;

ii. Made the contemporary issues clearer, while highlighting the gaps in knowledge and practice; and

iii. Acted in conjunction with the field results as basis for the formulation of the proposed operability and maintainability integrated design and construction process model. That is to say, as secondary data.

The search for relevant literature was carried out through the University of Nottingham Library Online Catalogue (UNLOC), University of Nottingham MetaLib (an integrated search engine that facilitates searching across different databases and electronic journals), and the British Library through the University of Nottingham Inter-Library Loan (ILL) service, the British Standards Institution (BSI) Knowledge Centre, Nottingham City library and internet search engines such as Google and Google Scholar. The sources include textbooks, researched journals and periodicals, archival reports and news articles, Government and professional bodies publications, conference papers, Parliamentary reports, etc. The NDLTD (Networked Digital Library of Theses and Dissertations), and the British Library Electronic Theses Online Service (EThOS) were also explored.

2.3.3 Interviews

The interview was designed as a one-on-one interview with each participant at the venue, date and time chosen by the participant. A *semi-structured* form of interview was adopted, where an outline set of open ended questions were used, and still allowing room for the respondents to speak freely, and further questions emanating from the participants' responses to set an atmosphere of free-flowing discussion and created opportunities for indebt probing, further insights and clarifications.

Its purpose was to create platform for discovery of possible case studies; explores the low carbon technologies in the cases and their associated operation and maintenance challenges. Participants were chosen from professionals who have been involved with design, construction, management and/or research of low carbon buildings. Detailed discussion of the interviews purpose, process and population characteristics are discussed in chapter 6.

2.3.4 Questionnaire Survey

Two sets of structured questionnaires were used to further execute the inquiry. The first in web format, directed at professionals who have been involved with design, construction, management and/or research of low carbon buildings, but were not able to be reached for interview. The second survey was in a hard copy format, directed principally at facilities managers who are professionals directly responsible for the day to day running of buildings (end-user professionals). Details of the purposes of these two survey formats, processes involved in collecting and analysing data as well as the character of the population studied are also discussed in chapter 6.

2.3.5 Case Study

From the results of the interview, survey and secondary data 20 exemplar low carbon buildings were noted and analysed. However, in other to make an in-depth study, and considering the limitation of time and funds for the research it became necessary to select one case for in-depth study, although some lessons learnt in the general cases helped in drawing conclusions as well. The No.1 Nottingham Science Park was selected based on information oriented sampling as postulated by Flyvbjerg (2006).

The Post Occupancy Evaluation (POE) technique was employed for the study. The POE method adopted involved:

- Walk-through physical evaluation of the building and its surrounds;
- Building User Survey (BUS) occupants survey developed by Usable Building Trust (UBT) for the purpose of assessing occupants' perception of their buildings performance;
- A bespoke questionnaire developed by the researcher to address operation and maintenance issues not covered by the BUS;
- One-on-one interviews with persons involved with managing the building, including a representative of the client organisation, who has direct oversight of the building under study.

Details of how the case study was selected and methods adopted for the case study are discussed in chapter 7.

2.4 DATA ANALYSIS METHODS USED IN THIS RESEARCH

As discussed in section 2.3, multi-methods were employed in prosecuting this research, purely because of the exploratory nature of the research; seeking answers to processes and meanings that are not experimentally examined or measured. Methods used included; interviews, structured and semi-structured surveys, with case studies which also used interviews, physical observations with photographic evidences, and multi-sets of structured questionnaires, including the Building Use Studies (BUS) Occupants Questionnaire. The process of gathering and analysing this huge data calls for systematic, analytical, rigorous, disciplined, critical, insightful and creative approach. Taylor-Powell and Renner (2003) argued that "there is no single or best way" of analysing qualitative data, and that your process depend on:

- the question you want to answer,
- the need and those who will use the information, and
- your resources.

2.4.1 Thematic and Content Analysis Approach

A thematic analysis concept was planned to be adopted for analysing the data ab-initio; i.e., from research planning stage, as Burnard (1991) posits that it is essential to think through the method to be used for analysis before collecting the data. In this research, this was thoughtfully considered by listing out the methods of research against each objective as shown on table 1.1. That is, the medium of collect the data that will inform the achievement of that objective. So it became easier to know the objective(s) of a particular data collection tool as evident on figure 2.3. These objectives became the main themes while analysing the data gathered through a particular medium. For example, table 1.1 shows that interviews were to be used to find answers for research objectives 1, 3 and 4, on figure 2.3, these objectives were now spelt out as the purpose for conducting the interview. So the interview questions were planned and prepared around these objectives. At the analysis stage, these objectives were used as the main theme, from which sub themes were developed. Additional sub themes were also developed from the data itself (responses of participants)

The thematic analysis process has been noted to be pragmatic (Aronson, 1994), but lacks sufficient literature that outlines its pragmatic process (Ibid). However, it is a common general method of analysing qualitative data that is exploratory (Schwandt, 2007). This style of data analysis is aimed at producing a detailed and systematic recording of the themes and issues addressed in the interviews and linking the themes and interviews together under a reasonably exhaustive category system (Burnard, 1991).

According to Marks and Yardley (2004), the themes also referred to as codes, are drawn from existing theoretical ideas that the researcher brings to the data (deductive coding) or from the raw data itself (inductive coding). In this study, both inductive and deductive coding systems have been used as explained in the last two sentences of the first paragraph of this section 2.4.1.

Schwandt (2007) describes thematic analysis as 'qualitative thematic analysis' or 'interpretative content analysis'. This differs from 'Content Analysis' even though they have a lot of similarities. The content analysis approach results is a numerical description of features of a given text or series of images, whereas, the interpretative content analysis or thematic analysis emphasises the qualitative aspects of the material analysed (Marks and Yardley, 2004).

Content analysis encompasses establishing categories and then counting the number of instances they are used in the data. It is a partial quantitative method (Julien, 2008), and provides room for systematic qualitative analysis with clear procedures for checking the quality of the analysis conducted (Marks and Yardley, 2004). Both methods focus on identifiable themes and patterns of living and/or behaviour (Aronson, 1994).

Both the Content and Thematic approaches have been adopted in analysing the data gathered from all interviews conducted for this research. A system referred to as 'thematic content analysis' in Burnard (1991).

2.4.2 The BUS Methodology

In section 2.3, it has been established that the methods of collecting and analysing data in qualitative research are emerging. At the outset of the research design, there was no plan to study the case studies through a POE method, at this time the actual method to be used was not clear. However, in the course of the research, it became coincidental that other researchers and staff of the University of Nottingham were also carrying out a post occupancy indoor environment quality assessment of the same buildings highlighted as an exemplar low carbon building at the interview stage, and selected for indebt study. And it became necessary to collaborate with them in the distribution of questionnaires and sharing of relevant data. The standard Building Use Studies (BUS) Occupants Questionnaire developed over the years by Usable Building Trust (UBT) was adopted for the study. This method is simply referred to as the BUS methodology and has been widely adopted as a standard POE procedure in the UK and globally. The questionnaire was obtained on licence from UBT. Details about the distribution and collection process are discussed in chapter 7.

However, the data collected through the questionnaires were carefully fed in to a pre-formatted Excel spread sheet assessable only by a licensee on the UBT website. This was then forwarded or exported to the BUS database where the data was processed by series of scripts to produce the results. This process is graphically represented on Figure 2.4. The output information (the results) could be accessed by the researchers after the data have been processed.

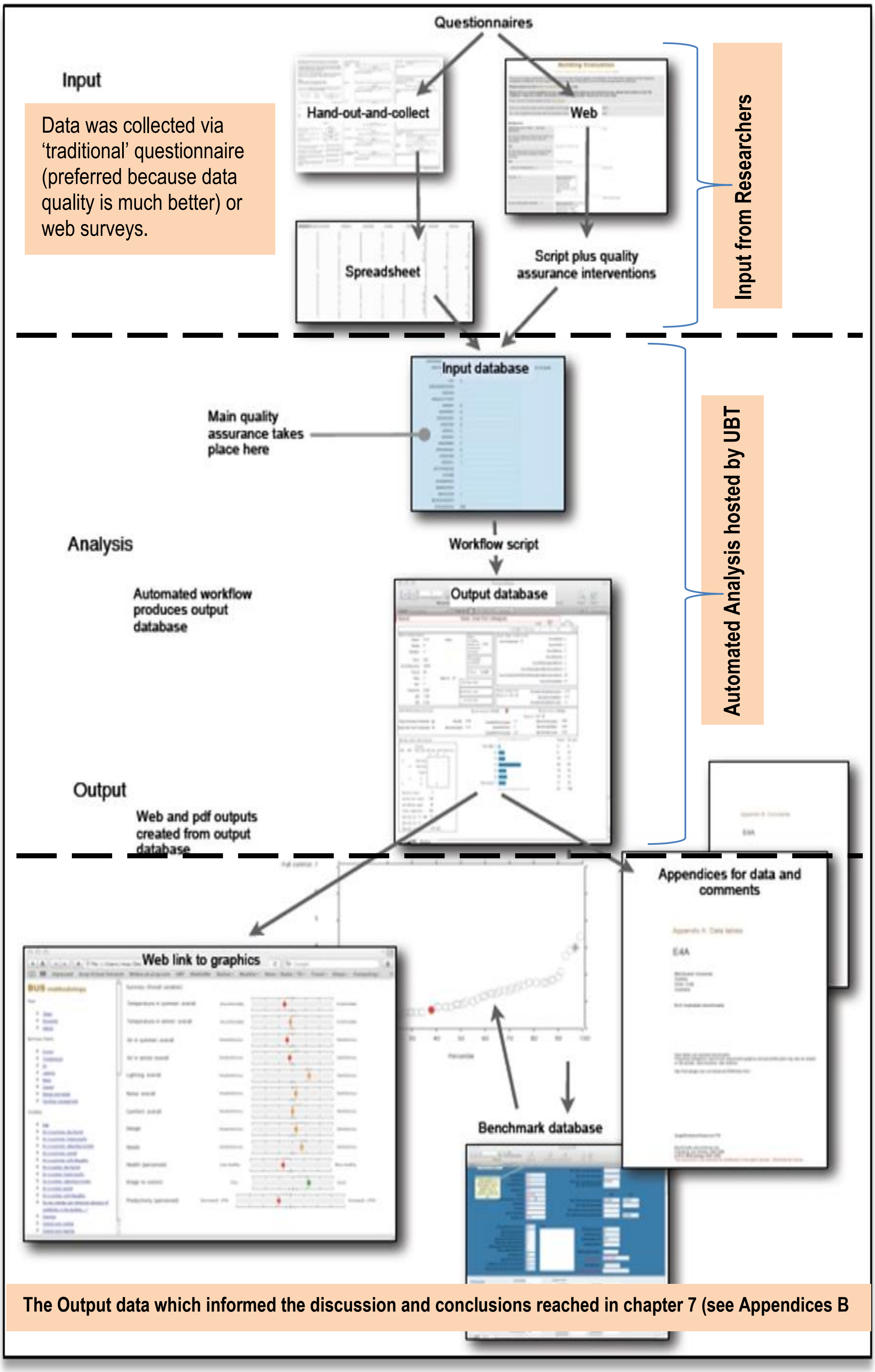


Figure 2.4: Components of the BUS analysis system
(Source: http://www.usablebuildings.co.uk/BUSMethodology.pdf)

2.4.3 Online Questionnaire – Survey Monkey

As a result of growth in technology and the widespread use of the internet, online or web-based survey method has also been on the increases and appear to be attractive because of its ability to provide access to a unique population which cannot ordinarily be reached by the researcher, saves time and cost of travels to distribute and collect questionnaires, as well as cost of paper and postage in some cases (Wright, 2005; Garton et al., 2003; Wellman, 1997; Bachman and Elfrink, 1996).

A careful review of the shortcomings of using the online method was made with the intent of adopting strategies that could eliminate or minimise such weaknesses, which include:

- *Sampling issues*: Relatively little is known about the characteristics of people in online communities (Dillman, 2000); a number of recent web survey services provide access to email lists generated from previous online surveys and there is no guarantee that participants from the earlier surveys provides the right sample for the new survey (Wright, 2005); particularly in this case; centred on low carbon buildings that is still a growing technology with limited number of specialists in the field. This of course could affect the validity of the data so generated.

  To overcome this shortcoming, using the services of the software company to distribute the survey was avoided; survey was sent through a customised link in an email to selected participants.
- *Response issues*: when compared with other forms of survey, online surveys are said to produce lower response rates (Dillman et al., 2009). Dealing with this issue was difficult because most of the persons contacted, even though they were not able to respond to the survey, were kind enough to send an email, saying they were not actively involved in low carbon designs.

- *Cost issue*: Although web surveys tend to save cost of paper and travels, however, some web based survey packages could be very expensive as well (Wright, 2005). The cost, time and risks involved in travels were weighed against the cost of the online software and the later was found to be cheaper and environmental friendlier.

- *Ethical issues:* The data storage methods of some web survey packages provide sources of ethical concern, particularly when trying to gather data on sensitive subjects. Issues of confidentiality cannot be guaranteed by the researcher (Wright, 2005). In ensuring ethical safety, it was necessary to understand the privacy policy of the software company chosen; Survey Monkey. They pledge to keep the emails of respondents safe and accessible only by the researcher or used only as directed by the researcher. They also claimed to be operating within the US-EU Safe Harbour Framework.

- *Ease of Use:* Some internet survey software may pose some difficulty in manipulation to achieve desired result. Although some companies provide technical support, but could be very expensive. The first step taken to tackle this short coming was to discuss with colleagues who had used online methods to learn from their experiences, which revealed that they found the 'Survey Monkey' a lot easier to use. Secondly a test survey was carried out and analysed using Survey Monkey, it proved easy to manipulate.

2.5 ETHICAL REVIEW

It is a requirement in the University of Nottingham for any research study involving human participants, to ensure that full consideration is given to ethical issues and that steps are taken to ensure participants well-being throughout the study. It is also a requirement to submit an application for ethical approval before conducting such research. Members of the Ethics Committee will read through the study plan to check that the researchers have demonstrated that they have given full consideration to ethical issues and that they have provided participants with appropriate and sufficient information. All participants involved in the research studies have a right to:

- Know the goals of the study and who is funding the work
- Make an informed decision about whether or not they wish to participate
- Leave the study at any time if they do not wish to continue
- Know what will happen to them during the study and how long it will take
- Know if they may experience any discomfort
- Know what will happen to the findings
- Privacy of personal information
- Be treated courteously

In pursuance of the above requirements, ethical approval for this research was sought, and approval received. The Ethics Committee Reviewer's decision/approval is attached as Appendix B.

2.6 CONCLUSION

A generic overview of research concepts and methodologies were discussed in this chapter. It identified that whereas research may mean different things to different people; it is a form of logical or systematic, detailed and careful inquiry, aimed at making discoveries that will add to knowledge. It is also solution seeking in a methodical manner; directed at either developing or enhancing a theory (pure research) or problem solving (applied research). The philosophical positioning of the research was discussed. It presents the research as basing on the belief and assumption that an improved information system from designers to the building end users is capable of bridging the information gap that exists between the two parties and also improve the in-use performance of new and innovative LCTs in buildings. The realist standpoint of ontology was viewed as an appropriate approach for the research design.

The chapter also reviewed the two key research approaches; quantitative and qualitative, including the mixed method referred to as triangulation, which was found to be most suited for this research because of its exploratory nature. It also outlines the methods adopted to investigate each objective, the general precautions taken and how the research was analysed; adopting the thematic content analysis approach for the qualitative interviews, the BUS methodology as a POE approach for the case study. The ethical cautions taken, as proposed by the faculty Ethics Committee was also enumerated in the chapter.

Chapter 3:

BUILDING MAINTENANCE

3.0 INTRODUCTION

The development of varying unconventional low carbon and low energy technologies to meet current demands for sustainable solutions and to make our *'buildings feel good'* (Strelitz, 2008) calls for good consideration to the maintenance of these buildings and the fitted technologies. It is more so when we realise that building elements, components and materials are not only exposed to the fast changing environmental vagaries which cause wear and tear and ageing, but are also subject to man-made causes such as misuse or mishandling, accidents and even change of taste.

This chapter therefore reviews relevant literature in the field of building maintenance; a field that is often cited as being under researched (Lewis et al, 2011; Wood, 2005). It also gives a general overview of maintenance and associated terminologies as to give an informed understanding of the subject. It discusses the history and concept of maintainability from the military engineering and other backgrounds and how it applies to the built environment. The chapter also examines and analyses critically, the maintainability optimisation strategies available in literature. The aim is to draw lessons that can enhance efficient and effective maintenance of these *'modern'* low carbon buildings.

3.1 BUILDING MAINTENANCE: AN UNDER-RESEARCHED FIELD

Sources from literature revealed that Building Care/Maintenance is an area that is poorly or under researched. Wood (2005) draws attention to this fact. He added that;

> *"Building Maintenance is not 'sexy' – yet it is 'big bucks', arguably more than new-build"*. (Wood 2005)

Sir Michael Latham in his forward to Wood (2003) noted that the author "*rightly confronts the dismissive attitude to building maintenance*". This presupposes that that, issues of building maintenance are often treated with dismissive attitudes or trivialised. Wall (1993) also emphasized that a search of published sources revealed a disappointingly small and fragmented literature relating mostly to technical and managerial aspects of building maintenance. Over 35 years ago, Seeley (1976) also decried the lack of research in building maintenance. This position was also maintained in Seeley (1987) where the author added that, the maintenance required through the building life-cycle is dependent on design, materials, workmanship, function, use and their inter-relationships. Quah (1990) also noted that the growth and awareness of the importance of maintaining buildings has unfortunately not been matched with sufficient research and development. RICS (2000) and RICS (2009) posit that building maintenance has been the 'Cinderella' of the building industry for many years, with insignificant consideration given to innovation and 'free thinking' in the delivery of its services.

3.2 OVERVIEW OF THE CONCEPT OF MAINTENANCE

3.2.1 BSI Definition of Maintenance

Seeley (1976) quoted the BS 3811 definition of maintenance from the 1964 Glossary of general terms used in maintenance organization as*: 'Work undertaken in order to keep or restore every facility, i.e. every part of a site,* *building and contents, to an acceptable standard'.* He also noted that BS 3811: 1964 was drafted by a team that was primarily concerned with mechanical engineering and as such has reduced the applicability and usefulness of the standard to building maintenance. He also added that the concept of 'acceptable standard' was defined by the Committee on Building Maintenance as; *'one which sustains the utility and value of the facility'*

Wood (2009) analysed the metamorphosis of the currently accepted building maintenance definition given by the BSI. He cited this definition from Department of Building (1972); *'….. work carried out in order to keep, restore or improve every facility, i.e. every part of the building, its services and surrounds to a currently acceptable standard and to sustain the utility and value of the facility'.* By 1984, BS 3811, according to Wood (2009), has modified the term maintenance to read; *'A combination of actions carried out to retain an item in or restore it to an acceptable condition'*. BS 8210 (1986) defined Building Maintenance as; *'Work other than daily and routine cleaning, necessary to maintain the performance of building fabric and its services'.*

The definition of Maintenance by BS 3811 was revised again in 1993 to read; *'The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function'* (BSI 1993, No. 4114). BS 3811 cited the source of this definition as BS 4778: Section 3.2: 1991. This seems to be the latest revision and as such the currently accepted definition of Maintenance by the British Standards Institution.

Reading through these various changing definitions of the term 'Maintenance', one wonders why the changes? However, Seeley (1976) gave the probable reason; that the 1964 version was drafted with mechanical engineering prejudice. Interestingly, a careful look through the various changing definitions reveals that the actual semantics of *'retaining in or restoring to good condition'* did not change all through the revisions; the changes were in the technical actions required.

However, in this thesis, the BS 4778 (1991) and BS 3811 (1993) definition of maintenance is adopted;

> *"The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function"*

3.2.2 The Objectives of Building Maintenance

It is already noted that in all the definitions, the phrase; 'to retain (keep, maintain) or restore (bring back, put right)' was constant. The first is 'to retain'; action(s) expected to ensure or enable the element or whole facility remain in its original state. This could be said to be preventive maintenance. To restore simply means bringing back what has been taken away in full or put right to the original condition, what has been damaged (this is a corrective maintenance). BS 3811 (1993) emphasizes that maintenance action must be with the intent to RETAIN or RESTORE an item to a state in which it can perform a required function. Arditi and Nawakorawit (1999b) see maintenance from the perspective of *"preservation of building so that it can serve its intended purpose".*

Seeley, (1987) noted that the prime essence of maintenance is to preserve a building in its initial state, as far as practicable, so that it effectively serves its purpose. He went on to state that some of the objectives of ensuring that a building is maintained are:

i) retaining value of investments,
ii) keeping the building in a condition in which it continues to perform its functions,

iii) presenting a good appearance and

iv) Protecting the health and safety of users and the general public as required by the Health and Safety Act 1974.

Bradley (2002) describes maintenance in the built environment as an *"exercise of technological knowledge in a commitment to the continued life and use of buildings; it keeps a building alive".*

It therefore follows that the overall objectives of building maintenance are:

1) to preserve or to keep in a continuous state of good repair and
2) to ensure that the building and all its component parts continue to efficiently perform its originally intended purpose(s).

A better perspective of looking at maintenance objectives is by seeing maintenance as the process of *maintaining an item in an operational state* by either preventing a transition to a failed state or by restoring it to an operational state following failure (BSI, 1991).

3.2.3 Impact of Building Maintenance on National Growth

Until recently, building maintenance has been a neglected aspect of the construction industry (Seeley, 1987), often considered as 'small works' (Headley and Griffith, 1997). Today, the story is slightly different; it is suggested that maintenance has "come of age" and is now married to facilities management, and with a change of name to "building care" (Wood, 2003). The subject, building maintenance has attained some significance in the UK; however, one of the more impending tasks is to minimize the rising cost of operation and maintenance (Chew, Tan and Kang 2004). It is said that Maintenance/repair activity in the UK is estimated at 47% of the construction industry's output (UWIC 2009). The Royal Institute of Chartered Surveyors (RICS) Building Cost Information Service (BCIS) estimated the total expenditure on maintenance in 2006 alone to be over £70bn, equivalent to

3.4% of GDP (RICS, 2009). Wood (2003) cited the Barbour Index (1998) which estimated the UK market for maintenance and related work at £28bn, while a new build for the same year was put at £10bn.

While a new-build is a short-term commitment, maintenance is a long-term commitment (Bradley 2002), and as such deserves good attention. Maintenance is said to start the day the project is handed over to the client (Ibid; Seeley 1987). The value of building maintenance is not only reflected in the contribution to employment and expenditure in the economy, but also the key to sustaining the built environment (RICS, 2009).

The building stock is arguably one of the nation's most valuable capital assets, its maintenance no doubt impacts on the whole nation (Turel 1997). Lee 1987 posits that *"the condition and quality of buildings reflect public pride or indifference, the level of prosperity in the area, social values and behaviour and all the many influences both past and present which combine to give a community its unique character".* The truth is that lack of good maintenance culture can mare the character of the community and even cause structural failure in buildings (Ayininuola 2004; Ishak, Chohan and Ramly, 2007).

3.2.4 Types of Maintenance

BSI (1991) sub-divides maintenance into Planned and Unplanned Maintenance; these are further sub-divided as shown in Figure 3.1: BS 3811 of 1993 also describes these various approaches to maintenance as follows:

3.2.4.1 Planned Maintenance: Maintenance organized and carried out with forethought, control and the use of records to a predetermined plan (No. 4254).

3.2.4.2 Unplanned Maintenance: the maintenance carried out to no predetermined plan (No. 4269). This is also a kind of Corrective Maintenance.

3.2.4.3 Preventive Maintenance: the maintenance carried out at predetermined intervals in accordance with prescribed criteria, and intended to reduce the probability of failure or the degradation of the functioning of an item (No. 4255). Figure 3.1 sub-divides it into Preventive and Corrective.

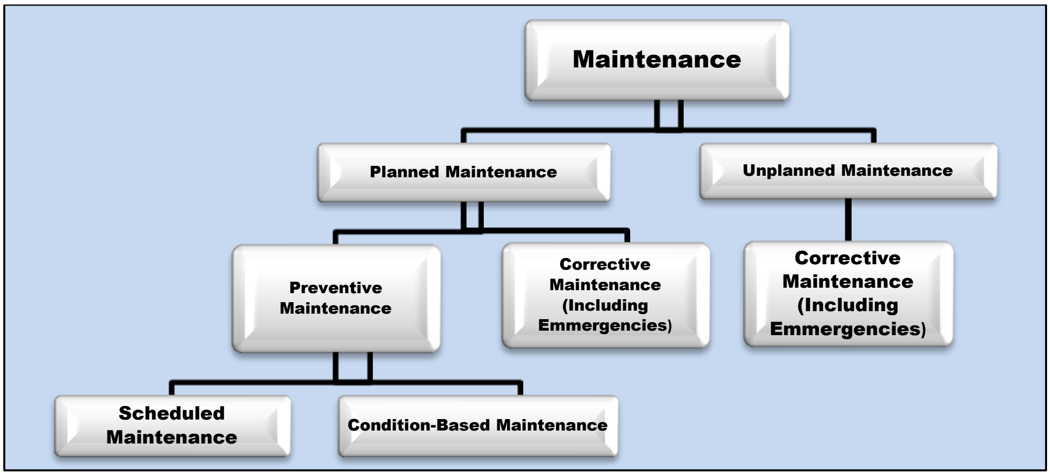


Figure 3.1: Types of Maintenance
(Source: Chanter & Swallow, 2007; BSI, 1991)

There also are varieties of contemporary approaches to maintenance available in literature, some of which include:

3.2.4.4 Just-In-Time (JIT) Maintenance: this system is hinged on 'getting the maximum life from each building component and piece of equipment, leaving repair or replacement until the component is broken down or fails to function, yet taking action prior to it having a serious effect upon the performance of the organization (Smyth and Wood, 1995).

3.2.4.5 Intelligent Maintenance: Intelligent building maintenance system comes in various forms, it involves the use of a computerized system to monitor and manage maintenance activities. It involves the development of hardware and software systems, sensors of various kinds, controls, fibre-optic and wireless systems, etc (Wood, 2003; pg.93).. Other terms akin to intelligence maintenance include: automatic maintenance and remote maintenance.

<u>3.2.4.6 Reliability Centered Maintenance</u>: This system of maintenance, usually abbreviated as RCM enhances the selection and specification of tested and highly reliable materials and components with consideration to cost (Blanchard and Lowery 1969; Smith 2004a). RCM is a management approach that provides a structured framework for analysing the functions and potential failures for physical assets (ReliaSoft Corporation 2011). It in turn aids the development of scheduled maintenance plans that provides acceptable level of operation and risks, in an efficient and cost-effective manner (Ibid).

3.2.5 Sustainable Maintenance

Wood (2005) posits that sustainable building maintenance applies to maintenance operation consideration of both the sustainability of the building and sustainability of the operations. So what then is Sustainable Building Maintenance? No single literature source reviewed has provided a clear definition of what sustainable maintenance is.

However, from the definitions of sustainable development and sustainable design in literature, it is deductible, what sustainable building maintenance is. A practice where the building maintenance process is planned and carried out in ways that are resource efficient, exerting little or no impact on the environment, the building and/or its users and ensuring continued comfort, utility and beauty of the facility through its life cycle'. Sustainable development has also been described by OGC and DEFRA (2003) to aim at achieving four objectives, which are:

- effective protection of the environment,
- prudent use of natural resources,
- social progress which recognises the needs of everyone and
- maintenance of high and stable levels of economic growth and employment.

Therefore, sustainable maintenance would seek to attain these objectives and within the framework of achieving value for money.

Logically, to achieve a sustainable maintenance regime, the maintenance operation has to be thought out from inception of design, and the design solution must be influenced by the maintenance and operation considerations. Mills (1994) noted that present buildings are designed to meet more complicated needs, with improved space and higher environmental standards than those of previous times. This he added means that the design influence on the maintenance of buildings will be greater than ever before. It therefore follows that sustainable maintenance will need to result from a sustainable design.

In discussing how operation and maintenance practices could be optimised, NIBS (2010b) states that *"buildings must be operated and maintained with security, safety, health, comfort and productivity of their occupants in mind, and with an understanding of the next generation's need to reuse and recycle building components".* This no doubt is a sustainable maintenance practice, but none of the requirements will be met if the building was not designed ab-initio with these considerations in mind.

3.3 THE CONCEPT OF MAINTAINABILITY & OPERABILITY

3.3.1 Maintainability

Maintainability is a discipline within the science of engineering; it was pioneered by the United States Military service in 1954, (Blanchard and Lowery, 1969). The discipline was initiated to provide designers with a source of specialized skills and knowledge related to the support and maintenance of equipment and systems (Ibid). The Dictionary of Military and Associated Terms defines maintainability as; *"the ability of an item, under stated conditions of use, to be* ***retained*** *in or* ***restored*** *to a state in which it can* *perform its required functions, when maintenance is performed under stated conditions and using prescribed procedures and resources"* (Farlex, 2011). This definition demonstrates the fact that the idea of maintainability is hinged on the principle that the conditions, procedures and resources to be used in performing particular maintenance activity should have been prescribed (pre-written or pre-stated). It is also deductible that maintainable items possess the ability to be easily retained in its functional state or restored back to the original functional state. By the word 'retained', it is implied that the item could remain in a continued good state (appearance and function) over a considerable period.

The US Institute for Telecommunication Science sees maintainability as; "*a characteristic of design and installation, expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources*" (ITS, 1996). BusinessDictionary.com defines it as a *"Characteristic of design and installation which determines the probability that a failed equipment, machine, or system can be restored to its normal operable state within a given timeframe, using the prescribed practices and procedures"* (Businessdictionary.com, n.d.). Dunston and Williamson (1999) also defined maintainability to mean *"The design characteristic which incorporates function, accessibility, reliability, and ease of servicing and repair into all active and passive system components, that maximizes costs and benefits of expected life-cycle value of a facility".*

These definitions relate maintainability to design; "design characteristic". The use of the phrase; "prescribed procedure" is also common in the definitions. Dunston and Williamson relate the definition more to buildings (facilities), with emphasis on maximizing costs and benefits of expected life-cycle value of the facility. Blanchard and Lowery (1969) makes it more explicit; *"Maintainability is a* *<u>characteristic of equipment design and installation</u>* *which is expressed in terms of* *<u>ease and economy of maintenance</u>**, availability of the equipment, safety, and accuracy in the performance of maintenance actions."* Chew (2010) defined maintainability as *"the ability to achieve the optimum performance throughout the lifespan of a facility within the minimum life cycle cost".* Chew's definition appears to be restrictive to just cost, the aspect of 'design focused', 'ease' and 'safety' highlighted in other definitions were missing. However, in the succeeding paragraph, the author explained that maintainability embraces all stages of the facility delivery process; planning, design, detailing, construction, operation, maintenance and disposal.

In concluding, and deducing from the above definitions, *'maintainability in building design'* would be said to mean 'a design that is conscious of the ease, safety and cost of maintenance, not compromising standards and quality, but ensures that building elements and components are kept in their continued good appearance and functional state, through the building life-cycle'. The outcome of maintainability will be a maintainable design.

3.3.2 Operability

The word operability appears to be scarcely defined in literature, however, BS EN 61069 – 6: 1998 defines operability as "the extent to which the operating means provided by the system are efficient, intuitive, transparent and robust to accomplish the operator's tasks. Again, this definition is applied to Industrial-process measurement and control – Evaluation of system properties for the purpose of system assessment. In an email correspondence with an Information Specialist at the Knowledge Centre of BSI, he clearly states; *"It is worth noting that definition for "operability" included in BS EN 61069-6:1998 might be specific for the topic covered by this standard in particular and might* *not apply to other areas".* Also, his search for the definition of operability in the BSI data base returned only the BS EN 61069 – 6: 1998.

However, a review of the etymology of the word *'Operability'* shows that it is a noun form of the word *'Operable'*; derived in the 1640s from *operate* + *-able* (Harper, 2012; Dictionary.com, 2013), or derived from late Latin – *operabilis,* equivalent to *opera(ri);* meaning 'to work' + *-bilis* '-able'; that is; "capable of being put to use" (Ibid). Relating to building therefore means that an operable building is a building that capable of being put to use or can be put to use with ease.

A document specifying 'operability, maintenance and construction' requirements for the Priority School Building Projects (PSBP) states thus; "*Buildings and grounds should be designed so that the facilities are straightforward and efficient to operate, with sufficient information provided to enable school staff to use facilities effectively …"* (Department for Education, 2012). Lush (1994) also argues that separating maintenance from operation, where services are concerned, can only be intended to divert attention from the close relationship which must exist between them. This suggests that operability and maintainability are closely related.

From the foregoing, it seems proper to conclude that like maintainability, operability is a design quality that assures that the facilities are easy and efficient to operate (use). Following the BSI's application of the definition to Industrial process measurement and control – evaluation of system properties for the purpose of system assessment, operability of a design can also be viewed as a design process measurement and control factor used for evaluating the design for the purpose of assessing the design quality. So that measurement and control factor is 'operability'.

So Design Operability as used in this thesis is a design quality measure that ensures that the facilities are operated in the most efficient, intuitive, transparent and robust way possible.

3.3.3 The Concept of 'Duty of Care'

> *"Everyone who offers a service to others and claims expertise to do what he offers has a responsibility to society in general and to his clients in particular ....."* (Speaight and Stone, 2010)

In the English law of tort, a duty of care is a legal obligation which is imposed on an individual requiring that they adhere to a standard of reasonable care while performing any acts that could foreseeably cause injury to others (Ibid). The term `injury' in this case is explained by P.J. Derbney, Partner, Cartwright and Lewis, Solicitors (1998) to mean *"primarily physical injury and consequential financial loses".*

By the concept of **'Duty of Care'**, a designer is expected to take reasonable care to ensure that his client or the third party users do not incur any foreseeable physical injury or economic loss as a consequence of his omissions or negligence (action or in-action). Section 13 of the Sales of Goods and Services Act 1982 as amended by the Sale and Supply of Goods Act 1994 of the English law and statute provides that the designer must carry out the design services with reasonable skill and care (Designing Buildings, 2013).

It therefore becomes imperative to put in place workable principles and procedures that can facilitate compliance to maintainability considerations, so that clients do not suffer the burden of high cost of maintenance and general under-performance in terms of energy savings and indoor air quality; thereby achieving good value for money. Blanchard and Lowery (1969) opined that, by applying the principles of maintainability, the problems of product support and maintenance of complex systems can be reduced, if not eliminated. They also added that *"the decisions made by the line manager in implementing a maintainability programme have much to do with the competitive success or failure of his firm".* Aligning this statement to building design, one would say – 'the decisions made by the building designer in implementing a maintainability programme have much to do with the competitive success or failure of his practice'.

3.4 MAINTAINABILITY OPTIMISATION STRATEGIES

The concept of maintainability is design focused; it is a 'maintenance conscious' approach to design. Although the term 'maintainability' is traceable to have originated in the 1950s, but its principles has been an age-long traditional theory of architecture; that from inception of design, the architect is expected to give considerations to maintenance possibilities and cost (Seeley 1976; Mills 1994; Lush 1994). As far back as 1895, Ruskin (1895) identified the need for designers and builders to be conscious of the durability of their works. There is no gainsaying that the degree of durability of a structure is determined by the materials used and how they are used (constructed). These of course will be determined at the detail design and specification stage of the design phase of the structure.

However, maintainability in building designs seems to still stand as theory rather than practice. CIRIA C686 (2009) corroborates this assertion as it states that the obligation for designers to deliver assets that may be safely and economically maintained is already enshrined in law, but it is often not well done, and there is a lack of practical guidance. Dunston and Williamson (1999) noted also that maintenance problems in facilities are heavily attributed to design limitations, among other issues.

Seeley (1987) noted that designers must ask themselves these 4 questions as they design each element or component of a building:

1) How can it be reached?
2) How can it be cleaned?
3) How long will it last?
4) How can it be replaced?

Unfortunately, most designers are often more concerned with aesthetics of the elements than their maintenance requirement (Zubairu 2010). In a study carried out of 211 large building design firms in the United States to investigate the relationship between design practices and maintenance considerations it was concluded that:

i) ease of repair and replacement, access to cleaning area and ease of cleaning were ranked by designers to be among the least important design factors considered during design,
ii) among the complains designers reported receiving from clients and tenants, maintenance related complains ranked much higher(Arditi and Nawakorawit 1999a),

It is therefore obvious that designers are largely responsible for the huge cost of operation and maintenance of buildings and should consequently be liable to finding an enduring solution.

Researchers are increasingly being aware of the concept of maintainability and have come up with several positions on how maintainability could be optimized. Some of these positions are further discussed below.

3.4.1 Procurement Strategy

Detailed discussion on procurement and procurement strategies common in the UK are outlined in chapter 4 of this thesis. However, suffice it to mention here that evidences in literature reveal that there have been considerable research into the choices for construction projects procurement strategies, yet no generally applicable solution has been found (Chan, 2002). Nahapiet and Nahapiet (1985) concluded also that there is no one best contractual arrangement (procurement method) for building projects, and that the most appropriate choice depends on the individuality of the particular project and its client and location. However, Ofori (2006) has argued that many studies have shown that the procurement route chosen for a construction project leads efforts in improving the building performance.

Literature reveals that emphasis on private sector participation in public sector building delivery has become very popular among governments, as it combines the procurement of design, construction, operation and maintenance from a single source. According to Wood (2003b), it is hypothesized that this route of procurement will encourage the provision of more durable and long-life structures and components. PFI's primary objective as discussed in chapter 4 is to transfer the responsibilities and associated risks of funding, designing, building, operating and maintaining public infrastructure to the private sector over a period of usually 25 to 30 years. In addition, the requirement for buildings to be maintained to high standards within the contract period was also expected.

In most developing countries like China (Ho, 2006), Nigeria (Ibrahim et al, 2006), Singapore (Gunanwansa, 2010) and India (Research Republic, 2008), the use of PPP is still in its early stage, However, many variants of private sector participation in public infrastructural delivery had existed before the advent of the PFI/PPP in these countries; commonest among the lots are:

- Build, Operate and Transfer (BOT)
- Build, Operate and Own (BOO)
- Build, Own, Operate and Transfer (BOOT)

- Build and Transfer (BT)
- Design, Build, Finance and Transfer (DBFT)
- Design, Build, Finance and Operate (DBFO)

In China for instance, BOT was introduced in the mid '80s (Cheng and Wang 2009) and early '70s in Honk Kong, with the building of the Cross Harbour Tunnel between Hong Kong Island and Kowloon in 1972 (Kumaraswamy and Zhang 2001).

Procurements systems common in the UK are discussed in chapter 4. However, the marked difference between these BOT variant and the PFI as it operates in the United Kingdom is that while in the BOT variants the investor recoups his investment from private patronage of the services, in the PFI, the investor is reimbursed by the public sector client over an earlier agreed period, usually 25 – 30 years. A very unique advantage of these routes of procurement is that the operation and maintenance responsibilities of these facilities are vested on the contractor/investor who normally is expected to keep the facility in high maintenance standard (House of Commons Committee of Public Accounts, 2011).

The question here, to which no answer is found in literature is, '*what happens to the facility after it has been transferred to the public sector for management?'* Wood (2003b) reported fears already being expressed that a contractor may be tempted to hand-over a building in very poor condition of repair. There have also been many other concerns within parliament, researchers and the general public, suggesting that neither PFI/PPP nor BOT can ensure maintainability or sustainable maintenance practice.

Whereas the choice of an appropriate procurement could ensure high standard of maintenance; it cannot guarantee maintainability and sustainable maintenance practice, if maintainability factors were not considered during design. Besides as stated in chapter 4.4 majority of clients prefer the traditional method where operation and maintenance are procured separately. Figure 3.2 is an excerpt of a recent survey carried out by RIBA Plan of Work Review Committee amongst members of the Architecture profession. This figure shows 86% of architects frequently use the traditional method in their projects execution. Also, architects who were engaged through the one stage design and build and two stage design and build (where O&M services are also procured separately) were respectively 41% and 39%. Whereas, those who used the PFI route which tend to promote high quality maintenance were only 10%. It therefore becomes pertinent to propose a maintainability and operability integrated process using the traditional system as a base, but flexible across all procurement routes.

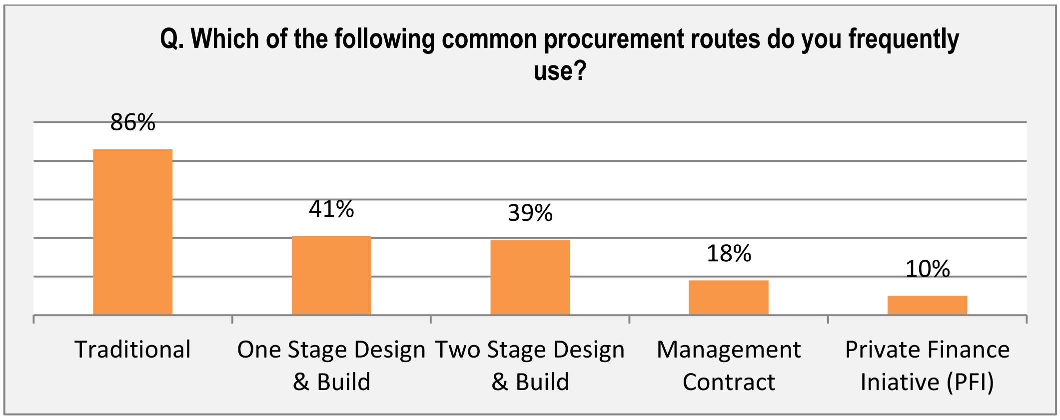


Figure 3.2: Procurement Routes Frequently Used by RIBA Members
(Source: RIBA, 2012b)

3.4.2 Involving Facilities Management Personnel at the Design Stage

Facilities management (FM) has been defined as the integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities. It encompasses multi-disciplinary activities within the built environment and the management of their impact upon people and the workplace (BIFM, 2013a). The increasing awareness of the need to operate and manage facilities for long periods no doubt requires the involvement of Facilities Managers (FMs) in the design process (El-Haram and Agapiou, 2002; Enoma, 2005; Jaunzens, n.d.). According to Enoma (2005), involving the FMs at the design stage will not only add value to the facility, but will consequently ensure less 'rework', emphasise value for money, efficient control of the supply chain and teamwork. Enoma (2005) added that FM practice borders on achieving better facility that that is easy to run, maintain and manage by applying whole-life costing and risk management techniques. Involving the FM skills in design process is seen to be capable of improving the way buildings are designed, built, commissioned, maintained and refurbished (El-Haram and Agapiou 2002; Jaunzens n.d.).

Although the Facilities management sector has been identified to be bedevilled with the absence of real body of theoretical knowledge to underpin thinking and decision-making (Davies, 2011); the BSI's construction section has set up a Facilities Management Committee that will be responsible for developing and maintaining UK standards in FM. The committee is also responsible for liaising on other standards in associated disciplines and deliberateon relevant work carried out by the European Committee for Standardisation (CEN) (BIFM, 2013b).

El-Haram and Agapiou 2002 also highlighted details of the procurement and contract management tasks of the FMs or their roles at the project planning and design stage to include among others, the following:

- reviewing and assessing the design from maintainability, maintenance, operability and serviceability point of view
- identification and selection of the optimum maintenance and replacement strategies for the facility
- liaison with the design and construction team to select the cost-effective design option which will optimize whole life costing

However, response to the call for facilities managers to be involved in the design process across the globe has been very lethargic (Mohammed and Hassanain, 2010; Silva, 2011). Also FM practitioners are seldom involved in briefing (and by extension design) (Bordass, Leaman and Eley, n.d.). A process that could facilitate the involvement of the Facilties Managers in the design process will no doubt ensure maintainability of low carbon buildings.

3.4.3 Post Occupancy Evaluation

Post Occupancy Evaluation (POE), also known as Building Performance Evaluation (BPE) (BSRIA, n.d.) involves a systematic evaluation of opinions about buildings in use, from the perspective of the people who use them (postoccupancyevalua-tion.com). It evaluates how well the building matches users' needs, and identifies ways to improve building design, performance and fitness for purpose (Ibid). POE is used to evaluate new and old buildings when they are fully operational; preferably, not less than 12 – 15 months of occupancy, in which period users must have adequately experienced and adjusted to their new environment and also allows for a full circle of the seasons (SGV, 2010). ORF (2006) identifies 3 forms of POE as Indicative, Investigative and Diagnostic. See details on Table 3.1

Preiser (1995) noted that the POE is a tool which facilities managers can use to assist in continuously improving the quality and performance of the facilities which they operate and maintain. He added that the tool presents short-term, medium-term and long-term benefits, which are:

- ***Short-term benefits*** – include user feedback on problems in buildings and identification of appropriate solutions.
- ***Medium-term benefits*** – include feedback of the positive and negative lessons learned into the next building cycle.

❖ ***Long-term benefits*** – enhances development of databases and generation of planning and design criteria for specific building types.

Table 3.1: Types of Post Occupancy Evaluation

Type of POE	Indicative POE	Investigative POE	Diagnostic POE
Requirements	* Identify major strength and weaknesses of a particular building's performance and data that supports the need for or against further in-depth evaluation. * A simple short term process that involves selected interviews, questionnaires, walk-throughs and document evaluation. * Compares "big picture" building performance against existing criteria, design intent and the programme	* The evaluation criteria such as Programme of requirements, guidelines, performance standards or published literature on buildings are defined prior to initiation of the Investigative POE * Performance after an indicative POE indicates that the building performance requires more in depth evaluation * Monitors Specific aspects of building performance over a period of time and compares to existing criteria and design intent and evaluates these factors. *Process uses more resources, more sophisticated data collection and analysis methodologies than the indicative POE	* Performed post-investigative POE if further data collection or analysis is required to take corrective actions or instead of an investigative POE if major design or operational flaws are discovered in the indicative phase POE * Comprehensive and high level investigation involving data collection and comparison of many variables for a single facility or across facilities with similar function * Generally requires a major investment of time, man power and resources;
Typical Outcome	+ Data is used to feedback into design guidelines, criteria and policies for the things that work well and should be carried forward to future projects. + Identifies problems that require further study + Identifies the need for corrective actions for minor problems early in the building life-cycle + Lessons learned applied to future projects	+Data is used to understand the cause and effect of issues in building performance +Data analyses are used to design corrective action plans +Lessons learned are applied to future projects	+ Systems analyses lead to recommendations for changing design criteria to improve facility performance for multiple facilities or types of facilities. + Long term facility application of lessons learned to future projects. + Improved performance knowledge base for comparison across buildings

Adapted from: Office of Research Facilities (ORF), 2006

Preiser (1995) also summarises the methodology of approaching these three forms evaluation as:

1. ***Indicative POE*** *involves quick, walk-through evaluations, using structured interviews with key personnel, focus group meetings with occupants/users, as well as inspections in which both positive and*

negative aspects of building performance are documented photographically, or on the notepad.

***2. Investigative POE** entails a more in-depth exercise using interviews and survey questionnaires, in addition to photographic/video recordings, and physical measurements, they typically involve a number of buildings of the same type.*

***3. Diagnostic POE** is a well-focused, longitudinal and cross-sectional evaluation study of such performance aspects as stair safety, orientation and way-finding, artificial versus full spectrum lighting, privacy, overcrowding, etc.*

The practice of POE in buildings is in itself not new, it was initiated in the 1960s (Ibid). However, what is new is the way in which POE is beginning to be viewed as a management tool and as a crucial building appraisal system for property owners, managers and designers (Kauntze, 2008 in Adewunmi et al, 2010). In the UK for example, it has become a part of the architect's responsibility to evaluate/review project performance in use as outlined in stage L3 of the RIBA Outline Plan of Work 2007, and also corroborated by BRE Group (2011).

The benefits of POE clearly show that it can inform maintainability in future designs if properly carried out, documented and made accessible to design professionals. However, it must be noted that the responsibility for initiating POE rests with the facility owner (SGV, 2010). He also funds the exercise, and will therefore be naturally reluctant where the essence of POE is to better future building and not his particular building, except he is a corporate body client that is in continuous development exercise or a professional developer. Bordass and Leaman (2005) noted some of the notions expressed by clients, which among others include:

- That the name POE was seen as academic, and too late to benefit the project concerned.
- Client did not appreciate why they should pay designers for POEs on recently completed buildings when this would benefit future clients more than themselves.
- Clients feared that feedback information would remain on the shelf and never get used
- They did not see why they should be called up to tackle the problems of the construction industry".

In practical terms, very few POEs are undertaken because even designers are also afraid of the risks of liability and of voiding their insurance (Bordass, Leaman and Eley, n.d.). It has also been noted in literature that the results of POE exercises are not readily accessible to those who need them for future projects (Bordass, Leaman and Eley, n.d.).

BSRIA (2007) also argued that whereas "*POE is certainly useful for researchers who want to find out what worked and what went wrong in a building, for building designers, it is more a case of shutting the stable door after the horse has bolted".* The authors added that, it is possible to make some improvements and fine-tuning from the evaluation outcome, but this may be too late for major changes, should the need arise.

Also, it must be noted that whereas there are many common futures including the technologies, each building is still unique in itself as site; building orientation and method of construction differ even for buildings of close proximity and of the same typology. Building designers' drive for creativity and innovations will definitely produce dissimilar buildings. So lessons learnt from earlier projects may not be sufficiently adequate to ensure operability and maintainability of the new project; no doubt, it may help to some extent.

If there is therefore a process is in place that ensures that maintainability issues are prerequisites, the design team will have no choice than to ensure that POEs are carried out and made references to for future designs.

3.4.4 Life Cycle Costing (LCC)

Life Cycle Cost has been termed as Real or 'Ultimate life Cost (Seeley, 1996). Holti et al, 1999 describes it as 'Through-life Cost'; it has also been referred to as 'Whole-life Cost' (BSRIA, 2008). In this section and all through the document, the terms are interchangeably used.

LCC is defined as *"the present value of the total cost of an asset over its operating life including initial capital cost, occupation cost, operating costs and the cost or benefit of the eventual disposal of the asset at the end of its life"* (Seeley, 1996). A similar terminology often confused with LCC is Life Cycle Assessment (LCA) which involves viewing designs in terms of the long-term environmental and economic benefits of the designed asset (Wang, Chang and Nunn, 2010). Other terms used to describe life cycle assessment include: life cycle analysis, life cycle inventory, ecobalance, cradle-to-grave analysis, well-to-wheel analysis and dust-to-dust energy cost (Greenoptions.com, 2011). The LCA concept applied to building design suggests that the design must be cognizance of not only cost and maintenance, but also, its impact to the environment during construction and operation stages. These environmental impacts include energy involved in the manufacture of components parts.

More often than not, building developers base their judgments on only the capital cost without consideration to the cost of running and keeping the building (Arditi and Nawakorawit, 1999a). Bokalders and Block (2010) analysed that this capital cost usually comprises of just about 10% of the total cost of a building calculated over a 50 year life cycle. 50 – 80% of the real cost is spent during the operational life of the building (Silver et al, 2004).

Despite the varying statistics, it is clear that the cost incurred during the operational life of a building exceeds the cost of design and construction and so cannot be ignored (Seeley, 1996). Silva et al (2004) posits that LCC approach should be incorporated into the procurement procedure at the tendering stage and that if implemented, is capable of providing motivation to improve maintainability.

However, NIBS, 2010 has posited that LCCA is especially useful when project alternatives with same performance requirements and with varying initial and operating costs, need to be compared with the view of selecting one with maximal cost savings.

Also, RIBA (2009f) has argued that life-cycle costing (LCC) or whole-life costing (WLC) is a 'money-based measurement' and does not take into account, important factors like the damaging impact of CO_2 emissions. It further explained that whereas the initial construction cost could be estimated with reasonable accuracy, the cost-in-use (operation and maintenance cost) could be more difficult to estimate due to future uncertainty. RIBA further advocates for life-cycle analysis (LCA) as a better approach.

To conclude, neither the LCC nor LCA approach can wholly enhance maintainability, but are essential aspects of maintainability considerations. The LCA approach which is described by Wang, Chang and Nunn (2010); and IAI (2011) as involving the environmental and economic factors should be seen as very vital in the maintainability considerations for LCBs and can better be considered along with other maintainability factors listed in chapter 3.3.2 to ensure maintainability of LCBs.

3.4.5 Maintainability Scoring System

The concept of maintainability scoring was initiated in Singapore, following the recommendation of the Construction 21 (C21) Steering Committee (Silva et al, 2004), set up with the mandate of re-inventing Singapore's construction industry (SNEF, 2010). The maintainability scoring system (MSS) is to provide objective measures of maintainable designs (Silver et al, 2004). Complementing the C21, the National University of Singapore through several researches developed the MSS for various elements/components of a building which it classes as; façade, basement, internal wet area, roof and M&E System (Das and Chew, 2007; Chew, 2010).

The system relies on a comprehensive database of material manual and defects library (Chew, 2010). The MSS is applied during the design stage to inform choice of a better maintainable design option, and also at the construction stage to enable further improvement on maintainability (Silver et al, 2004).

The MSS concept logically appears to present good potential for maintainability, however, all available literature seem to portray that this system is applicable only in Singapore. No literature has been found that indicates its applicability anywhere else in the world. However, it has provided background for the development of the proposed OMI Design and Construction Process Model.

3.5 OTHER STRATEGIES CAPABLE OF OPTIMISING MAINTAINABILITY

There are some strategies or systems that are already in place in the UK which are not necessarily acclaimed to optimise maintainability, but provided to inform effective planned maintenance or better performance. These concepts are reviewed with the intention to improve upon their approaches and adapt to the proposed OMI Design and Construction Process Model.

3.5.1 Client Design Advisor

RIBA recommends for clients to appoint an advisor on their projects, designated as RIBA Client Design Advisor whose responsibility shall be divorced from that of the project designer and the project manager (RIBA n.d.). The Advisor is usually an architect who sits on the client's side of the project, capable of rendering high-level expert advice and support on the project, assisting the client to maintain control over issues that concern quality, value, sustainability and lifecycle of the project. His specific duties are as follows (Ibid):

1. Explore high-level options for meeting client's business or strategic need. Is a new building the best solution or can better use be made of the existing estate?
2. Carry out strategic risk assessments of the project.
3. Identify lessons learned from previous experience of similar projects.
4. Define an agreed set of project outcomes.
5. Consult key stakeholders to identify significant project issues.
6. Prepare feasibility studies and a strategic business case for the project.
7. Help set a budget and propose a funding strategy, taking into account whole project-life costs.
8. Identify and develop the most appropriate procurement strategy for completing the project on time, to budget, to the quality required.

9. Ensure that the project is compliant with the original brief to ensure that the clients are getting what was originally asked for. Where changes are unavoidable, divergences or modifications will be agreed and reported as necessary.
10. Prepare the outline business case.
11. Prepare a full project brief, output specification and sustainability goals.
12. Apply for planning permissions.
13. Manage the invitation and evaluation of tenders from design and construction teams.
14. Check budgets, design proposals, construction details and project documentation.

It is possible that the calibre of advisor being proposed by RIBA will be capable of checking maintainability, however, no mention of such responsibility is made, or it is possibly implied in duty no. 7.

However, one of the pitfalls noted about this system is that architects are not directly engaged with operation and maintenance of buildings; evidences in literature reveal that the design team walks away to a new project once the project has reached completion (Bordass, Leaman and Eley, n.d.). So the RIBA advisor may not be experienced in terms of life-cycle cost, maintainability and client’s business or strategic needs, unless he has acquired FM experience by any means (work experience or training).

Also, literature sources, and results of survey undertaken for this research reveal that many designers do not take sufficient account of how occupants use and manage buildings and their fittings (UBT, 2009). So the possibility of an architect without FM experience given valuable advice on maintainability appears remote.

3.5.2 Soft Landings

Soft Landings is one of BSRIA's recent framework that seems to be attracting wide-spread acceptance within the UK government and amongst building professionals. The proposed new Government Construction Strategy (Cabinet Office, 2011) and the proposed RIBA Plan of Work 2013 (RIBA, 2012a) have adopted the principles of the soft landings framework. BREEAM 2011 has also incorporated soft landings (BSRIA, 2011b). Shao (2009) also sees the soft landings framework as one of the ways of tackling low reliability of low carbon buildings.

The framework is geared towards ensuring that designers and constructors of buildings extend their services beyond commissioning to 3 – 5 years into the operation and maintenance phase of the project. It advocates for a cultural shift in the way buildings are delivered in order to meet the changing expectations of users and to reduce the gaps between predicted and achieved performance (UBT, 2009). It proposes a five stage scope of activities which are summarised as follows (Ibid; Bunn, 2011):

- *Stage 1: Inception and briefing* – Clarify operational outcomes in the client's requirements
- *Stage 2: Design development & construction* **–** Review past experience, agree performance metrics, agree design targets, regularly reality-check
- *Stage 3: Pre-handover* **–** Prepare for occupation, train FM staff, demonstrate control systems, review monitoring strategy of occupants and energy use
- *Stage 4: Initial aftercare* **–** Support staff in first few weeks of occupation, be resident on site to respond to queries and react to emerging issues

- *Stage 5: Long term aftercare* **–** Monitor, review, fine-tune, and perform periodic feedback studies for up to three years to reach performance targets.

It is worthy of note that soft landings framework as explained in UBT (2009) requires that:

1) the design and construction team must commit themselves from inception and briefing to follow-through after handover and for the project management;
2) the team must also plan for commissioning, handover and aftercare, as well as involve the occupier in decisions which affect operation and management;
3) when occupants begin to occupy the building, the aftercare team will have a designated workplace in the building and be available to explain design intent, answer questions, and to undertake or organize any arising troubleshooting and fine-tuning;
4) for the first 3 years the aftercare team will continue, to monitor performance, to help to deal with any problems and queries, conduct independent POEs and to discuss, act upon and learn from the outcomes.

The new Government Construction Strategy proposes 1 – 5 years aftercare (Rowland, 2012). Similarly, Silva et al (2004) had also proposed an extension of defects liability period (DLP) beyond the usual 1 year period in Singapore. However, it does not seem clear whether the 3 years or 1 – 5 years of soft landings aftercare is a defect liability period. The DLP otherwise referred to as Rectification Period in JCT Standard Building Contract is usually a period of 6 – 12 months, during which the contractor is responsible for rectifying any defect that occur in the building (Glover, 2008).

One question is; will this not amount to added cost to the project? Even if it is considered as an extended Rectification period, the aftercare staff of the contractor and consultants will certainly be remunerated and the possibility for this cost finding its way into the design and/or construction cost is there.

Another question is; what happens in the event of change of occupiers? Consider a scenario where a commercial building was first occupied by company ABC Ltd and were given the 3 or more year aftercare assistance. Few years later, company ABC Ltd folds up or moves out and the building is re-let to company XYZ who are not familiar with the workings the systems in the building, will the aftercare team be called back to explain the design intent? This is doubtful; creating issues when the new occupiers get going with operating and maintaining their new workplace.

3.5.3 Developing an O&M Manual

The Building Operation and Maintenance Manual is a document that guides the building owner/developer, property manager and/or the users on how to organize the repair and maintenance of the fabric of a building, its services and surrounds effectively and economically. It also directs on the efficient day to day cleaning of the building and directs its user(s) on the operation of its services efficiently (Ministry of Public Building and Works, 1970). Another very important role of a properly prepared and comprehensive manual will be to provide a link between the design team, the client and the operation & maintenance organization to their mutual benefits (Ibid). This link will provide useful information that will be handy and useful for Post Occupancy Evaluation, Condition Survey and by extension, 'the next design'. By this, many of the faults which tend to be repeated in new designs will be averted.

Preliminary investigations reveal that in countries like the United Kingdom, Australia, United States of America (USA) and the Caribbean, the use of

BUILDING OPERATION & MAINTENANCE (O&M) MANUALS has become popular and made a legal component of building delivery documentations. In most cases, they are prepared after the buildings had been built and occupied, and in some cases, by a team that was not involved in the design process (AHDA, n.d.) The preliminary survey also shows that the Architects' involvement in the O&M manual drafting and collation had been very passive, and this seem to undermine its usefulness as a tool for building care, but just to fulfil the law, particularly in the UK.

The O&M manual is a form of long term maintenance plan for the specific building it is made. It is also an updatable document, particularly with change in use and ownership (CIRIA, 1999). Some of the benefits of a properly prepared O&M manual include:

1) The O&M manual will produce significant benefits when it is used as the basis for timely, correct and efficient building maintenance, operation and planning.
2) Better designed and constructed buildings resulting from project team members' improved understanding of operational and maintenance requirements to meet the design life specified for the building.
3) The ready availability of information for components, e.g. life expectancy.
4) A proper understanding by the occupants, of purpose and use of the building.
5) Retaining the value of the building as a result of better maintenance
6) A reduced level of disruptive and costly effects of breakdown or failure. (CIRIA, 1999)

Silva et al (2004) and Blacker (1994) posits that the development of O&M Manuals will facilitate the proper maintenance of the buildings throughout the life cycle and also influence the architect in the decision-making process.

3.6 THE ANTECEDENT AND DEVELOPMENTS IN THE O&M MANUAL

3.6.1 Legal Requirements for O&M Manuals in the UK

In the UK, it has become a 'legislative must' since 1974 for owners of buildings to be provided with information on how to safely and efficiently operate and maintain building services (BSRIA, 2007). This is supported by the provisions of Sections 3 and 6 of the *Health and Safety at Work Act 1974*, as amended by the *Consumer Protection Act 1987* (Ibid). By the Act as amended, designers, manufacturers and importers or suppliers of plant and systems are duty bound to provide adequate operating information for the occupants that will enable them operate the plants or systems in safe manner and so that they are not injurious to health when in use (Ibid).

Section 3 of Part L1A and L2A of the Building Regulations for England and Wales also highlighted on the imperative for owners of buildings to be provided with sufficient information about the building, fixed building services and their maintenance requirements so that the building can be operated in a manner as to use no more fuel and power than is reasonable in the circumstances.

The Statutory Instruments (2007 No.320) establishing the Construction (Design and Management) Regulations 2007 (CDM) requires designers to take all reasonable steps to provide with their designs sufficient information about aspects of the design of the structure or its construction or '*maintenance*' as will adequately assist clients, other designers and contractors to comply with their duty under the Regulations.

Other primary instruments supporting this requirement include:

1) Construction (Design and Management) Regulations 2007 Approved Code of Practice (APCoP)
2) BS 4884: Part 3: 1993 Technical Manuals – Guide to presentation.

3.6.2 Imperative for Change

However, findings from literature (BSRIA, 2011; Silva et al, 2004; CIRIA, 1999) have revealed that despite the foregoing, the O&M manual has continued to fail in meeting its expected requirements. BSRIA (2011) indicates the construction industry has a poor reputation when it comes to O&M manuals; in terms of quality and timeliness of delivery. Preliminary studies in course of this research also reveal that O&M manuals in the UK are provided just to meet legal requirements rather than meeting the needs for efficient, safe and healthy operation. It therefore becomes very imperative to identify a process that is capable of engineering change in the building delivery protocol in a manner that will ensure that the building designers are not only maintainability conscious but that owners are provided with appropriate documents that will ensure that the buildings are operable and maintainable efficiently, in safe and healthy manner.

3.7 'RIGHT FIRST TIME' CONCEPT

Very few buildings are built from a prototype design that has been tested and refined over a substantial period; most are responses to site, context, design and specification which may be similar to an earlier design, but are seldom identical (Bordass, Leaman and Ruyssevelt, 2001). Building designers are trained to be creative and ingenious in their designs. Design has been defined in Zhu (2005) as *"a creative activity which involves bringing in something new and useful that has not existed previously".* This statement presupposes that if a replica of what a designer claims to have designed, previously existed somewhere, it is not a design, but rather a copied or plagiarised work, or infringing on copyright law as contained in the Copyright, Designs and Patents Act 1988 of the UK (Speaight and Stone, 2010). By this copyright law, a designer cannot even replicate a design for which client A has fully paid for, to client B without the consent of client A who is the copyright owner (Ibid).

Perhaps this may be one of the reasons why adequate lessons have not been learnt from previous designs, because the new design is a brand new idea even though there may be some similarity across buildings of same typology. However, one will argue that for low carbon buildings, the systems which are the major focus of this research are electro-mechanicals, which in most cases are prototype products from the factory. However these systems are not stand-alone, they are integrated in the whole.

It becomes therefore necessary to ensure that each design is treated in its merit and adequate care taken from inception to ensure that the designed building is capable of meeting design expectations first, before they are constructed. This is what this research was centred on – 'right first time'.

The 'right first time' concept is advocated because it is beneficial and more cost effective to take the necessary steps upfront to ensure a product or service meets its requirements than to provide a product or service that will need rework or not meet customer needs ShenbangaKuma (2010) and Sharma (2013).

The key to accomplishing this objective is to have the right process spelt out in clear and unambiguous manner (AuBuchon, 2012). That is why it became necessary to propose an Operability and Maintainability Integrated Design and Construction Process Model for low carbon buildings – 'getting operation and maintenance right first time'.

3.8 CONCLUSION

Taking an overview of building maintenance, this chapter presents the facts adduced from literature that it is an under-researched field, noting that the growth and awareness of the importance of building maintenance is yet to be matched with sufficient research and development. The chapter also looked at the metamorphosis of the definition of building maintenance by the BSI from 1964 through 1984, 1986 to 1991 and 1993. It noted the key objectives of building maintenance as 'to preserve or to keep in a continuous state of good repair' and 'to ensure that the building and all its component parts continue to efficiently perform their originally intended purpose(s)'.

The subject, building maintenance was seen to have attained significance in the UK; (building maintenance has come of age and is now married to facilities management, with a change of name to building care). Maintenance activities in the UK was estimated at 47% of the construction industry's output, in 2009, and in 2006 the Building Cost Information Services estimated the total expenditure on maintenance alone to be over £70bn. The 1998 Barbour Index puts the expenditure for maintenance and related works in the UK at £28bn, while new build in the same year amounted to just £10bn. This therefore puts building maintenance in a preeminent position over new build, and deserving of concerted efforts to finding solutions to cost reduction and realisation of value to investors, hence ensuring sustainable building maintenance which involves maintenance operation in terms of sustainability of the building and sustainability of the operation.

Sustainable maintenance was described in this chapter as a practice where the building maintenance process is planned and carried out in ways that are resource efficient, exerting little or no impact on the environment, the building and/or its users and ensuring continued comfort, utility and beauty of the facility through its life cycle’. It argued that, to achieve a sustainable maintenance regime, the maintenance operation has to be thought out from inception of design, and the design solution must be influenced by the maintenance and operation considerations. Also, that sustainable maintenance will need to result from a sustainable design approach which the author argues, should involve maintainability and operability considerations.

The chapter also discusses the concept of maintainability and operability. It defines maintainability in the context of this research to mean ‘a design that is conscious of the ease, safety and cost of maintenance, not compromising standards and quality, but ensures that building elements and components are kept in their continued good appearance and functional state, through the building’s life-cycle’. Similarly, operability was considered to mean ‘a design quality measure that ensures that facilities are operated in the most efficient, intuitive, transparent and robust way possible’. The concept of ‘Duty of Care’ which requires a designer to take reasonable care to ensure that his clients or third party users do not incur any foreseeable physical injury or economic loss as a consequence of his omission or negligence was used to further underscore the need for maintainability and operability practice in designs.

The chapter also discussed maintainability optimisation strategies identified in literature, including: procurement strategy; involving maintenance personnel at the design stage; Post occupancy evaluation, Life-cycle costing; Maintainability scoring system; involving client advisors, soft landings and developing O&M manuals. It also argued that the most appropriate strategy would be that that is directed at tackling it from inception, following the concept of ‘Right First Time’.

Chapter 4:

BUILDING DELIVERY STRATEGIES IN THE UK

4.0 INTRODUCTION

This chapter discusses various building delivery or procurement systems available to building owners/clients with a view to appraise how they impact on operation and maintenance. It begins with a general overview of building procurement and reviews the Royal Institute of Chartered Surveyors (RICS)'s Contracts-in-Use survey in the UK from 1985 – 2010. It also examines the private sector participation in public sector project delivery, operation and maintenance, and how the strategies have addressed maintenance and maintainability, or perhaps, it has just been a shift of responsibility without the actual problem being solved.

The chapter presents background information on building delivery processes which also serves as secondary data; acting in conjunction with the field results as basis for the research outcome (formulation of the proposed operability and maintainability integrated design and construction process model).

4.1 BUILDING PROCUREMENT OVERVIEW

Building procurement has been defined as "the amalgam of activities undertaken by a client to obtain a building" (Franks, 1998). This clarification is necessary as to distinguish building procurement from the procurement of other goods and services and buying a building from a developer or property agent. Building procurement is a complex process involving the interaction of the client, a team of consultant designers, constructors, suppliers and various statutory/public interest bodies (The Scottish Government, 2011). The construction industry contrasts most other industries, in that whereas others are mass producers, the construction industry most often produce a one-off prototype (Rijn, 2005). The Scottish Government (2011) describes building procurement as *"encompassing the purchase of construction-related services with the ultimate aim of:*

- ❖ *creating a new building or structure, including all associated site works; and or*
- ❖ *alteration, refurbishment, maintenance, extension or demolition of an existing building or structure".*

McDermott (1999) also defines building procurement as *"the framework within which construction is brought about, acquired or obtained".*

The importance of Choice of an appropriate procurement system has been argued by Ofori (2006) to be to be the key to performance improvement in the construction industry. The International Council for Building Research Studies and Documentation Working Commission W92 (Procurement Systems) established in 1990 illustrates the eminence attached to the subject, 'building procurement'. This global body of international researchers is committed to investigating construction procurement and publishing, through symposia and workshops for the past two decades, and several innovations have been introduced to the procurement systems (Walker & Hampson, 2008).

It is imperative to point out at this juncture that the terms 'procurement system', 'procurement strategy', 'procurement route', 'procurement method', 'contractual arrangement' and 'project delivery system' are often used interchangeably to refer to the same process (OGC, 2007; Cheung et al, 2001; Tookey et al, 2001). Such interchanging nomenclature is also used in this thesis.

CIRIA, 2009 classified all the numerous construction procurement strategies in generic models as; A-Traditional, B-Traditional Design & Build (D&B) and C-Single Point of Responsibility. Figure 4.1 graphically illustrates these models.

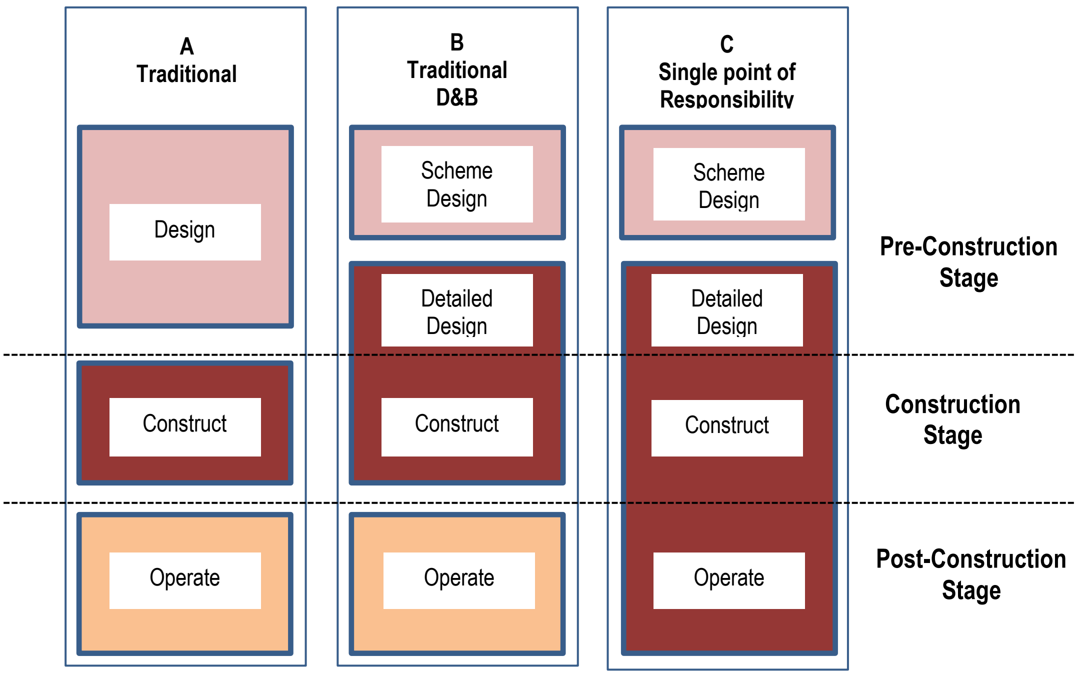


Figure 4.1: Project Procurement Options (Adapted from: CIRIA, 2009)

Procurement routes A & B are both traditional, except that route A separates the functions of designing and constructing in two different persons or firms, while in route B, the two functions are handled by an individual or a firm, while the operation and maintenance stage is procured separately in both cases. In route C, all 3 functions of design, construction and operation are procured from a single firm or a consortium. These models can be used for new-build, maintenance and rehabilitation works (Ibid).

4.2 A SUMMARY OF CURRENT PROCUREMENT PRACTICES IN THE UK

A study of the 11th & 12th survey of 'Contract in Use', undertaken by the Royal Institute of Chartered Surveyors (RICS), claimed to be *'the single most authoritative survey of construction contracts used in the UK'* (Langdon, 2011) reveals the trend of building procurement in the UK construction market from 1985 – 2007. The 12th survey covering (Contracts in Use 2010) which is probably the most recent, at the time of writing up this thesis was published on 8 November 2012 (RICS, 2012) also authored by Davis Langdon on behalf of RICS (Langdon, 2012). The prevalent procurement methods recorded include:

Table 4.1: List of Contracts in Use in the UK (1985 – 2010)

S/n.	Traditional Methods	Traditional D&B Methods	Single Point of Responsibility
1	Lump Sum – Firm BQ	Lump Sum – Design & Build	Partnering Agreement
2	Lump Sum – Spec & Drawing	Target Contract	
3	Re-measurement – Approx. BQ		
4	Prime Cost Plus Fixed Fee		
5	Management Contract		
6	Construction management		

(Adapted from Langdon, 2011 and Langdon, 2012)

4.2.1 Lump Sum – Firm BQ

A variant of the traditional procurement method which uses a firmed up lump sum based on a priced bill of quantities (BQ) as the contractor's fee. Though the final cost may change due to variations, and such cases, the additional cost is calculated based on the rates on the BQ, which had been firmed up (Greenhalgh and Squires 2011).

4.2.2 Lump Sum – Spec & Drawings

Also a variant of the traditional method where the contract is entered into based on the drawings and specification, usually, where the scope of work is limited and reasonably certain. So lump sum is agreed upon. The client pays the fixed/agreed sum, regardless of the actual cost (Seeley 1996).

4.2.3 Re-measurement – Approx. BQ

This contract is based on schedules of rates, approximate quantities and bill of quantities (Seeley 1996). The contractor submits rates and prices for labour and materials against an indicative BQ; given an indication of an approximate final cost, eventually, the actual quantities are measured as work progresses to determine real cost (Speaight and Stone 2010). Mainly used in traditional procurement, but can also be applied to a D&B system where the designer is also the contractor.

4.2.4 Prime Cost Plus Fixed Fee

In this method of procurement, the contractor is paid the actual cost of completing the contract (the prime cost) plus an earlier agreed fixed fee (Seeley 1996). This falls under the traditional form.

4.2.5 Management Contract

This is another traditional system where the contractor is paid to manage the construction on behalf of the client. His responsibility entails procurement, management and supervision, not to build (Seeley 1996). He is the client's representative on the project and liaises with the various consultants at the early stage of the design, including the Quantity Surveyor. He also employs the various work contractors (Chappell and Willis 2011).

4.2.6 Construction Management

Here the construction manager is employed, usually at the construction stage, where the client himself assumes the responsibility of the main contractor and appoints works sub-contractors for various aspects of the construction (Seeley, 1996). It is also a traditional procurement form.

4.2.7 Lump Sum – Design & Build

In this contractual arrangement, the responsibility of designing and constructing is entrusted to the contractor (Seeley 1996). Because the drawings are less detailed in this kind of arrangement, the pricing will be less precise, so the lump sum arrangement is usually adopted; usually broken down into item/sub-heads to allow for cost control. Design & build has many variants which include: *Design and Construct, Develop and Construct, Package Deal* and *Turnkey contracts* (Chappell and Willis 2010).

4.2.8 Partnering Agreements

According to Speaight and Stone (2010), Partnering contracting results from a framework agreement between the client and a supplier (Contractor or consultant) for a number not just a single project, but to be used on a number of projects. That is to say that the entire project team is carried from one site to the other with mutual trust and understanding, without needing to go through a bidding process. The arrangement provides conditions that encourage the parties to work together in a manner requiring openness and a spirit of mutual trust and respect. This operates usually under the single point procurement system and in some cases design and build.

4.2.9 Target Contracts

This is also referred to as GMP (Guaranteed Maximum Price) (Greenhalgh and Squires 2011). This type of contractual agreement is based on a target cost which the construction cost is not to go beyond. The GMP is usually raised above the target cost to create a buffer zone (Chappell and Willis 2010). When the actual cost exceeds or fall below this GMP, the cost overrun or savings is shared by the contractor and the client (referred to as 'Painshare or 'Gainshare' respectively (Greenhalgh and Squires 2011). This method can be used following any of traditional, D&B or Single point procurement method.

4.2.10 PFI/PPP

The RICS Contracts in Use' survey 2007 reported that it received no information about PFI/PPP (Langdon, 2011); this trend was also reported for the 2010 survey. However, PFI is known to have taken the centre stage of the construction industry in the UK (particularly with public services and infrastructure), until 2011 when the new Government Construction Strategy was launched. What sets it apart from other contract forms is that the responsibility to design, build, operate and maintain over a long period is entrusted to a single supplier.

4.3 EVALUATING THE RESULTS OF THE RICS CONTRACTS IN USE SURVEY

One of the objectives of this research is to evaluate prevalent delivery processes of low carbon buildings in the UK, and the operation and maintenance challenges that exist there in. It was also intended that secondary data will be employed for this purpose, since such information are available in the public domain. Although the RICS data was not specific to low carbon, it encompasses all buildings (including the low carbon buildings) within the private and public authorities in the United Kingdom both new builds and refurbishments; excluding overseas work, civil engineering work and heavy engineering projects, term contracts, routine maintenance and repair works as well as sub-contracts which form part of the larger contract

(Langdon, 2012). Secondly, the claim by the author in the 11th Survey report that it is the single most authoritative survey of construction contracts used in the UK market has not been challenged (Harris, 2011). The data provided in both reports cover data from 1985, using the same parameters.

4.3.1 Findings from the RICS Contract in Use Survey Data

The following were noted from the 11th (2007) and 12th (2010) RICS Contract in Use Survey Reports:

i) The majority of building contractors in the UK continue to use various variants of the traditional procurement methods both in the 2007 and 2010 surveys, as evident from the percentage of contracts distribution according to procurement routes as shown on Table 4.2. Figure 4.3 compares the total percentage distribution of contracts procurement patterns according to the generic classification system, for 2004, 2007 and 2010 surveys. On the average, over 75% of the contracts are procured through traditional methods.

Table 4.2: Trends in Methods of Procurement by number of Contracts

	Type of Contract	1985 (%)	1987 (%)	1989 (%)	1991 (%)	1993 (%)	1995 (%)	1998 (%)	2001 (%)	2004 (%)	2007 (%)	2010 (%)
Traditional	Lump Sum – Firm BQ	42.8	35.6	39.7	29.0	34.5	39.2	30.8	19.6	31.1	20.0	24.5
	Lump Sum – Spec & Drawing	47.1	55.4	49.7	59.2	45.6	43.7	43.9	62.9	42.7	47.2	52.1
	Re-measurement – Approx. BQ	2.7	1.9	2.9	1.5	2.3	2.1	1.9	1.7	2.9	1.7	0.3
	Prime Cost Plus Fixed Fee	2.1	2.3	0.9	0.2	0.3	0.7	0.3	0.2	0.2	0.5	0.6
	Management Contract	1.7	1.2	1.4	0.8	0.9	1.2	1.5	0.6	0.2	0.7	0.0
	Construction management	-	-	0.2	0.2	0.4	1.3	0.8	0.4	0.9	1.1	0.3
Design & Build	Lump Sum – Design & Build	3.6	3.6	5.2	9.1	16.0	11.8	20.7	13.9	13.3	21.9	17.5
	Target Contract	-	-	-	-	-	-	-	-	6.0	4.5	3.7
Single point	Partnering Agreement	-	-	-	-	-	-	-	0.6	2.7	2.4	1.0
	Total	100	100	100	100	100	100	100	100	100	100	100

(Source: Langdon, 2011; Langdon, 2012)

ii) Fig. 4.4 shows a line graph of the trends of the various procurement routes used within the last twenty years (from 1993 - 2010). The graph shows that the Lump Sum – Spec & Drawing method has been the most widely used in the country, till date. Over 50% of building contracts in the UK still adopts this traditional method where contractual obligations are discussed based on the drawings and detailed specifications, according to the 2010 survey.

iii) Figure 4.4 also shows that the top 3 form of contracts are the Lump Sum contract forms; lump sum – spec & drawing, lump sum – firm BQ and lump sum design & build, and the rest return below 5% each. Figure 4.5 compares these top three routes to all other routes of procurement grouped together, for the 2004, 2007 and 2010 surveys. It shows significant drop in the use of other procurement forms.

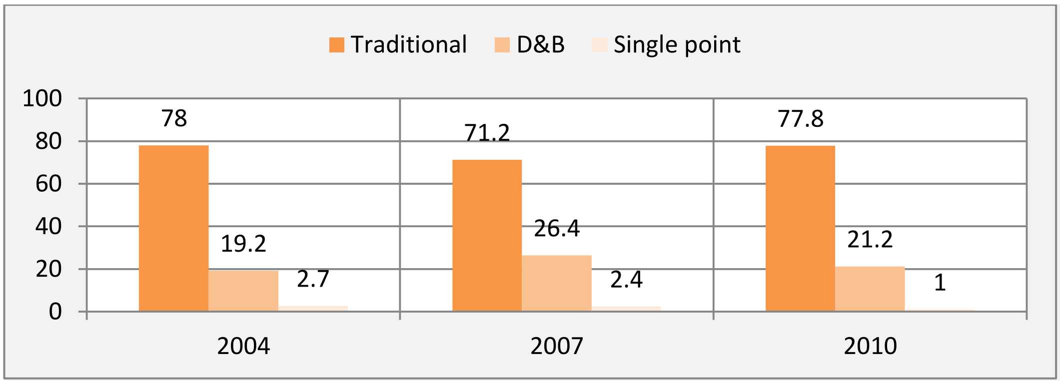


Figure 4.3: Total % of Contracts Distribution According to the Generic Procurement Routes from 2004, 2007 and 2010 RICS Survey Data

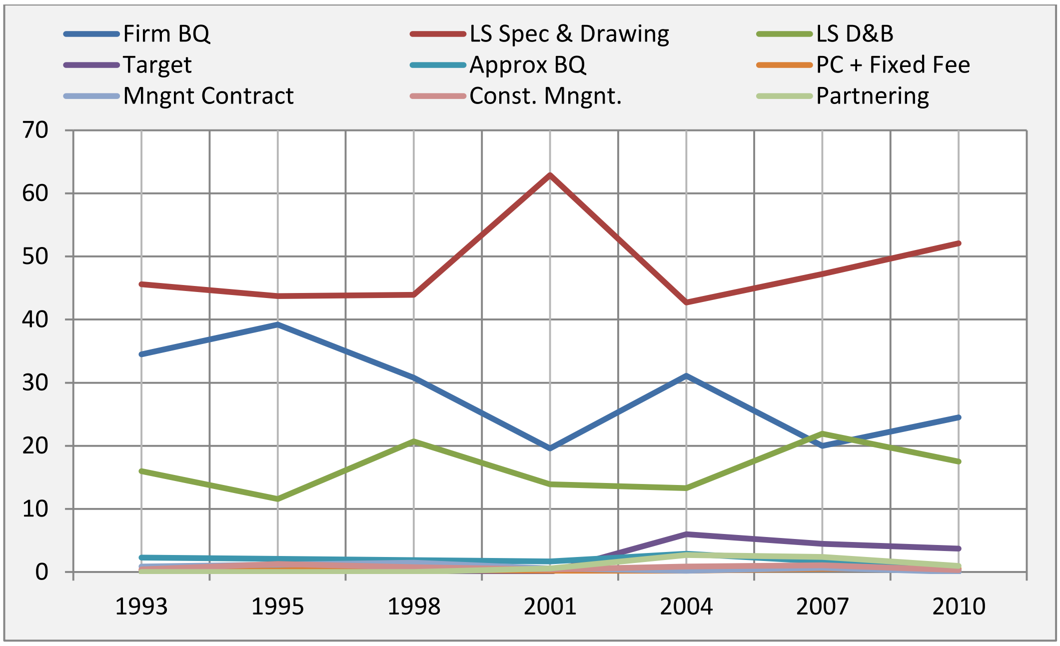


Figure 4.4: Comparing the Trends of Various Procurement Routes in the last 20 years

iv) There is also a linear rise in the Spec & Drawing route from 2004 to 2010 as shown on figures 4.5 and 4.7). Whereas the Firm BQ route experienced a decline from 31% in 2004 to 20% in 2007, in 2010 it rose above 24% (Figure 4.6), following behind the Spec. & Drawing at 52%.

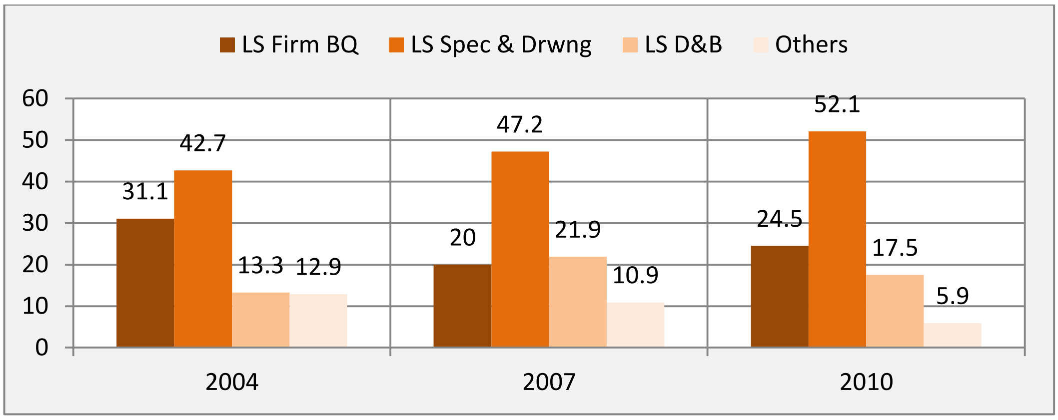


Figure 4.5: Comparing the Top 3 Procurement Routes with all others for 2004 – 2010

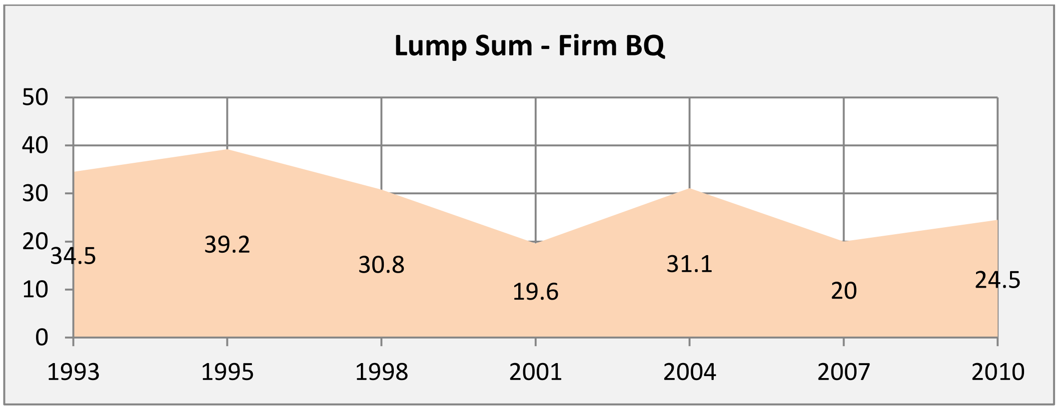


Figure 4.6: Trend of Use of Lump Sum – Firm BQ Procurement Route in the last 20 years

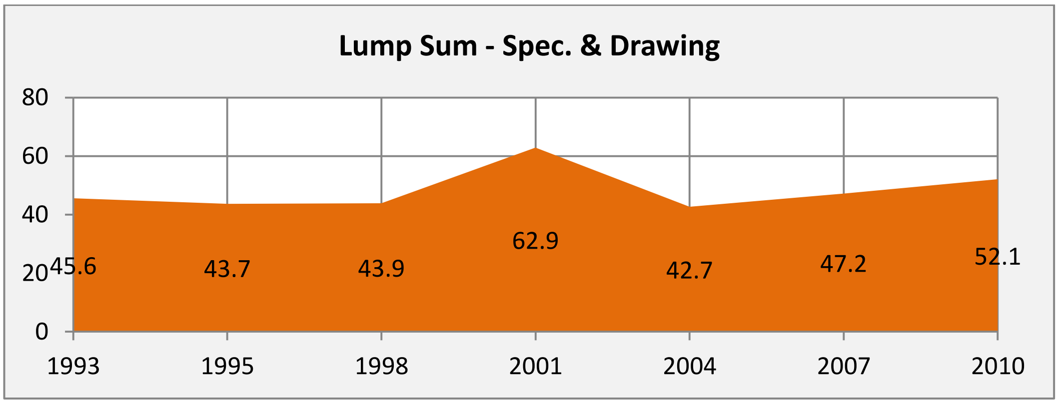


Figure 4.7: Trend of Use of Lump Sum – Spec & Drawing Procurement Route in the last 20 years

v) Figures 4.5 and 4.8 show that the Design & Build route is on the decline; it followed a converse trend to the Firm BQ; it rose to about 22% in 2007 and dropped to 17.5% in 2010.

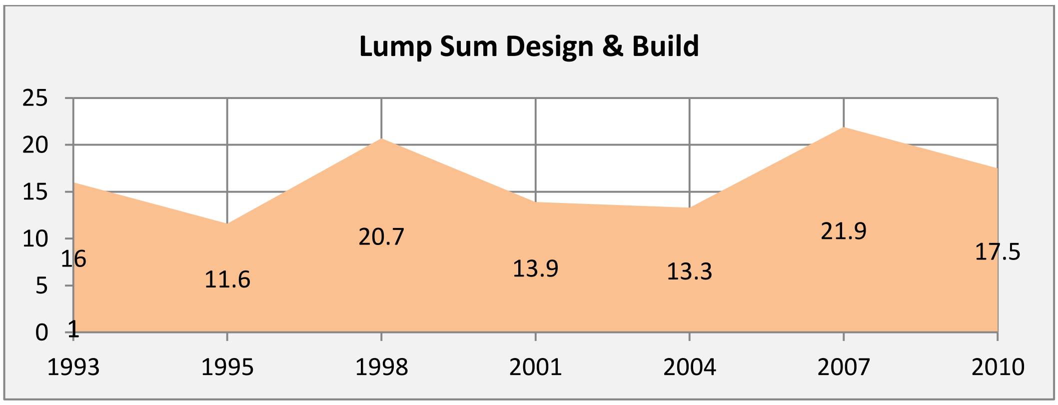


Figure 4.8: Trend of Use of Lump Sum – Design & Build Procurement Route in the last 20 years

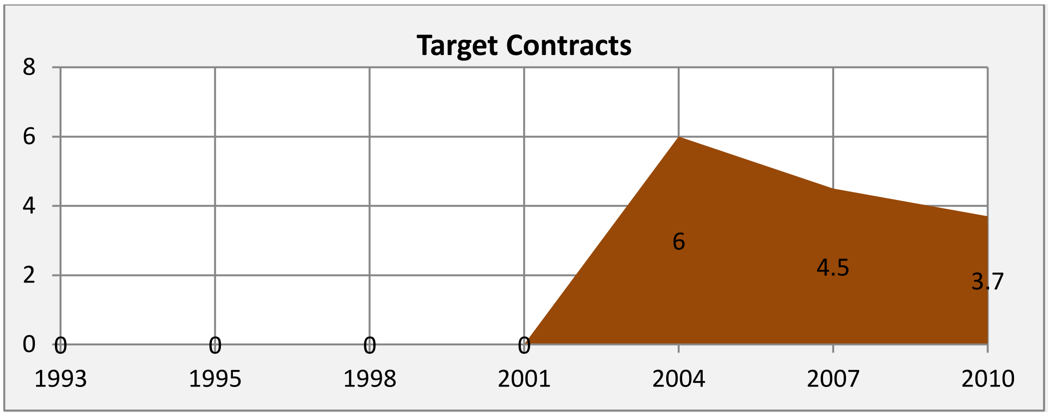


Figure 4.9: Trend of Use of Target Contracts Procurement Route in the last 20 years

vi) That there has been a reduction in the adoption of Guaranteed Maximum Price (Target Contract), which is a variant of the D&B system. From table 4.2 and figure 4.9, Target Contract was 6% in 2004 and reduced to 4.5% in 2007 and to 3.7% in 2010.

vii) Partnering Agreement form of contract rose from 0.6% in the previous survey where it was first captured to 2.7% in 2004, by 2007, no significant difference was apparent, but by 2010, there was a reduction to 1.0% as shown on table 4.2 and figure 4.10.

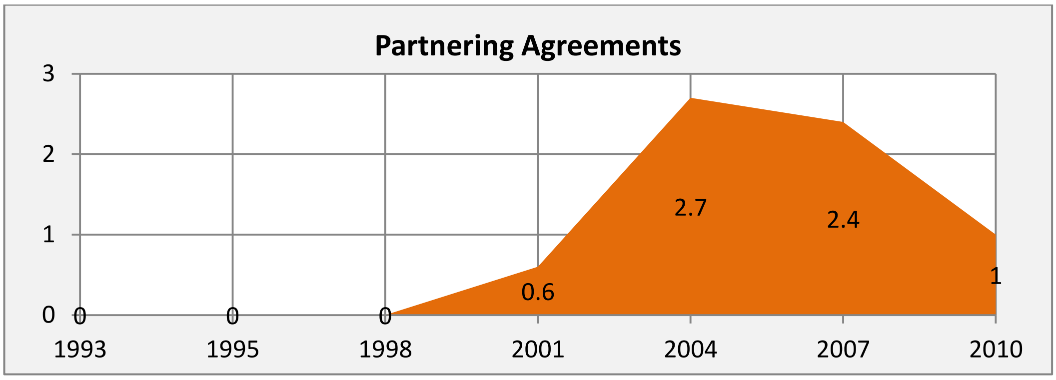


Figure 4.10: Trend of Use of Partnering Agreements Procurement Route in the last 20 years

viii) From table 4.3, it can be noticed that from 1998 to 2010, the Lump Sum Design & build system has accounted for the greater value of contracts in the UK, although in terms of number of projects it ranked number 3. In 2010, it accounted for 39.2%. The 2007 survey report noted that over 50% of contracts valued from £10,000 - £50,000,000 were procured on design and build basis, whereas, in the 2010 report it is reported that the design and build contract is the most commonly used contract form for projects valued from £500,000 to£10,000,000 and £20,000,000 to £50,000,000.

Table 4.3 Trends in Methods of Procurement by value of Contracts

	Type of Contract	1985 (%)	1987 (%)	1989 (%)	1991 (%)	1993 (%)	1995 (%)	1998 (%)	2001 (%)	2004 (%)	2007 (%)	2010 (%)
Traditional	Lump Sum –Firm BQ	59.3	52.1	52.3	48.3	41.6	43.7	28.4	20.3	23.6	13.2	18.8
	Lump Sum – Spec & Drawing	10.2	17.7	10.2	7.0	8.3	12.2	10.0	20.2	10.7	18.2	22.6
	Re-measurement – Approx. BQ	5.4	3.4	3.6	2.5	4.1	2.4	1.7	2.8	2.5	2.0	0.7
	Prime Cost Plus Fixed Fee	2.7	5.2	1.1	0.1	0.2	0.5	0.3	0.3	<0.1	0.2	0.6
	Management Contract	14.4	9.4	15.0	7.9	6.2	6.9	10.4	2.3	0.8	1.0	0.0
	Construction management	-	-	6.9	19.4	3.9	4.2	7.7	9.6	0.9	9.6	0.1
Design & Build	Lump Sum – Design & Build	8.0	12.2	10.9	14.8	35.7	30.1	41.4	42.7	43.2	32.6	39.2
	Target Contract	-	-	-	-	-	-	-	-	11.6	7.6	17.1
Single point	Partnering Agreement	-	-	-	-	-	-	-	1.7	6.6	15.6	0.9
	Total	100	100	100	100	100	100	100	100	100	100	100

(Source: Langdon, 2011; Langdon, 2012)

4.3.2 Conclusions Drawn from RICS Surveys

Deductively, one could conclude as follows:

a) The majority of clients prefer the traditional method which involves procuring design, construction and operation/maintenance separately and usually following a tradition generic sequence of stages as outlined by McGraw-Hill Construction 2010 in Greenhalgh and Squires (2011); Pre-design – Design – Bidding/negotiation – Building (Construction) – Operation.

b) In most traditional routes, operation and maintenance contracts are procured after practical completion, when the entire project team may have been disengaged, so the inherent problems of maintenance still remain unsolved.

c) The continued preference for lump sum forms of contract, particularly, the Spec. & Drawing variant implies that greater responsibility is placed on the design team to make their drawings more detailed, clearer and maintainable – *'right first time'.*

d) Although the design & build variant does not account for as much building stock, but accounts for the biggest investments in the building sub-sector of the economy, and as such needs to be given consideration in the design of any improved design and construction model.

e) The use of GMP/Target contract is usually applicable to Prime Contracting where the GMP is based on the optimum life-cycle. The study shows a decline in its acceptance, it therefore implies that a proper approach is not adopted for this model, and will therefore warrant need for an alternative life-cycle consideration model.

f) Partnering arrangement which usually involves operation and maintenance responsibilities is seen not to be attractive. Although, this differs slightly from the PFI arrangement, the shortcomings in the post-construction stage seem to be the same (See section 5.5 for discussions on PFI).

4.4 PROCUREMENT SYSTEMS AND ASSOCIATED MAINTENANCE ISSUES

4.4.1 PFI/PPP

The Private Finance Initiative (PFI) was initiated in Australia as Public-Private-Partnership (PPP) (Pretorius et al 2008) as far back as the late 80s with railway and toll road projects (Timmins 2009). By 1992, it was used in the UK for the first time (Greenhalgh and Squires 2011). PFI's primary principle is to transfer the responsibilities and associated risks of funding, designing, building, operating and maintaining public infrastructure to the private sector over a period of usually 25 to 30 years (Harris 2004, Smith 2004 and Pretorius et al 2008). By this arrangement, a private sector firm, usually the contractor or ProjectCo; the consortium of main contractor and private sector funders (House of Commons HC 68, 2010) undertakes the responsibility of sourcing for funds for the project, produces designs - in-house or outsource designers (Smith 2004), constructs, operates and maintains the building from which quality public services are delivered.

According to Pretorius et al 2008, the expectations of the public sector for a PFI scheme is to achieve Value for Money (VfM). One way of achieving this VfM and in fact the key benefit of PFI procurement route is the requirement for buildings to be maintained to high standards over the life of the contract (HC 631, 2011).

Of all the procurement systems currently in use today, the PFI/PPP seem to be most attractive to government operatives all over the world some few years back, as they defer spending, while enabling government authorities deliver social services to her populace. As contained in the report by the National Audit Office of June 2010, it noted that the intended benefits of PFI include:

1) transferring the risk of failing to deliver services to time and budget to the private sector;
2) the maintenance of assets over the life of the contract
3) transparency of service provision cost; and
4) innovative approaches to building design and services provision

However, there have been growing concerns by researcher, the Government and the general public that PFI arrangement is far too expensive, a means of transferring debts to future generation, mortgaging the nation’s future and not providing good value for money (Smith, 2004; House of Commons Report-HC 754, 2007; Monbiot, 2010; Norman, 2010). HC 631 (2011) noted that there was no clear and explicit justification and evaluation found for the use of PFI in terms of value for money (VfM). It was seen as a back-door form of privatization (House of Commons, Dec.7 1993). In Northern Ireland, up till 2002, one of the critiques of PFI/PPP wrote; *"A naïve embrace of PFI would risk locking the public sector in Northern Ireland into long-term financial commitments offering poor value for money for the taxpayer."* (Wilson 2002). Nevertheless, the Treasury considered the scheme advantageous and encouraged its acceptance because of limited public sector capital (Monbiot, 2007).

In terms of maintenance, HC 631 (2011) noted that; *"the requirement for buildings being maintained to high standards over the life of the contract is supposed to be a key benefit of PFI. Yet around 20% of hospital Trusts were not satisfied with the maintenance services".* Figure 4.11 shows the result of a survey carried out by the National Audit Office about NHS Trusts' assessment of ProjectCo's and contractors' performance by service (HC 68, 2010).

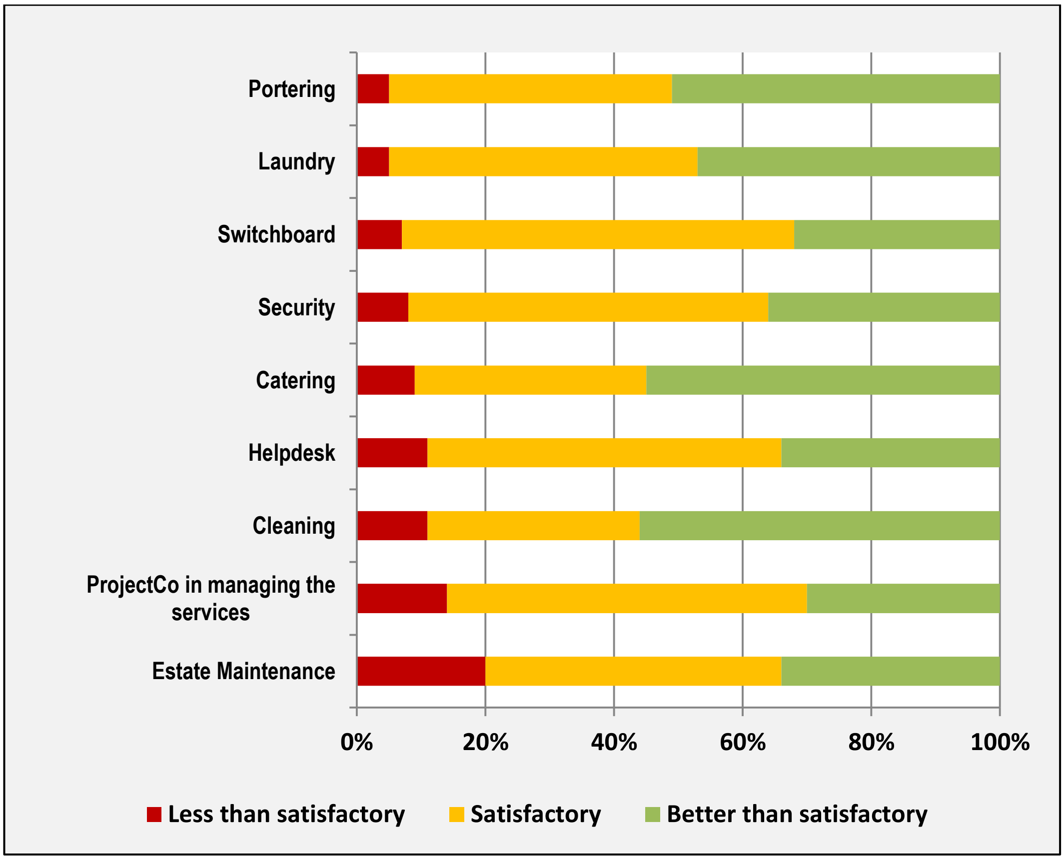


Figure 4.11: Trusts' assessment of ProjectCo's and contractors' performance by service (Source: National Audit Office 2010 pp.18)

The report also made a call for the need to identify how value for money tests and incentives to improve maintenance could be built into the life of PFI contracts.

In addition, Smith (2004) raised several concerns about maintenance as well as design implications of the PFI projects. Some of which include:

- That the argument of the PFI advocates that long-term savings would be achieved through cheaper maintenance and running costs, and more efficient facilities management, sounds convincing in theory, but yet to be proven in practice. Similarly, HC 68 (2010) reports that "*there is no clear evidence to conclude whether PFI has been demonstrably better or worse value for money for housing and hospitals than other procurement* *options. In many cases local authorities and Trusts chose the PFI route because the Departments offered no realistic funding alternative".*

- That the transfer of risks to bidders makes the whole process (including O&M) more expensive because of the time-scale and the dangers of having to cover the unforeseen over such long periods. Corroborating this, Mathieson (2010) reports; *"In August, the BBC found that NHS projects valued at £11.12bn are set to cost the health service £65.1bn."* This shows high cost of O&M stage and meaning that 'today's' government operatives are merely accumulating debts for 'tomorrow's' government operatives and by extension, the taxpayers.

- That PFI contracts are usually signed at RIBA stage C/D which are outline proposals/scheme designs and as such lacks sufficient details. There is therefore considerable room to allow contractor to squeeze out quality. At this stage, no specification detail is given, and bearing in mind that the contractor's major interest is to make gains, tendency to cut corners after the contract is awarded cannot be waved off, particularly in developing countries like Nigeria where corruption is still a bane.

- Contractors will understandably always make commercial incentives override other considerations. National Audit Office in her Summary 19 agrees with this. It states, *"Investors and contractors will naturally seek to maximize their profit margins and we have seen examples where this is at the expense of the Trusts".*

- That in a PFI contract, the contractor is the architect's client, and that this separation of user client and design team at critical stages has been a major concern to designers working on PFI schemes. That this separation can impact profoundly on the understanding and resolution of complex brief in some contexts. This may also impact on the window of opportunity for designers to innovate, explore and research.

❖ Comparing the PFI with the traditional procurement method, it requires longer period (twice or thrice) in the run-up to mobilization to site. The House of Commons Report HC631 also noted in its conclusion and recommendation 2; *"PFI contracts have cost considerably more than originally planned and, on average, have been let two and a half years late".*

In concluding, Smith (2004) opined that success depends largely on design quality, yet this is one part of the process that is usually short-changed. He added; *"this need not be so, but to ensure that design is given due recognition. Architects need to become involved in shaping the PFI process, not accepting an ever-diminishing role within it".*

The National Audit Office study of the performance management of hospital PFI contracts consisting of 76 such operations in England, managed by Foundation Trusts (Foundations), NHS Trusts and Primary Care Trusts (PCTs) noted among others, the following key findings:

a) cleaning, laundering and portering costs are about the same with non PFI hospitals.
b) hospitals with PFI buildings spend more on maintenance annually
c) Trusts'(client) assessment of ProjectCo's and contractors' performance by service as presented on figure 4.11 shows on the average, a satisfactory score card but Estatesss Maintenance was seen to be area of service with highest score of dissatisfaction, followed by ProjectCo in managing the services (general operation management) and then cleaning services.

d) Figure 4.12 also shows clearly the number of Trusts who stated that performance is less than satisfactory. Here maintenance services and general Management topped the scale.

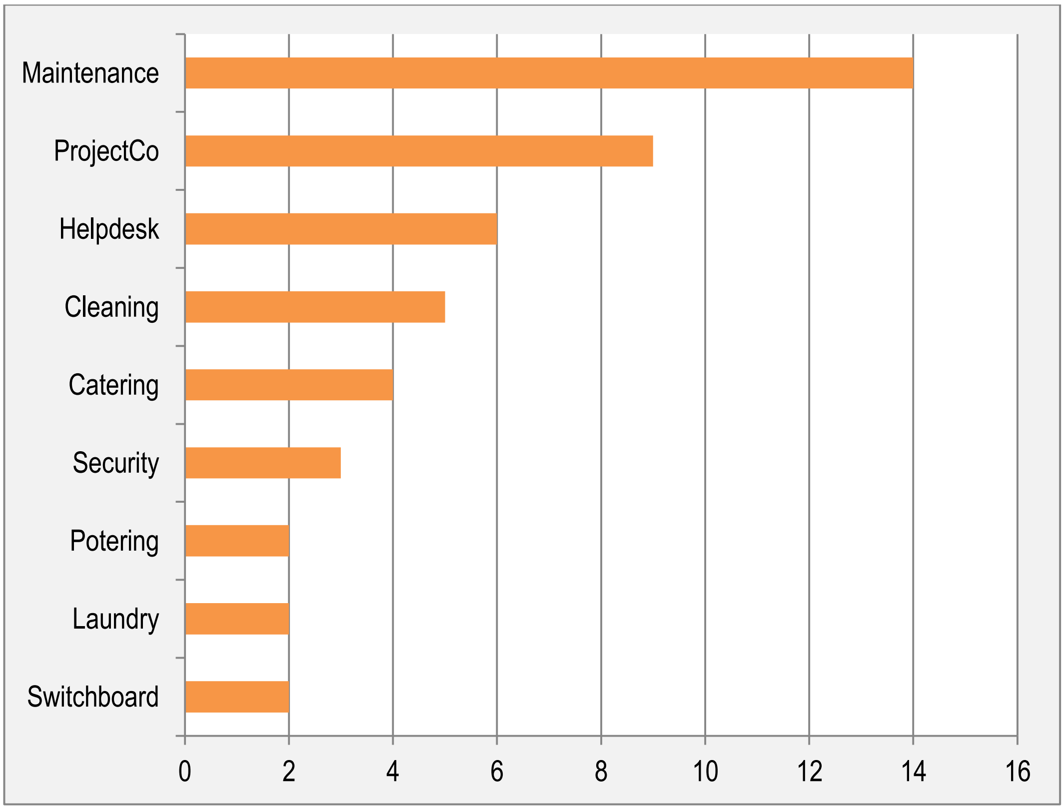


Figure 4.12: Number of Trusts who stated that performance is less than satisfactory (Source: National Audit Office 2010, pp.22)

The House of Commons Report HC631 under its conclusion/recommendation noted that *"there are no mechanisms built into generic PFI contracts to test the continued value for money of maintenance work during the contract period".* This mechanism is indeed what this study sought to explore.

4.4.2 Prime Contracting

This is another form partnering arrangement of the private sector with the public sector to deliver social services to the public. Like the PFI, it involves a single point procurement route through a prime contractor who is responsible for design, construction and maintenance. Unlike the PFI, the contractor is not directly involved in the operation, but rather, monitors the operation stage for a period of time (Holti et al 1999), the prime contractor also is responsible for maintenance only within the period of operation monitoring and not as long as 25 – 30 years as is the case with PFI. Holti et al (1999) describes prime contracting as *"a systematic approach to procurement and maintenance of buildings which draws on the best available tools, techniques and practices, including through-life costing, supply chain management, value engineering and risk management, to achieve significant efficiency of the completed building."* From available literature so far, it is not clear how this project is being funded whether direct or indirect.

The Construction Supply Network Project (CSNP) set up as a learning mechanism and charged with the responsibility of establishing the working principles of prime contracting approach to procurement (Holti et al, 1999) designed a procurement model described in figure 4.2. Prominent and interesting elements of this model are:

1) At the concept design stage, the prime contractor in collaboration with the supply chain team he has put together provides the client with an initial guaranteed maximum price (GMP) based on the optimum through-life (life-cycle) cost, which forms the basis for further project action.

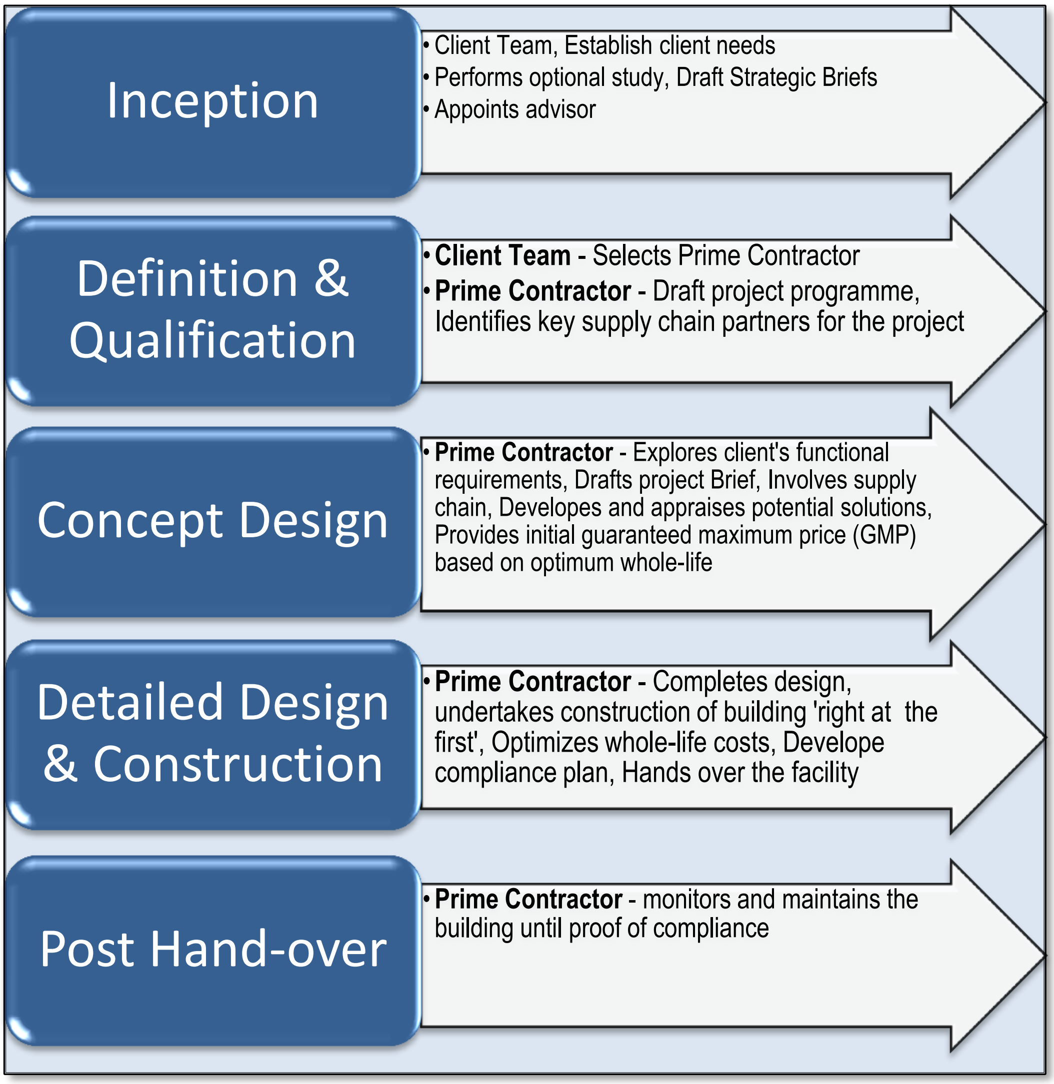


Figure 4.2: CSNP Construction Process Model (Source: Holti et al, 1999)

2) At the detailed design stage, the process requires the supply chain undertaking value engineering and risk management in order to ensure that the construction is undertaken in the most efficient manner.

3) By the end of the detailed design stage, the contractor produces a refined GMP and further develops a 'Proof of Compliance Plan' of the optimum life-cycle cost before mobilising to site.

4) After handing over, during the operation stage, the prime contractor monitors and maintains the facility until the proving of the life-cycle costs. This is expected to be a minimum of 15 months from handing

over (Ibid), depending on the nature of the compliance plan and the actual performance of the building in use.

However, this model of procurement is a partnering/framework arrangement used for wide scale regional projects (Greenhalgh and Squires 2011). Such arrangement entails that the contractor remains a single contractor carried from one site to the other by the client on similar projects without need to re-tender (Speaight and Stone 2010). This system is restrictive and may not encourage new entrants and SMEs.

It therefore becomes imperative to work out a system drawing from this GMP and 'poof of life-cycle cost compliance model that can fit into any method of procurement.

4.4.3 Conclusions drawn from the PFI and Prime Contracting Routes

The studies in this section or chapter as a whole was not intended to assess or recommend any procurement model as the best practice standard, but to examine their operational arrangements and how they impact on the maintenance of structures during operation stage. The following deductions were made with respect to PFI and Prime Contracting:

1) No information in literature indicating that maintenance consideration was a key factor in the choice of procurement method; except in the PFI/PPP and Prime Contracting arrangement where operation and maintenance was fundamental, even though the driving factor was not maintenance, but that of risk transfer.

2) In the PFI projects in the UK; the government, the people and even the client body (NHS Trust) are already disenchanted about the

arrangement. The projects started by previous administrations have accumulated so much debt for present and future government to pay.

3) There is also no proof in literature to show that the facilities are being maintained economically, and in comparing PFI to non-PFI hospitals, no appreciable difference in standard was recording, including rates of operating costs.

4) One can therefore conclude that the PFI arrangement is just a shift of maintenance responsibility from the public sector to the private sector and not in any way solving the problem of high cost of maintenance.

5) The Prime Contracting model used by the Defense Estatess in the UK, where at the outline design stage, the client is made to be aware of the Guaranteed Maximum Price (GMP) calculated based on the optimum-life-cycle cost, and an updated version of the GMP re-discussed before start of construction is perhaps the best model that could address the problem of maintenance cost. However, data from RICS shows a negative reception of this model by clients.

6) Consequently, it will be in the construction industry's interest to explore avenues of solving maintenance problems across all procurement routes.

Sir Michael Latham in his forward to Wood (2003) noted thus;

> *"Putting maintenance at the centre of the continuing post-Egan reform process is long overdue. There is much more to the industry than great structures such as a bridge or a PFI hospital. New or refurbished projects also need to work properly and be in continual use …".*

4.5 GOVERNMENT CONSTRUCTION STRATEGY 2011

The industry witnessed another intervention by the UK government in 2011, with the introduction of the new *'Government Construction Strategy'*, designed to exploit the potential of public procurement of construction and infrastructure projects to drive growth (CCINW, 2011). This was made public by the Minister for the Cabinet Office through a public launch on May 31 2011. The Strategy introduces reforms in the way government procures construction; calling for a profound change in the relationship between public authorities and the construction industry to ensure that government consistently gets a good deal and the country gets the social and economic infrastructure it needs for the long-term (Cabinet Office, 2011). The strategy objective is focused on reducing the cost of government construction projects by 15 - 20% by the end of the current Parliament (Cabinet Office, 2012). It also aims to use construction and infrastructure projects to drive growth and increase competitiveness through the elimination of waste and stimulate higher levels of innovations (CCINW, 2011).

The 2011 and 2012 documents were analysed and the following deductions made:

- That the need for this new strategy is consequent upon the fact that there was widespread belief across government and within industry; supported by recent studies that construction under-performs in terms of its capacity to deliver value and that there has been a lack of investment in construction efficiency and growth opportunities;
- That recent procurement practices show poor and inconsistent practices, particularly in the public sector which accounts for about 40% of the construction industry output.

- That these procurement practices lead to waste and inefficiency, compounded by low levels of standardisation, and fragmentation of the public sector client base.
- The Latham and Egan Reports were criticized for proposing the need for clients and their suppliers to work together on a shared improvement plan, resulting to a process of working with fewer suppliers in a more settled supply chain. Although working with fewer suppliers has it benefits, it stands the risk of locking out new entrants (particularly SMEs), competition and innovation.
- Government has therefore set out a model which she calls 'the right model' for public sector procurement in the UK. This model requires that;
  - clients issue a brief that concentrates on required performance and outcome; designers and constructors to work together to develop an integrated solution that best meets the required outcome;
  - contractors to engage key members of their supply chain in the design process where their contribution creates value;
  - industry is provided with sufficient visibility of the forward programme to make informed choices (at its own risk) about where to invest in products, services, technology and skills; and
  - to ensure that there is an alignment of interest between those who design and construct a facility and those who subsequently occupy and manage it.
- This model also encourages the use of Building Information Modelling (BIM); a collaborative 3D working environment that enables all parties to have a shared platform/data. This, the government believes will ensure that all project information, documentation and data are electronic and easily accessible by relevant stakeholders by 2016.

- The model also requires designers and constructors to prove the operational performance of the building they designed and construct for a period of say three to five years. That is, adopting the Soft Landings principles.
- Encourage competitive tension, and make cost (derived from agreed principles of value for money) a key driver, rather than an outcome.
- The strategy also encourages the adoption of lean procurement principles. However, it is argued that lean manufacturing and lean procurement have often not fulfilled their true potential and the record of implementation success is ambiguous (Wilson and Roy, 2009). It is also interesting to noted that less than 10 per cent of lean implementations in the UK are considered successful (Bhasin and Burcher, 2006).
- It is also clear that the strategy is subject to improvements as the framework document clearly states that *"Government will, in collaboration with the National Improvement and Efficiency Partnership, investigate the effective use of frameworks and other routes to market across the public sector, addressing what works and assessing the effectiveness of existing arrangements".* In this wise, this research becomes imperative and could serve as a spring board.

4.6 CONCLUSION

While discussing procurement systems and associated maintenance issues, the chapter draws conclusion from Sir Michael Latham's forward to Wood (2003) which suggests that putting maintenance at the centre of the present day construction reform process is long overdue, and that new or refurbished projects need to work properly and be in continual use.

The chapter began by defining building procurement as "the amalgam of activities undertaken by a client to obtain a building"; seeing it also as a complex process involving the interaction of the client, a team of consultant designers, constructors, suppliers and various statutory/public interest bodies. It also discussed the historical developments in building procurement from pre-World War II through the various historic economic periods up to 1991 – 2008 which witnessed the growth of PFI. Various government reports and their influence on the procurement systems were also discussed, including: Simon's Report (1944), Phillip's Report (1950) up to the Latham's and Egan's 1994 and 1998 respectively.

The chapter also reviewed the RICS' survey of contracts in use 2010, as published in November 2012. The review indicates that more than 75% of buildings the UK were procured through the traditional methods in 2010, and that within the last 20 years, over 50% of buildings in the UK used this traditional method where contractual obligations are agreed upon based on the drawings and detailed specifications. The results also show that within the 20 year period, the top 3 procurement systems included: Lump sum – spec & drawing, Lump sum – firm BQ and Lump sum – Design and build. This indicates that majority of clients prefer the traditional method which involves procuring design, construction and operation/maintenance separately. In most traditional routes, operation and maintenance contracts are procured after practical completion, when the entire project team may have been disengaged. The continued preference for lump sum forms of contract, particularly, the Spec. & Drawing variant implies that greater responsibility is placed on the design team to make their drawings more detailed, clearer and maintainable – *'right first time'.*

Although the PFI projects were not captured in the RICS survey, but a review of some House of Commons (HC) Reports on PFI indicates that the requirement for buildings being maintained to a high standard over the life of the contract (ideally, 25 – 30 years) was supposed to be a key benefit of PFI, yet some hospital Trusts were not satisfied with the maintenance services. The HC Report also concluded that "*there was no clear evidence to conclude whether PFI has been demonstrably better or worse value for money for housing and hospitals than other procurement options. In many cases local authorities and Trusts chose the PFI route because the Departments offered no realistic funding alternative".* It was also observed from the report that PFI contracts have cost considerably more than originally planned and that "*there were no mechanisms built into generic PFI contracts to test the continued value for money of maintenance work during the contract period".* The report; HC 631 of 2011 also called for the need to identify how value for money tests and incentives to improve maintenance could be built into the life of PFI contracts.

Chapter 5:

LOW CARBON BUILDINGS AND LOW CARBON TECHNOLOGIES

5.0 INTRODUCTION

The deployment of renewable sources of energy as alternative to the fossil-fuel driven energy sources, has been identified in literature as a sustainable approach to attaining the reduction in greenhouse gas emissions (RIBA, 2009a; Hensen and Lamberts, 2011; Adshead, 2011). In the built environment this development has led to varying and continued innovation of low carbon and renewable technologies. They are also referred to as sustainable technologies, green technologies or energy efficient technologies which are gradually replacing the traditional fossil fuel driven technologies in buildings.

The main thrust of this research was focused on how the associated challenges of managing (operating and maintaining) these new and unconventional technologies in buildings can be addressed early in the procurement process. This chapter examines relevant literature associated with low carbon buildings, and low carbon technologies. It looks at the antecedents; climate change and sustainable developments, and the UK efforts in striving to attain a zero carbon built environment by 2016 (for all new domestic buildings) and 2019 (for all new non-domestic buildings) (DCLG, 2007). The chapter explores the body of knowledge that led to the development of low carbon technologies, some passive and active control considerations to low carbon technologies as they relate to the temperate climate in which the UK situates.

5.1 CLIMATE CHANGE IMPERATIVES ON THE BUILT ENVIRONMENT

Climate change has been identified as the greatest challenge confronting human society in this 21st century (RIBA, 2009a). Human activities have also been fingered as having both direct and indirect impacts on the climate as well. The climate consequently impacts on the economic and social activities, as well as health, wellbeing, safety and demands for resource use (BRE, 2009). RIBA (2009a) also affirms that there is an overwhelming scientific consensus indicating that climate change is a consequence of greenhouse gas emissions resulting from human-induced activities; such as running buildings, travelling, extracting resources and industrial manufacturing.

It has been noted that within the last 50 years, the burning of fossil fuels have caused remarkable increase in the quantity of CO_2 and other greenhouse gases, which has adversely affected global climate. CO_2 concentration in the atmosphere has increased by more than 30% since pre-industrial times, trapping more heat in the lower atmosphere (WHO, 2013). The WHO report added that the resulting changes in the global climate come with a range of risks to health; from deaths in extreme high temperatures to changing patterns of infectious diseases.

Friends of the Earth (2010) quoted report from the Met Office indicating that:

- The rise in global surface temperature has averaged more than 0.15°C per decade since the mid-1970s.
- Central England temperatures have increased by 1°C since the 1970s.
- The 10 warmest years on record have occurred since 1997.
- Sea levels around the UK have risen 10 cm since 1900.
- If emissions continue to grow at present rates global temperature could rise as much as 7 °C above pre-industrial temperature by 2100.

The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) discussed some of the current knowledge about observed impacts of climate change on the natural and human environment which is summarised as follows (IPCC, 2007):

- By 2020, between 75 million and 250 million people in Africa are projected to be exposed to increased water stress. Yields from rain-fed agriculture could be reduced by up to 50% in some countries by 2020.
- Freshwater availability in parts of Asia, particularly in large river basins, is projected to decrease. This could adversely affect more than a billion people by 2050.
- In Southern Europe, climate change is projected to cause high temperatures and drought in a region already vulnerable to climate variability, and also reduce water availability, hydropower potential, crop productivity, etc. It is also projected to increase health risks due to heat-waves, and the frequency of wildfires.

Summarily, the effects of climate change are complex and numerous, cataloguing all in this thesis may be unnecessary, within the context of the research scope. However, these effects, as could affect the way buildings are planned and designed are summarised in RIBA (2009a) as:

- *Increased average temperatures*
- *Rising sea levels/flooding*
- *Increased precipitation*
- *More frequent extreme weather events*

Knowledge of this earth threatening challenge has existed since late 19th century, but only became an issue for global concern in the late 20th century following series of UN conferences. Table 5.1 gives a historical overview of the development of the awareness of CO_2 emission and climate change.

Table 5.1: Historical Overview of CO_2 & Climate Change Awareness Agenda

Dates	Events
1896	Svante Arrhenius, Swedish chemist, gives *CO_2 warming theory* due to coal burning
1924	Alfred Lotka, US physicist, speculates *industrial activity will double CO_2 in 500 years*
1949	Guy Callendar, British scientist, *links 10% CO_2 increase from 1850 to 1940 with warming beginning in 1880's*
1958	Keeling, Scripps scientist, *begins CO_2 measurements at Mauna Loa*, 315 ppm and rising
1976	Scientists identify *CFCs, methane, and nitrous oxide* as greenhouse gases
1979	The first World Climate Conference (WCC) held; to assess the state of knowledge of climate change
1985	UNEP, WMO, ISCU form *consensus of international community* about global warming
1988	*Intergovernmental Panel on Climate Change* (IPCC) established to prepare reports for 1992 Rio Earth Summit
1990	Second World Climate Conference (WCC 2) convened in Geneva; received the first report of IPCC
1995	IPCC 2nd Assessment "there is a *discernible human influence* on global climate" The first Conference Of the Parties (COP 1) in Berlin
1997	*Kyoto Protocol* adopted by 160 nations to give binding obligations to limit emissions
2001	IPCC 3rd Assessment "there is *new and stronger evidence* most of warming observed in last 50 years is attributable to human activity"
2002	*Kyoto Protocol ratified* by more than 100 nations – but not by U.S. or Australia; US president G.W. Bush calls for 10 more years of research
2005	*Kyoto Protocol* meeting in Montreal, Canada
2007	IPCC 4th Assessment "*Very likely* that *greenhouse gas forcing has been the dominant cause* of the observed globally averaged temperature increases in the last 50 years"
2009	Copenhagen Accord drafted at COP15 in Copenhagen. This was taken note of by the COP. Countries later submitted emissions reductions pledges or mitigation action pledges, all non-binding.
2010	Cancun Agreements drafted and largely accepted by the COP, at COP16
2011	The Durban Platform for Enhanced Action drafted and accepted by the COP, at COP17
2012	The Doha Amendment to the Kyoto Protocol is adopted by the CMP at CMP8.
2013 (Apr29–May3)	Bonn Climate Change Conference; the second of the Ad-hock Working Group on the Durban Platform for Enhanced Action (ADP 2)

(Adapted from: Houghton, 2007; UNFCCC, 2013a; UNFCCC, 2013b; WMO, n.d)

5.1.1 Political Actions at Addressing Climate Change

This earth threatening challenge created the need for several intergovernmental and non-governmental initiatives aimed at evolving strategies/policies for mitigation and adaptation to climate change. While mitigation policies are designed to reduce greenhouse gas emissions in order to slow down or stop the progression of climate change; the adaptation policy looks at how society can adjust in order to cope with climate changes that are already happening (RIBA, 2009a).

A few of the political actions aimed at addressing the climate change challenge are now discussed.

5.1.1.1 UN Framework Convention on Climate Change (UNFCCC)

In November 1990, the United Nations (UN) initiated the Framework Convention on Climate Change (UNFCCC). By June 1992, at the Rio Earth Summit it was flagged off (Meyer, 2004; UNFCCC, 2013a). The objective was to stabilise the increasing atmospheric greenhouse gas concentration, by the principles of equity and precaution established in international law (Meyer, 2004; UNFCCC, 2013c). The convention reached a consensus that '*a deep overall contraction'* of greenhouse gas emissions from human sources was necessary to achieve the objective of the UNFCCC (Meyer, 2004). The Convention also accepted the Global Commons Institute (GCI) analysis which highlighted the worsening 'expansion and divergence' of global economic development. It showed that the majority of the (countries/individuals) who are most affected by climate change are already impoverished by the economic structures of those who are now responsible for the damaging emissions (Ibid).

5.1.1.2 Contraction and Convergence

To resolve the inequity identified by the UNFCCC, the GCI developed a model for future emission which it called 'Contraction and Convergence' often referred to as 'C&C' (Ibid). The model is the science-based, global climate policy framework to harmonise global greenhouse gas emissions to a safe and sustainable level per person by 2050 (Ibid). It requires that the emissions from industrialised nations (those who generate more emissions) be reduced (contracted) and emissions from all nations converge to an overall target consistent with stabilising greenhouse gas concentrations in the atmosphere. Over time, the emissions would contract and converge to an equal share per person, globally (RIBA, 2009a). This implies that global anthropogenic CO_2 emissions would be significantly reduced (contract) and the per capita emissions would gradually be equalised across countries/regions (converge) (Bohringer and Welsch, 2004; Stott, 2006).

In operating this principle of contraction and convergence, the IPCC proposed that global carbon emissions be reduced by 25%, by 2050 relative to the 1990 emissions levels as a way to achieve contraction. In terms of convergence, it is postulated that each person in the world should have an equal share in the overall carbon emission right by 2050 (Bohringer and Welsch, 2004). This therefore resulted in setting 'global carbon budget', which allocates an entitlement of this carbon budget to each region, country or person. The initial allocation is then subsequently contracted at an agreed pace and time until the allocations per person equals out across the globe (Stott, 2006). See Table 5.2 showing the per capita CO_2 emissions budget.

Table 5.2: Per Capita Emission Budget by Regions (in tons of carbon per capita)

Year	2000	2010	2020	2030	2040	2050
Sub-Saharan Africa (AFR)	0.21	0.20	0.27	0.34	0.41	0.48
China (CHN)	0.72	0.83	0.74	0.66	0.57	0.48
India (IDI)	0.22	0.23	0.29	0.36	0.42	0.48
Latin America and Caribbean (LAM)	0.58	0.60	0.57	0.54	0.51	0.48
Middle East and North Africa (MEA)	0.55	0.52	0.51	0.50	0.49	0.48
North America (NAM)	5.23	5.66	4.36	5.07	1.78	0.48
Pacific OECD (PAO)	2.87	5.26	2.56	1.87	1.18	0.48
Other Pacific Asia (PAS)	0.68	0.73	0.67	0.60	0.54	0.48
Reforming Economic Countries (REC)	1.83	2.10	1.70	1.29	0.89	0.48
Western Europe (WEU)	2.75	5.15	2.48	1.82	1.15	0.48
WORLD	1.07	1.11	0.91	0.75	0.60	0.48

Source: Bohringer and Welsch (2004)

5.1.1.3 The Kyoto Protocol

The Kyoto Protocol is an international framework of governance put in place by the UNFCCC with the prime purpose of regulating levels of greenhouse gas emissions to the atmosphere (Makarenko, 2007). This protocol was adopted in principle and for the first time at the 1997 convention in Kyoto, Japan. It is a treaty of nations that commits its parties (participating nations) to a binding obligation to reduce the emission of greenhouse gases.

The Protocol placed a heavier burden on developed nations (UK being one), under the principle of "common but differentiated responsibilities" (UNFCCC,2013d). By that, the developed nations were to implement and/or further elaborate policies and measures in accordance with her national circumstances, such as:

(i) Enhancement of energy efficiency in relevant sectors of the national economy;
(ii) Protection and enhancement of sinks and reservoirs of greenhouse gases, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation;
(iii) Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies;
(iv) Encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures which limit or reduce emissions of greenhouse gases;
(v) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy; (UNFCCC, 1998)

The Protocol's first commitment period was from 2008 to 2012 and the second commitment period began on 1 January 2013 and will end in 2020

(UNFCCC, 2013e). In the first commitment period, reduction was expected to be at an average level of 95% of 1990 emissions (Adshead, 2011).

5.1.2 Strategies Adopted by the European Union

Following the Kyoto Protocol agreement, the European Union (EU) was expected to reduce her emission level to 92% of the 1990 level by 2012 (Adshead, 2011). However, the EU committed herself to a tougher target; following a strategy it referred to as ’20-20-20’ (RIBA, 2009a; Ibid) which involves:

- ❖ Reducing emissions by 20% of the 1990 levels by 2020
- ❖ Increasing her contribution to renewable energy by 20% of the total energy produced by 2020
- ❖ Reducing energy usage by 20% of the projected 2020 levels, by adopting energy efficiency measures.

The EU, via the European Commission had also issued several mandatory directives which promote energy efficiency and greenhouse gas emissions reduction. Prominent amongst these directives include the Energy Performance of Buildings Directive (EPBD) and the Energy Services Directive (ESD) which were respectively approved by the European Parliament on 16 December 2002 and 5 April 2006 (Anderson, 2006; EN, 2006).

The EPBD was aimed at promoting the improvement of energy performance of buildings (new and existing, domestic and non-domestic) within the EU member states through cost-effective measures by:

1) Establishing a calculation methodology for the energy performance of buildings;
2) Setting a minimum energy performance requirements;
3) Certification of energy performance of buildings at initial occupation and when re-sold or let out;

4) Carrying out regular checks on the efficiency of building services plants (including heating and cooling facilities) (Anderson, 2006; RIBA, 2009a).

The ESD was aimed at setting national indicative energy saving target of 9% by 2017, and requires the public sector to play an exemplary role in meeting the target. It also places obligations on suppliers and distributors of energy to promote energy efficiency and energy metering and billing systems such as could allow consumers make better and informed decisions about their energy usage (RIBA, 2009a).

5.1.3 The UK Climate Change Programmes

By January 1994 The UK had published her first programme on Climate Change which identifies her obligations and commitments to tackling the problems of climate change. There has also been widespread support and commitment from businesses, local authorities, pressure groups and trade unions, as well as the general public in pursuing the climate change mitigation agenda introduced by government (Enviropedia, 2013).

In her commitment to the international mitigation agenda, the UK government sets for herself a more ambitious target than those set by the Kyoto Protocol and even more than those set by the EU (Adshead, 2011). The UK is said to be the first nation worldwide to adopt a legally binding long-term framework to reduce carbon emissions (Ibid). The Energy White Papers of 2003 and 2007 respectively established and reaffirmed an 'aspirational' target referred to as the 'carbon 60' (or C60) target (RIBA, 2009b);

> *"to put ourselves on the path to cut the UK's carbon dioxide emissions by some 60% by about 2050, with real progress by 2020".*

However, under the Climate Change Act 2008, by the advice of the climate change scientists, deeper cuts in emissions will be required, the Government has adopted a more ambitious target of reducing emissions by 80% by 2050 (Ibid), with reference to the 1990 level. The UK government has consequently introduced several programmes and measures designed to both mitigate and adapt to the changing climate. Some of these measures which relate to the built environment are discussed in following sub-sections.

5.1.3.1 The Building Regulations Part L – this stipulates minimum standards of energy efficiency for new buildings and for refurbished existing building. By this, energy use in new homes is to be reduced by 25% from 2010 and 40% by 2013; relative to 2006 standards. It also requires that new domestic and school buildings to be zero carbon by 2016 and other public sector buildings in 2018 and private sector non-domestic in 2019 (BSRIA, 2009; UKGBC, 2013). However, this target has been adjusted under the present (David Cameron's) Government, so that *the zero carbon target for all non-domestic buildings is 2019 and domestic buildings' target remains at 2016* (UKGBC, 2013).

5.1.3.2 The Code for Sustainable Homes – sets broad environmental performance standards relating to energy efficiency, performance levels (1 – 6); setting Code level 3 as the minimum for all publicly funded new housing (RIBA, 2009a).

5.1.3.3 Energy Performance Certificates (EPC) – required to be made available for all new and existing buildings when they are first occupied, or re-sold or rented out. Large public buildings are also expected to visibly display the energy certificates. The EPC is expected to convey information about the property's energy use and typical energy costs, and recommendations about how to reduce energy use and save money (RIBA, 2009a; GOV.UK, 2013a).

5.1.3.4 Climate Change Levy (CCL) – is essentially a tax on fossil fuel use, imposed on business energy users (non-domestic and non-charity organizations). There are 4 groups of the taxable commodities under the CCL which are:

- Electricity;
- Natural gas when supplied by a gas utility;
- Liquid petroleum gas (LPG) and other gaseous hydrocarbons in a liquid state;
- Coal and lignite; coke, and semi-coke of coal or lignite; and petroleum coke (GOV.UK, 2013b).

5.1.3.5 Carbon Emission Reduction Target (CERT) – places obligation on domestic energy suppliers to invest in measures that would reduce greenhouse gas emissions.

5.1.3.6 Warm Front Scheme – aimed at reducing emission and tackling fuel poverty by means of free or subsidised improvements to energy efficiency of homes occupied by low income households (RIBA, 2009a). This scheme ended on January 19, 2013 (GOV.UK, 2013c).

5.1.3.7 The Low Carbon Building Programme – initiated in January 2006 to support the growth of micro-generation industry in the UK. It provides grant support for integration of renewable energy technologies into new and existing buildings (RIBA, 2009a; DECC, 2011).

5.1.3.8 The Carbon Trust – a Trust funded by government to promote energy efficiency in industry, the public sector and non-domestic buildings (RIBA, 2009a). Their activities and services since 2001 when it was founded involve:

- rendering advice to businesses, governments and the public sector on their opportunities in sustainable low carbon energy

- measuring and certifying the environmental footprint of organizations, supply chain and products
- developing and deploying low carbon technologies and solutions, from energy efficiency to renewable power (Carbon Trust, 2013)

5.1.3.9 The Energy Saving Trust Foundation – helps in offering independent advice to communities and households on how to reduce carbon emissions, how to use water more sustainably and how to save money on energy bills (EST, 2013).

5.2 SUSTAINABLE DEVELOPMENT

The concept of sustainable development has been subject to many different interpretations. However, its central theme is a development that tends to balance different, and often competing, needs against an awareness of the environmental, social and economic limitations we face as a society (SDC, 2011a).

SDC (2011b) and Pearce et al. (2012) traced the history of sustainable development to the 1972 UN Conference on the Human Environment held in Stockholm, when it gained its first major world recognition. Although the term was not explicitly referred to, but the international community agreed to the notion, which is now fundamental to sustainable development. That is, the notion that *"both development and the environment, hitherto addressed as separate issues, could be managed in a mutually beneficial way" (Ibid).* SDC (2011b) added that this was also the focus of the Brundtland Commission Report of 1987; 'Our Common Future'.

As at the time of writing this thesis, sustainability has taken a prominent place in every human activity at international and national levels. It so appears as if any form of human endeavour that does not at least consider sustainability is not in tune with modernity. Veon (2004) noted that: "*Today everything is sustainable: sustainable water, sustainable forest, sustainable market, sustainable agriculture, etc."* The author also added that *"Sustainable development has become like a prism. Every time you turn it, you get a different colour".* This implies that sustainable development can be seen in different perspectives, in different fields of development.

According to the 1987 Report of the World Commission on Environment and Development, Sustainable development is concerned about the fast deterioration of the environment and natural resources and the consequences of that deterioration for economic and social development (UNDESA, 1999). In essence, sustainable development also interchangeably used as sustainability (Isiadinso, 2010) calls for a paradigm shift in the way the world manages her activities. This is in consonance with Drexhage and Murphy (2010) who see sustainability as a systemic change which require a revolution in the way the world does business. The 'Brundtland Report, *Our Common Future' proposed a definition for sustainable development, which has become the commonly used definition (*Graham, 2003; Drexhage and Murphy, 2010;). It defines sustainable development as;

> *"Development that meets the needs of the present, without compromising the ability of the future generation to meet their own needs"*

In other words, a development that is geared towards archiving desired result, using minimal resources, such as will not impact negatively on the environment, and so that future generation will be able to carry out similar development under the similar conditions.

5.2.1 The Guiding Principles of Sustainable Development

At the global level, certain action plans or principles were set out to achieve sustainable development. These principles are summarised by Pearce et al. (2012) as follows:

- *Eliminate Poverty and deprivation*
- *Conserve and enhance natural resources*
- *Encapsulate the concepts of economic growth and social and cultural variations into development*
- *Incorporate economic growth and ecological decision-making.*

In the UK, there are indicators to suggest that government, the academia and professional bodies alike are playing front-line roles amongst the nations, in ensuring sustainability in all spheres life, particularly in the built environment. The Government believes that the goal of living within environmental limits and a just society will be achieved by means of a sustainable economy, good governance, and sound science (DEFRA, 2011). To pursue this, the government, through her Department for Environment, Food and Rural Affairs set out her vision and commitments for the sustainable agenda in a five (5) point guiding principles of sustainable development as outlined in figure 5.1.

These principles suggest that government will be very willing to support scientific research that seeks to uncover best practice approach to low carbon building delivery process that ensures efficiency in operation and maintenance. This research therefore, becomes imperative.

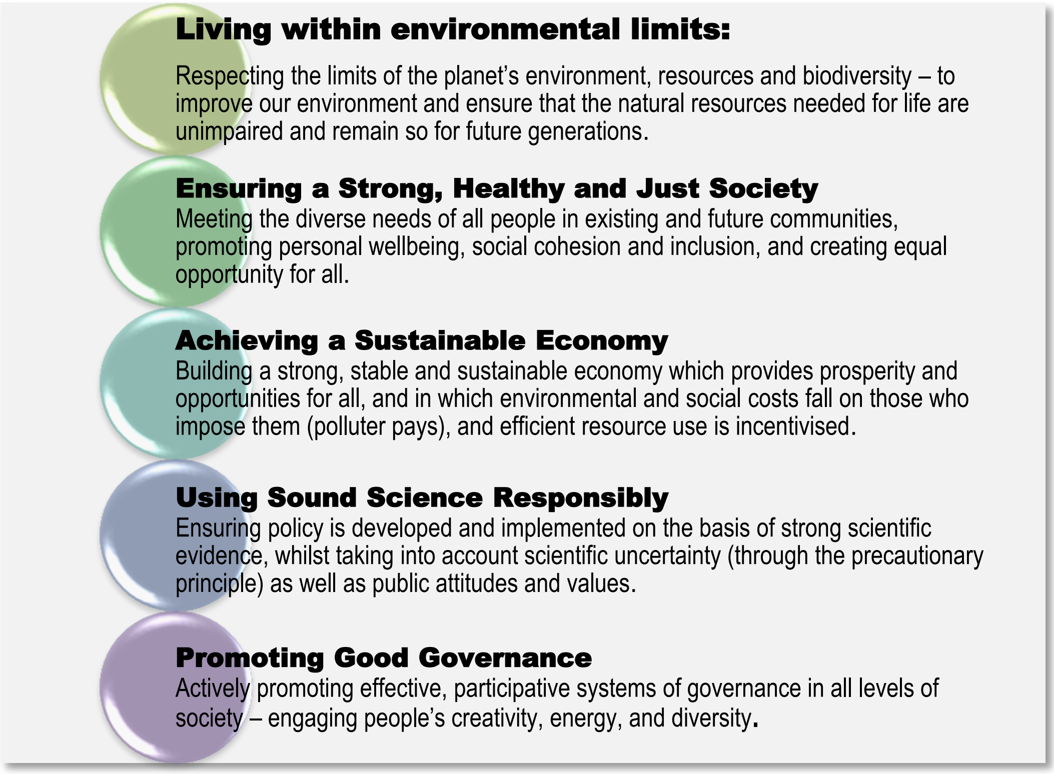


Figure 5.1: The UK Government five guiding principles of sustainable development (***Adapted from***: DEFRA, 2011)

5.2.2 Sustainable Development and Climate Change

Climate Change and Sustainable development share some strong complementary propensities. They are both multi-sectorial, requiring international commitments to address the problems, and the problems are intertwined through economic and technological development networks (Drexhage and Murphy, 2010). Sullivan (2012) also sees climate change (mitigation and adaptation) as one of the drivers for sustainability in the built environment. There is also growing emphasis in literature concerning a two-way relationship between sustainable development and climate change, which may not always be mutually beneficial (Sathaye et al, 2007).

However, in several ways climate change has determined what sustainable approach to development would look like and Climate Change policies are better understood in the context of sustainable development goals (Drexhage and Murphy, 2010). Table 5.3 outlines the approaches to achieving the objectives of the three concerns of sustainable development. These are environmental protection, social equity and economic growth (Graham 2003), commonly referred to in literature as the 'triple bottom line' (Pearce et al., 2012).

Table 5.3: Approaches for Achieving the Goals of Sustainable Development

Environmental Protection	Social Equity	Economic Growth
• Protecting air, water, land ecosystems • Conserving natural resources (fossil fuels) • Preserving animal species and genetic diversity • Protecting the biosphere • Using renewable natural resources • Minimising waste production or disposal • Minimising CO_2 emissions and other pollutants • Maintaining essential ecological processes and life support systems • Pursuing active recycling • Maintaining the integrity of the environment • Preventing global warming • Preventing climate changes	• Improving quality of life for individuals and society as a whole • Alleviating poverty • Achieving satisfaction of human needs • Incorporating cultural data into development • Optimising social benefits • Improving health, comfort and well-being • Having concern for inter-generational equity • Minimizing cultural disruption • Providing education services • Promoting harmony among human beings and between humanity and nature • Understanding the importance of social and cultural capital • Understanding multidisciplinary communities	• Improving economic growth • Reducing energy consumption and cost • Raising real income • Improving productivity • Lowering infrastructure costs • Decreasing environmental damage costs • Reducing water consumption and cost • Decreasing health care costs • Decreasing absenteeism in organizations • Improving return on investments (ROI)

(**Source:** Pearce, Ahn and HanmiGlobal, 2012)

5.2.3 The Concept of Low Carbon building and Low Carbon Technology

It is evident from the foregoing sections that there is global imperative to improve intergenerational quality of life while reducing greenhouse gas emissions. The goal is to keep global warming below its dangerous level, as adduced by Nana and Stokes (2012). In the building industry, this growing concern for the environment has caused governments, practitioners, researchers and manufactures alike to be in constant collaboration to develop new technologies and techniques that will improve the quality of life, reducing economic waste and emitting minimal carbon to the environment. This has resulted in several concepts such as:

- Green buildings and green technologies
- Sustainable buildings and sustainable technologies
- Energy Efficient buildings and energy efficient technologies
- Low carbon buildings and low carbon technologies
- Zero Carbon buildings and zero carbon technologies

Pullen (2013) argued that all of these terms are intended to describe something other than the conventional brick-and-block, energy consuming building'. Some of these terms have been interchangeably used in literature. Most common is green buildings and sustainable buildings (McDonald, 2007; Adshead, 2011; Cassidy and Pinkard, n.d.). Adshead (2011) argued that both are entirely different concepts. She argued that while sustainable building draws its meaning from the Brundtland definition of sustainable development quoted in section 5.2 of this thesis, green building is simply described as a system of creating buildings, using processes that are environmentally responsible and resource efficient throughout the building's life-cycle from siting through to deconstruction.

However, despite their differences, they all emanated in response to saving the environment; reducing emissions of carbon, as discussed in previous sections of this chapter. Apparently, it will not be out of place to describe a green building, sustainable building, low energy building or eco-home as a low carbon building. The concept of Zero carbon is argued by Pullen (2013) to be a Government idea for moving the country towards energy efficiency. By the current definition of 'zero carbon' it excludes carbon from energy use for cooking and electrical appliances (UKGBC, 2013). This therefore still qualifies to be a low carbon building.

So for the purpose of this research, every form of non-conventional technologies in buildings, that are renewable, energy efficient, sustainable or green are considered to be low carbon technologies, and the buildings for which they are applied as Low Carbon buildings.

5.3 TECHNIQUES FOR ACHIEVING LOW CARBON IN BUILDINGS

It has been established in section 5.2.3 that low carbon technologies are responses to the need to design buildings in sympathy with the natural environment; to reduce the anthropogenic influence on global warming. Literature sources indicate that buildings provide better indoor climate when they are designed with consideration to the climatic conditions within the region where the building is to be sited (Szokolay, 2008). The designer's focus usually, is to create comfortable thermal, well lit (luminous) and sound controlled (sonic) environment (Ibid). The author added that comfort conditions can be achieved with the building form, elements and orientation (passive control) and/or by the use of energy (active control). Bokalders and Block (2010) also identified two strategies of ensuring a sustainable energy future; using energy more efficiently and sourcing them from renewable sources. Low carbon principles are built on these premises; encouraging efficient use of energy and the use of natural and renewable sources.

However, efficient use of energy involves designing the fabric of the buildings in a manner that facilitates adaptation to the environment, with minimal energy input. This is a passive control approach to achieving low carbon. The active control methods involve using renewable or energy conserving fittings or systems fitted to or isolated away from the building fabric. Szokolay (2008) posits that designers should aim to ensure that the required indoor conditions are attained with little or no use of energy, other than from ambient or renewable sources. To achieve this, designers are expected to

1) examine the given conditions of the site (local climate, daylight, noise and other site parameters)
2) establish limits of desirable or acceptable indoor conditions (temperature, lighting, noise levels, air quality, etc.)
3) attempt to control these variables by practicable passive means
4) provide for energy-based services (heating, cooling, lighting and sound control) only for the residual control task; such as could not be achieved by passive means

Consequently, many forms of low carbon techniques have been developed to assist building designers meet the challenge of achieving desirable indoor conditions. For the purpose of this study, low carbon technologies have been generally classified as:

- ❖ Renewable Micro-Generation Systems
- ❖ Heating, Ventilation and Air Conditioning (HVAC) Systems
- ❖ Day Lighting Systems
- ❖ Renewable and Environmental Friendly Materials
- ❖ Energy Efficiency and Conservation Systems
- ❖ Bio-diversity Systems
- ❖ Water Management Systems

The section discusses some of these technologies which are commonly used in the UK; including their technical details, performance and applications in buildings. However, it is imperative to firstly discuss some basic outdoor environmental parameters (climate/weather) that influence passive control of indoor environment.

5.3.1 Indoor and Outdoor Environmental Design Parameters

Historically, long before the advent of science and technology man has continued to design and construct buildings to suit their indoor comfort with an intuitive responsiveness towards their outdoor environment (Heywood, 2012). Olgyay (1963) corroborates this, adding that this is '*as old as man himself*'. As early as the 1st Century BC, Vitruvius provided guidelines for the design of houses in different climatic zones of the then Roman Republic; adding that; *"Thus we may amend by art what nature, if left to himself, would mar"* (Hawkes et al, 2002). So a good understanding of the outdoor environmental parameters and how buildings react to these parameters can help designers design buildings that use minimal active control methods (energy) to create the desired indoor environment quality; ensuring energy efficiency by passive (building) control. Heywood (2012) noted that;

> *"Understanding and harnessing the forces of nature in buildings is the key to climate-response architecture".*

This underscores the fact that understanding how the surrounding systems work is the key to a sustainable design, so observing and designing in harmony with the systems will blend rather than destroy the environment (organicarchitect, 2013). Dahl (2010) also argues that architectural sustainability discourse should focus more on ensuring optimum utilisation of adaptation to the outdoor climate, rather than on minimising energy consumption. The 'Vitruvian Tripartite Model of Environment' shown on figure 5.2 establishes the environmental function of architecture in which the form and fabric of the building mediate between the natural environmental climate and the comfort of man in the environment (Hawkes et al, 2002). It portrays architectural elements as the principal component of environmental control in all buildings until the development of new sources of power and power-operated systems (technology) in the 18th and 19th century (Ibid).

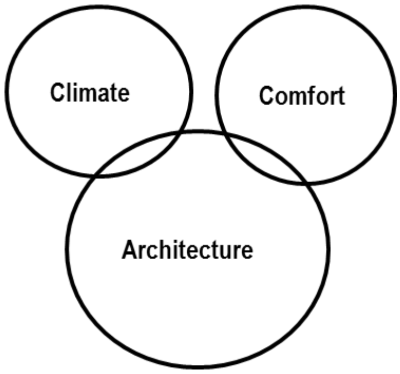


Figure 5.2: The Vitruvian Tripartite Model of Environment
(***Source***: Hawkes et al, 2002)

Consequently, Olgyay (1963) published an improved model using the terminology of the period, showing the fundamental relationship between 'climatology' and 'biology' (climate and human comfort) as now being mediated by the combined process of architecture (passive control) and technology (active control) as shown on figure 5.3.

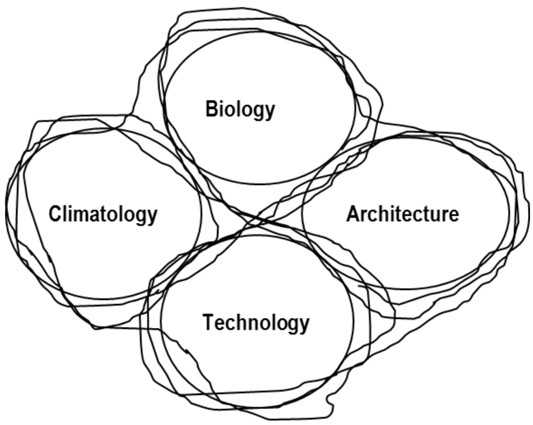


Figure 5.3: Olgyay's Model of Environment Processes – Interlocking Fields of Climatic Balance (***Sources***: Hawkes et al, 2002; Olgyay, 1963)

Similarly, Heywood (2012) demonstrated graphically that although active control method (energy) coupled with occupants behaviour can improve indoor comfort, but that if well-designed, a building that is 'free running' (total unplugged to energy) will provide conditions close to the indoor comfort zone for most or all of the year. This is shown in figure 5.4. The thick black line represents the outdoor climate conditions, while the green box represents the indoor comfort zone. At stage 1, being the earliest stage of design, when environmental design parameters are not yet considered and the building is assumed to be free-running, the result will be that it will gradually settle into a direct response to the outdoor climate. At stage 2 when the proper orientation and form has been considered, a difference between outdoor and indoor climate is noticed, and at stage 3, with a well-designed fabric the indoor climate conditions is greatly improved, close to the indoor comfort zone for most or all of the year. At stage 4, the occupants have a choice to use energy or adapt to the environment by changing their behaviour in terms of activities or types of clothing they wear.

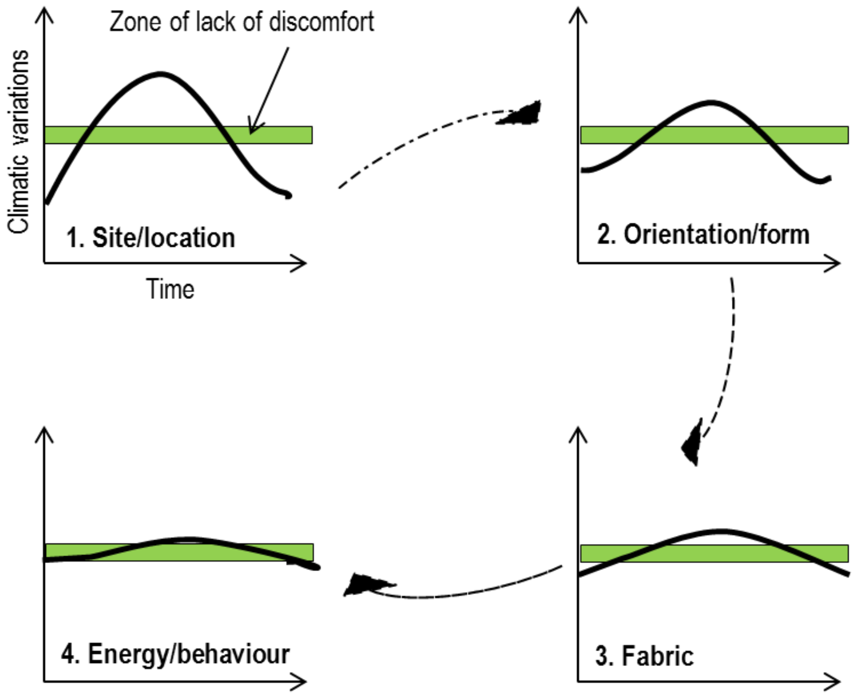


Figure 5.4: Graphic Demonstration of how a Well-designed Free-running Building can perform (***Source***: Heywood, 2012)

Architect Frank Lloyd Wright's philosophy of organic architecture was also hinged on designing with nature; adapting to site, climate and materials. It believes that ‘a building or design must grow, as nature grows, from the inside out (Fred, 2007; Pearson, 2001). Heywood (2012) posits that there are universal rules of nature which govern the way buildings respond to their environment. Some of these rules as well as the acceptable indoor climate are here discussed.

5.3.1.1 *Acceptable Indoor Climate* – It is common knowledge that buildings are designed and constructed to create a comfortable indoor climate within the harsh external (outdoor) climate. So the conditions that ensures comfort or absence of damaging effects on health, and for which at least 80% of occupants of the building are satisfied with is regarded as the acceptable indoor climate (Dahl and Sorensen, 2010). The concept of comfort is also described as a state of ease and satisfaction of bodily wants; where the body not only finds protection against the elements, but also experiences well-being and satisfaction (Ibid). Bokalders and Block (2010) divide indoor comfort into the following categories:

- *Thermal Comfort* – relating to the room temperature, surface temperature, draughts and temperature variations within the room.
- *Relative Humidity* – relates to air moisture levels that are neither too moist nor too dry.
- Air Quality – addresses the freshness, quantity, smell, dust, emissions, etc.
- Sound Quality – relates to sound level, speech comprehension, reverberation time, echo, noise, vibration, etc.
- Light Quality – addresses issues relating to lighting; light strength, colour reproduction, daylight/sun light, glare and reflections
- Electro-Climate – relates to electric and magnetic fields, including static electricity (causing sparks or shocks)

- Ease of Adjustment – has to do with user ability to control the indoor climate; i.e., temperature, ventilation and light.

The indoor climate is therefore a multi-dimensional play of complex inter-acting factors, including natural and artificial conditions.

Comfort Zone is referred to as the range of acceptable thermal comfort conditions (Konya and Vandenberg, 2011; Szokolay, 2008). The human body is said to have reasonable capacity for thermal well-being within a range of -20°C to about 40^{oC}, because of other factors that affects the hot/cold sensation of the body, besides the air temperature (Dahl and Sorensen, 2010). Such factors include: relative humidity, wind velocity, heat radiation, the body's movement and the thermal quality of clothing over the body. Olgyay (1963) proposed a design aid schematic procedure based on a bioclimatic chart, which will aid designers to adapt the design of buildings to human requirements and conditions as shown on figure 5.5.

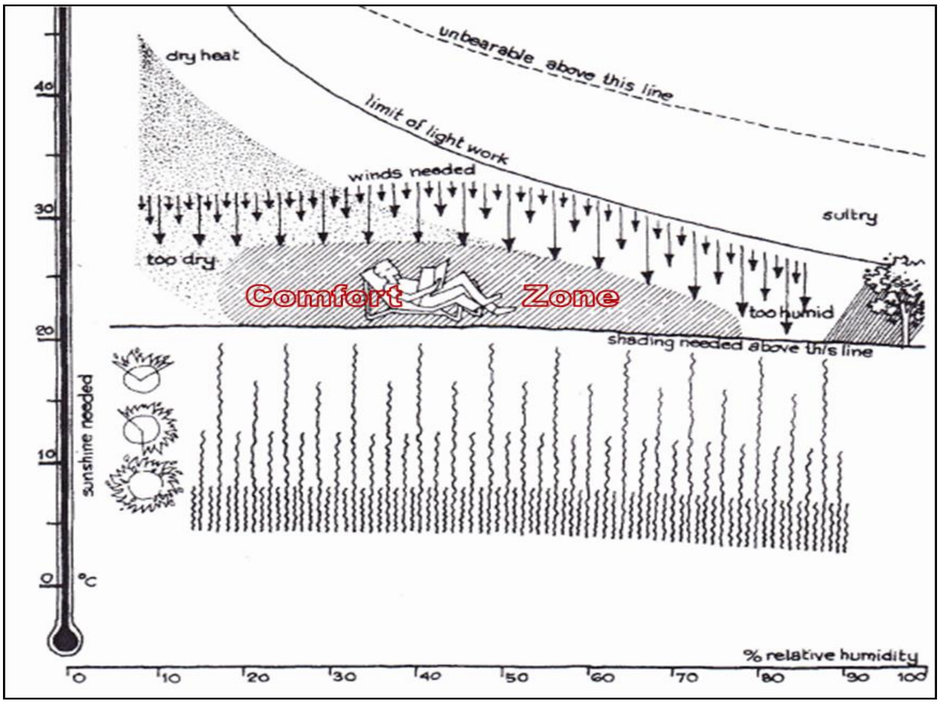


Figure 5.5: Schematic diagram of Victor Olgyay's Bioclimatic Chart
(***Sources***: Konya and Vandenberg, 2011)

Olgyay's consideration was based on the fact that comfort is principally dependent on the air temperature (dry-bulb temperature) and relative humidity. From the chart, comfort can be attained at about 21°C (70°F) provided relative humidity is between 20% and about 75%; also at a temperature of between 21°C and 27°C at a relative humidity level of between 20 and 50%. Temperature over 40°C with humidity level over 60% will be unbearable. Dahl and Sorensen (2010) considered the acceptable indoor thermal comfort level to be 22°C $\pm$2°C. The author also noted that the human body can also tolerate a relative humidity of between 20 – 80% without any noticeable discomfort. However, Comfort is best achieved at 40 – 60% relative humidity (Bokalders and Block, 2010). Heywood (2012) suggested that indoor room temperature should be maintained at 18 – 25°C in winter and 20 – 27°C in summer, and that people could find their comfort by what they are doing and what they are wearing.

5.3.1.2 Harnessing the Sun for temperature and lighting – The energy input from the sun is one of the determining factors for climate (Szokolay, 2008). Scientific discoveries have made it easier for its pattern of behaviour and the effects on buildings to be predictable and thus harnessed for human comfort.

Firstly, the sun produces both light energy and heat energy; giving brightness and warmth to the environment. The light energy is often referred to as *'natural light'*, having two components; the direct beam of the sun, referred to as *'sunlight'* and the diffused light from the sky or cloud, referred to as *'daylight'* (Szokolay, 2008) or skylight (Hall, 2008). However, these constitute the basic component of daylight (Ibid). This interchangeable use is also adopted in this thesis. When the direct sun beam reaches on any surface through radiation, heat is generated (Discovery.com, 2011).

The amount of radiant energy (solar radiation) or sunlight that strikes any particular part of the building changes, due to the changing position of the sun in the sky (Givoni, 1998), resulting from the earth's daily rotation and annual revolution. The daily and annual patterns are predictable, so the daily and annual effects of the sun on buildings can also be predictable and such predictions could help in the way buildings are designed and orientated for optimum indoor comfort. It is also important to be reminded that the sun rises from the east and sets at the west. In the northern hemisphere, after rising, the sun transverses across the sky in the south, while reverse is the case in the southern hemisphere. In the mid-latitudes of the northern hemisphere, the sun rises south of east during winter and from north of east during summer (Heywood, 2012) as shown in figure 5.6 below.

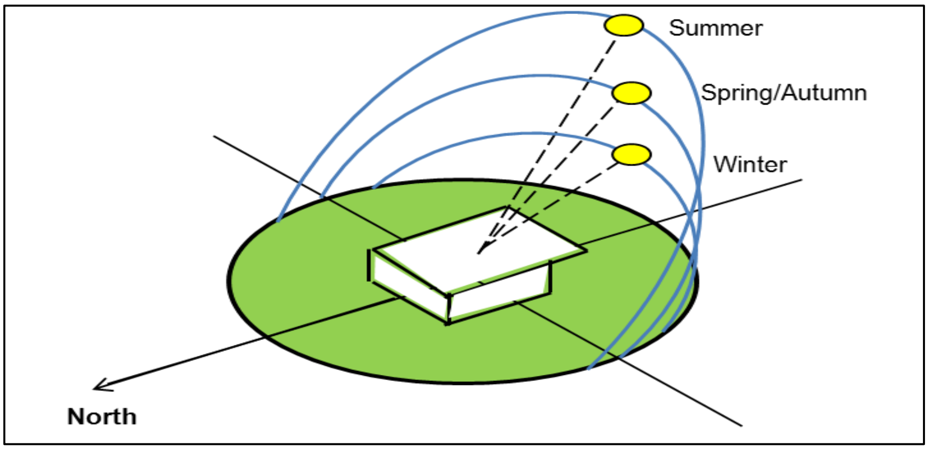


Figure 5.6: Daily and Annual Sun Pattern across the sky in the Northern Hemisphere (**Source:** Heywood, 2012)

What this implies is that in the UK for example, is that it is only during the summer months that the north façade of a building might be very briefly exposed to the warmth of the rising sun, but the south façade receives warmth all through the year. So the south face of the buildings in this region will be the best side from which the any benefit or hazards (e.g. glare) from the sun can best be tapped or managed.

The incident angle of the sun to the horizontal plan of the earth or objects on the earth varies with latitudes (Givoni, 1998) and with time and season. Heywood (2012) indicates that in London for example, the maximum angle of the sun at mid-day is about 62° in summer June) and about 15° in winter (December). Figure 5.7 shows how the hot summer sun is prevented from getting into the building to cause overheating and during the winter when the sun's incident angle is lower, it is allowed to penetrate deep into the space to warm up the space, thereby reducing need for active control cooling energy in summer and heating energy in winter.

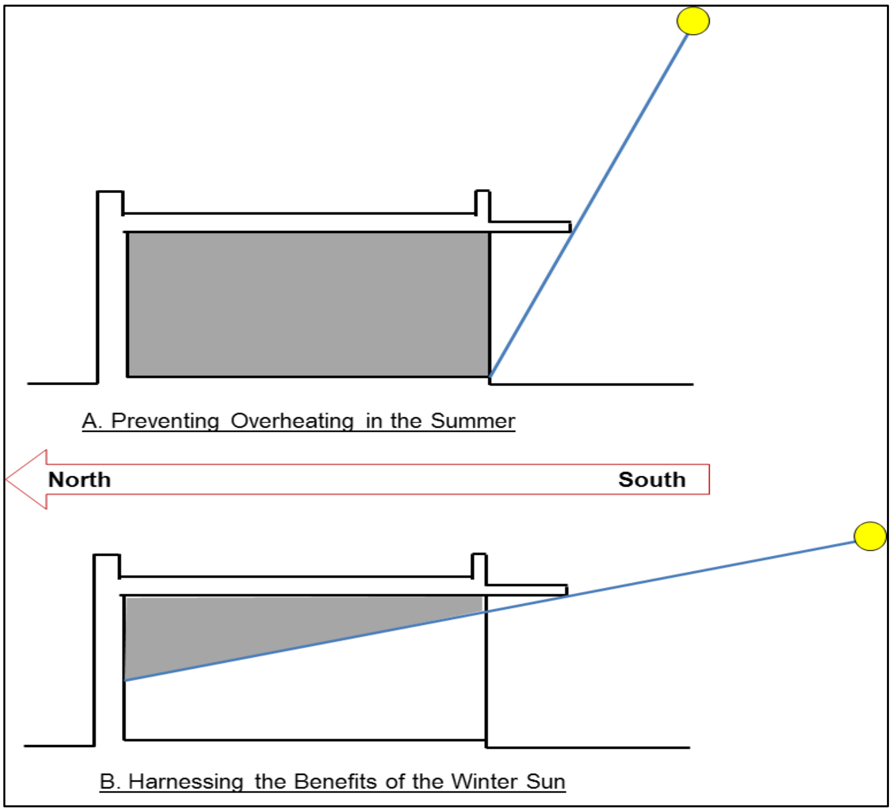


Figure 5.7: Preventing Summer Overheat and harnessing the power of the winter Sun (**Source:** Heywood, 2012)

It is also helpful for designers to note that in the mornings and evenings, the sun is low in the sky in the east and west respectively. So the low incident sun can also penetrate deeper into the interior through the openings (windows, curtain walls, etc.). The west façades are also exposed longer to intense radiation (Heywood, 2012). Therefore ability to understand basic solar geometry is a key skill for LCB designers

5.3.1.3 *Harnessing Wind and Air Movement* – Air movement affects body cooling; it does not necessarily reduce the air temperature, but it increases the rate of evaporation, thus enhancing heat loss by convection from the body and resulting to a cooling sensation on the body (Hawkes et al, 2002; Olgyay, 1963). Hence, indoor comfort level can be improved upon by ensuring good air flow within the building; as the velocity of air flow increases, the upper comfort limit is raised, though the rise slows as higher temperatures are reached (Ibid). This implies that increased wind velocity could restore comfort even when temperature and humidity are outside the comfort zone.

Wind directions and their characteristics, like sun patterns are also predictable. The earth is divided into 6 parts by meteorological scientists for the purpose of describing the types of wind on a global perspective based on their pattern and direction of flow (ThinkQuest, 2000). The types are basically three, acting on each of the earth's hemisphere as described in figure 5.8.

1) Tradewinds – acting north and south, within the region close to the equator
2) Westerlies – acting north and south of the mid-latitudes and
3) Polar Easterlies – acting at the Polar Regions, north and south.

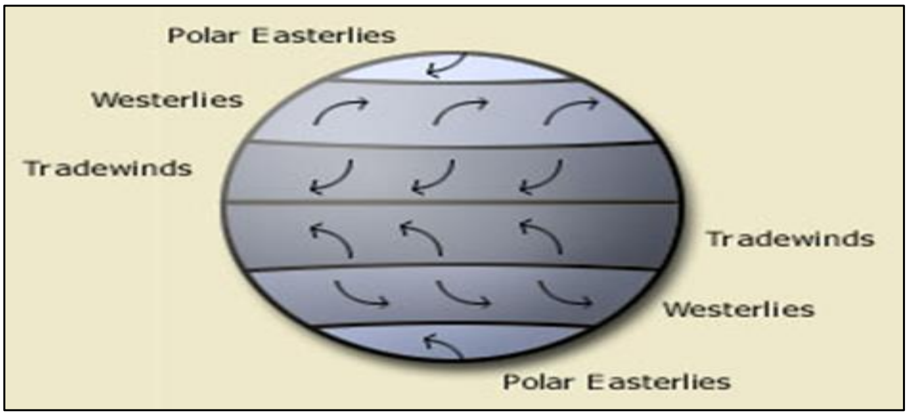


Figure 5.7: Meteorological Global Classification of Winds
(**Source:** ThinkQuest, 2000)

Local wind data is also available for particular regions/zones. Designers could take advantage of these local meteorological data.

Wind could often be draughty, dusty and sometimes destructive and as such times, undesirable. Olgyay (1963) argued that the desirable range of wind speed is limited by its impact on man. Table 5.4 explains Olgyay's views of the impact of range of wind speed on man.

Table 5.4: Impacts of Wind Speed on Man

Wind Speed (mpm)	Probable Impact
Up to 15.24	Unnoticed
15.24 – 30.48	Pleasant
30.48 – 60.96	Generally pleasant but causing a constant awareness of air movement
60.96 – 91.44	From slightly draughty to annoyingly draughty
Above 91.44	Requires corrective measures if work and health are to be kept in high efficiency

(**Adapted from**: Olgyay, 1963)

Designers need also be aware that wind direction and intensity are altered or influenced by topography and other features like trees, hedges, fences, garden walls, water bodies, other contiguous structures, etc. The wind direction is often diverted in both horizontal and vertical directions by a hill, resulting in higher speeds near the hilltop on the windward side lesser at the top leeward side (Olgyay, 163). Heywood (2012) noted that in valleys and mountainous terrains, wind patterns often change between day and night.

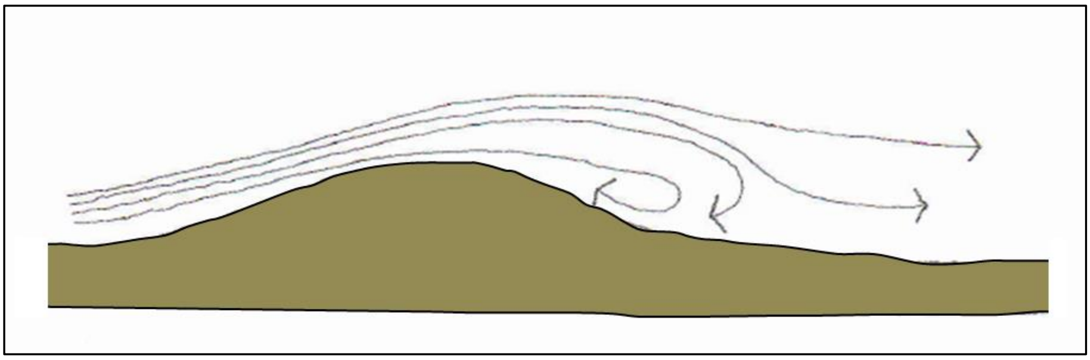


Figure 5.8: Wind Behaviour over Valleys and Mountainous Terrains
(**Source:** Heywood, 2012)

It is of interest to note that planting trees on the windward side of the building could act as a windbreaker or buffer to the building and is capable of reducing the wind speed by half. In temperate and cold climates this could result in 15 – 20% energy savings, because cooling of the building is reduced (Ibid). The author recommends a distance of 5 times the tree height between the building and the tree as being appropriate for effectiveness of the strategy, as illustrated in figure 5.9.

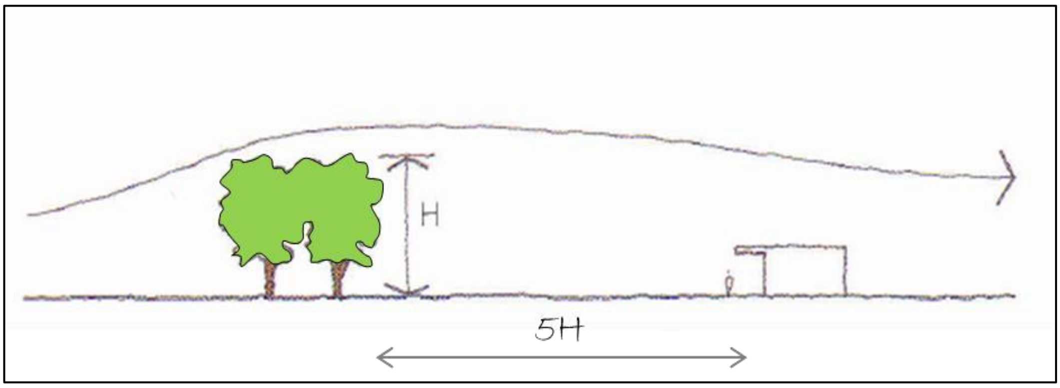


Figure 5.8: Using Trees as Windbreakers (**Source:** Heywood, 2012)

Siting a building at the direction of airflow over water bodies like artificial or natural lakes, rivers or sea will influence the air temperature and humidity (Ibid). This would work best in warm-dry climates. However, care should be taken in regions of high humidity, because while temperature decreases, humidity is likely to increase.

Air movement or exchange is a vital requirement for buildings; it provides oxygen for breathing, dilutes and displaces polluted air such as body odours, CO2 from human breath, fumes from cooking and odours from the toilets. Air exchange also aids in removing moist air thus avoiding condensation. It also helps to keep buildings cool by removing excess heat (Hall, 2008) as earlier discussed in preceding paragraphs. One disadvantage of air exchange is that it removes warm air needed indoors during the cool seasons, thus resulting in what is referred to as heat-loss (Ibid).

Air exchange is achieved through thoughtfully provided ventilation systems and sometimes through unintended avoidable means referred to as infiltration through cracks, construction joints, etc.

5.3.1.4 _Harnessing Humidity and Precipitation_ – The humidity of the outdoor climate in the form of precipitation; rain or snow in an architectural context presents itself as a challenge as well as an inspiration (Dahl, 2010b). Givoni (1998) posits that low humidity could cause irritation; dry skin, crack on lips, etc., and that too high humidity could indirectly affect human comfort and physiology. Konya and Vandenberg (2011) describes humidity as the water vapour content of the atmosphere gained as a result of evaporation from exposed water bodies, moist ground and from plant transpiration. Relative humidity is the ratio of the actual moisture in a given volume of air to the maximum moisture capacity at that temperature (Ibid). It is usually given as a percentage. If for instance the amount of water vapour in the air is the maximum capacity the air could hold at that temperature, then the humidity is 100%. The vapour pressure, which is that part of the total atmospheric pressure which is solely caused by water vapour, affects the rate of evaporation from the human body. This is influenced by the relative humidity. When a local area of the atmosphere becomes saturated with water vapour (by evaporation and cooling) so that water condenses, it then precipitates (falls under gravity) in the form of rain, snow, hail, etc. (AMS, 2009). When water evaporates from the sea, rivers, lakes and other exposed water bodies, moist ground and plants, it is cleansed and recirculated as precipitation that falls back, in an endless 'water cycle' or 'hydrological cycle' as referred to by Szokolay (2008), illustrated in figure 5.9.

The form, intensity, amount and occurring intervals of precipitation depend on the general global climate systems, difference in climatic belts and the particular regional geographic circumstances (Sorensen, 2010). Therefore a good understanding of the precipitation characteristics of the region will assist designers in creating appropriate roof and façade. Sustainable practices also encourage the collection and reuse of the precipitated water – 'water management systems'.

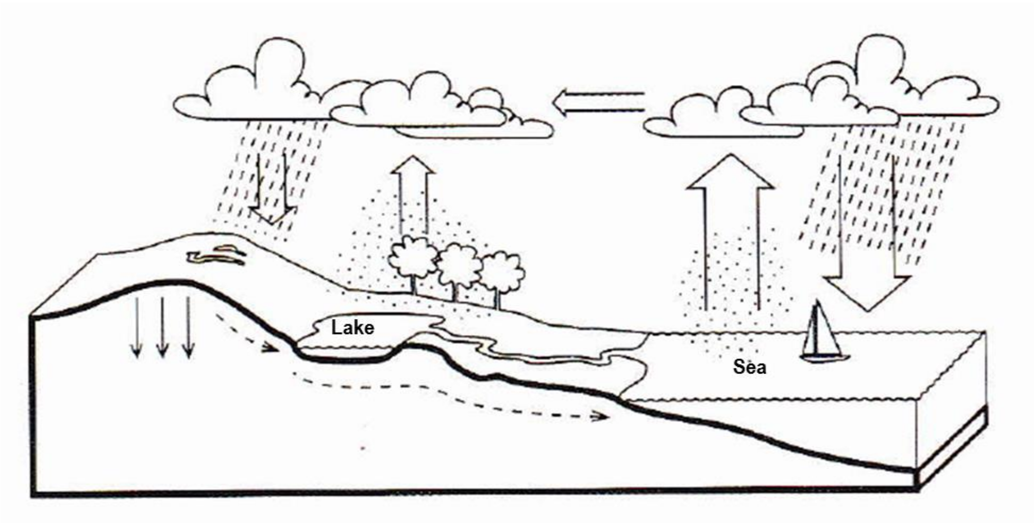


Figure 5.9: The Water Cycle (**Source:** Sorensen, 2010)

Humidity is also supplied indoors through perspiration from the human body. Sorensen (2010) conjectured that at normal use, a typical house for a family of four will supply humid air of up to about 10 litres to the house in one day. High humidity is a strain to the indoor environment; it could cause condensation and dampness in buildings, thereby resulting to speedy deterioration of the element/component so affected (Ibid). Moisture deposited on surfaces of materials due to condensation could lead to growth of algae or fungi attacks, which may constitute risk to human health and well-being (Ibid). On some materials it could cause corrosion and deformation. So it is important for spaces to be adequately ventilated to facilitate air exchange between the indoor and outdoor to keep the indoor moisture content at a reasonable level.

Figure 5.10 is an excerpts of the Mollier Diagram as presented by Sorensen (2010). The diagram shows the relationship between the water vapour content and relative humidity of the air and temperature. Building designers and engineers have employed it in the design of spaces (particularly wet spaces) in buildings. If rightly employed in the design of the building fabric (passive control), the use of electro-mechanical ventilators/extractors (active control) will be highly minimised and thereby ensuring energy efficiency.

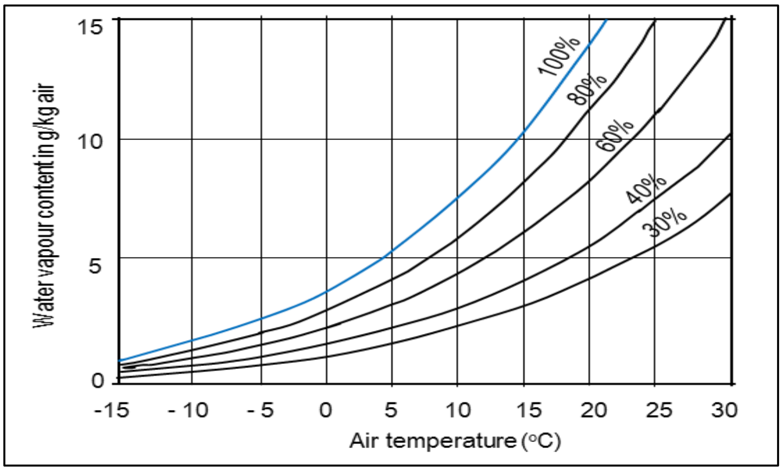


Figure 5.10: The Mollier (Water Vapour) Diagram (**Source:** Sorensen, 2010)

Figure 5.11 explains how the inter-relationship between the curves in figure 5.10 is interpreted to aid design decisions. In fig. A, at a room temperature of 25°C with relative humidity of 80%, air will condense on surfaces with temperature ≤ 21°C. This explains why condensation occur more in wet spaces like the bathroom. Room temperature may be at 18 -20°C and humidity level of 50 – 60%, with steam coming out of the hot-bath, humidity and temperature of the air increase to about 80% and 25°C respectively, on contact with the walls, room air condenses. Similarly, in fig. B, it shows that at 20°C room temperature and a relative humidity of 60%, condensation will occur on surfaces that are 12°C or less. Fig. C explains that condensation will occur on surfaces that are at a temperature of 6°C or less if the air temperature increases to 20°C at a humidity level of 40%. Also for rooms with air temperature as low as 18oC with 30% relative humidity (e.g. dry storage spaces), condensation is likely to occur on surface below freezing point.

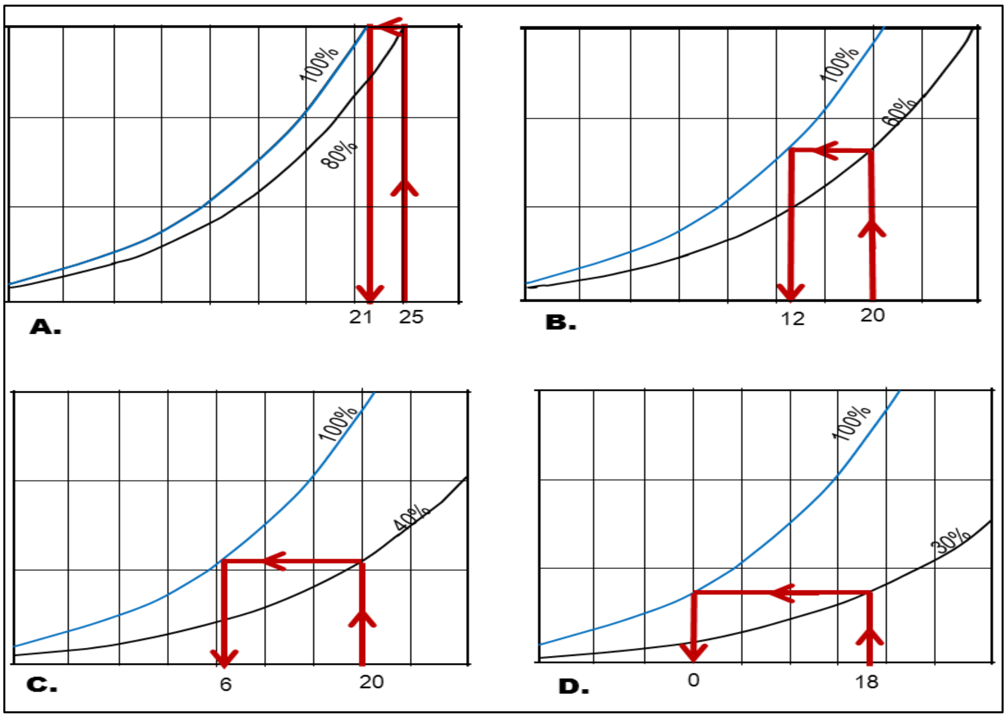


Figure 5.11: The Mollier Diagram Explained (**Source:** Sorensen, 2010)

5.3.1.5 <u>Fabric First Approach</u> – Buildings experience heat-loss and heat-gain through their fabric; walls, roofs and floors, including openings like doors and windows and infiltration through cracks and construction joints that are not air tight (Heywood, 2012) as shown in figure 5.12. These occur through a combination of some heat transfer mechanisms; conduction through the building elements like floors, walls and roofs, through convection and radiation across openings like windows, doors and cavities (Hall, 2008).

Heywood (2012) showed how heat-loss and heat-gain occur in various elements of the building fabric for a typical building in temperate region as illustrated in figure 5.12. RIBA (2009c) suggested that the amount of heat-losses through the fabric is dependent on: the area of the element, the amount of insulation (usually expressed as thermal transmittance or U-value) of the particular element and the indoor and outdoor temperature difference.

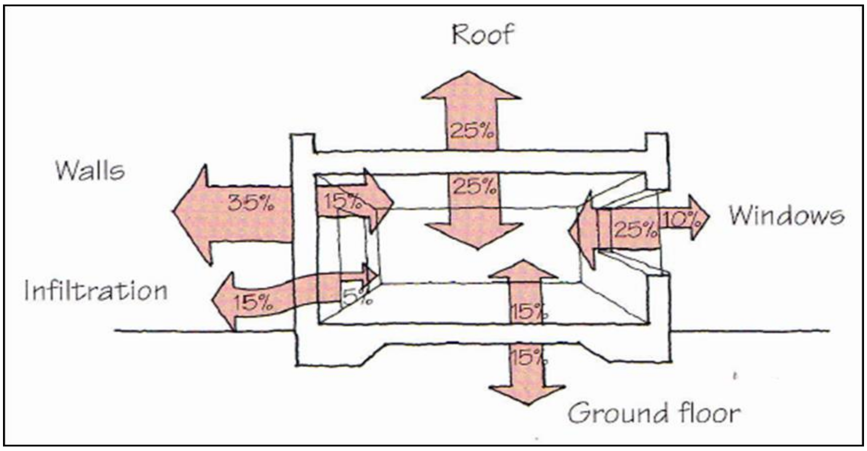


Figure 5.12: How Heat is typically lost and gained in Temperate Climates
(**Source:** Heywood, 2012)

It could therefore be concluded that if the building fabric is appropriately designed; backed by this understanding and with the right solution, it is possible to reduce the rate of heat losses and thereby reduce dependence on active energy sources.

Taylor et al (2012) posits the UK governments strategy to meeting the 2016 zero carbon target for homes was based upon 'fabric first' principles in design. It also commonly believed that the 'fabric first' approach is the most cost effective way to meeting green standards, because it is capable of elimiting the use of active control devices, including the renewables (Wilding, 2013). With this understanding, the UK Energy Saving Trust (EST) has published documents encouraging new and refurbished building designers to focus first on the building fabric, then on services improvements as a means of increasing energy performance in the domestic sector (EST, 2010). The document encourages *'pushing fabric to the limit of what is achievable'*. It also specified i) improving fabric U-values, ii) reducing the effects of thermal bridging and iii) ensuring effective airtightness and ventilation strategies as means by which the building fabric can be improved upon in order to reduce heat losses and ensure energy efficiency in homes.

Improving Fabric U-value – EST (2010) recommends improvements to standards stipulated in the 2006 Building Regulations with respect to the thermal transmittance of floors, walls, roofs, windows and doors. It recommends that wall cavities be made wider to achieve a lower thermal transmittance and that careful consideration needs be given to how the insulation is installed and how it is bridged. For floors it recommends that rather than increase the thickness of insulation, it will be best to select an insulation material with significant thermal performance. It argued that in theory there are limits as to how much thick floor insulation can be, but in practical terms, using progressively thicker insulation could result in diminishing returns in terms of performance, at additional construction cost. Similar choice of appropriate insulating material with significant thermal performance is advocated for roof lofts. For windows, besides the provision of daylight it also allows in heat energy as well as heat loss. The solar heat gain could be influenced by appropriate orientation as discussed in section 5.3.1.2.

Reducing Thermal Bridging – A thermal bridge is described to be an area of reduced insulation through which the rate of heat loss is greater than through the adjoining insulated area (EST, 2010). This could be interpreted to mean a part of an element (floor, wall, roof, door and windows) which has a greater

U-value than the element itself. For instance, the mortar joint in light weight block wall, or the steel member used as lintel over window and door openings in the wall, timber studs used to support the construction of openings in walls, etc. EST (2010) encourages efforts at reducing the effect of thermal bridging as one other way of reducing heat loss.

Improving Airtightness and ventilation – As discussed in section 5.3.1.3, warm air is lost to the cold outdoor environment is through infiltration and ventilation systems. So the Energy Saving Trust recommends that good airtightness coupled with appropriate ventilation strategy will always produce the most energy efficient outcome. EST (2010) recommends that strategic decisions about how to build in airtightness be made early in the initial design stage and built correctly on site as well. This means that it is important to identify the routes through which infiltration is possible to occur. Hall (2008) identified such possible routes as:

- Porous building materials
- Cracks around service entries
- Cracks in the joints between window/door frames and the wall
- Door and window opening
- Suspended timber ground floors
- Floor to wall joints
- Ventilated cavity routes around dry lining plasterboard
- Open flues and chimneys
- Openings for wall extractor fans
- Gaps between and around curtain walling elements.

EST (2010) also identified that with different trades and sub-contractors working on a project, it will be best for one person to have the responsibility for ensuring that the provisions for airtightness are rightly delivered.

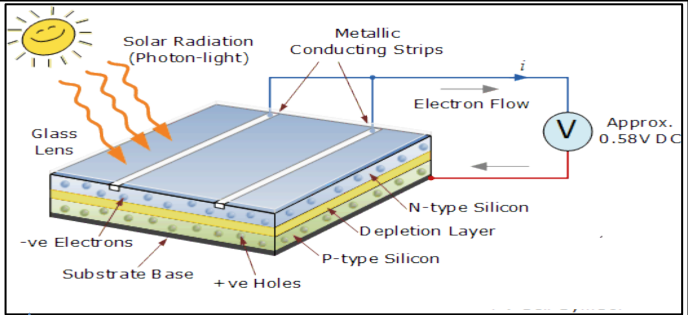
5.3.2 Renewable Micro-Generation Systems

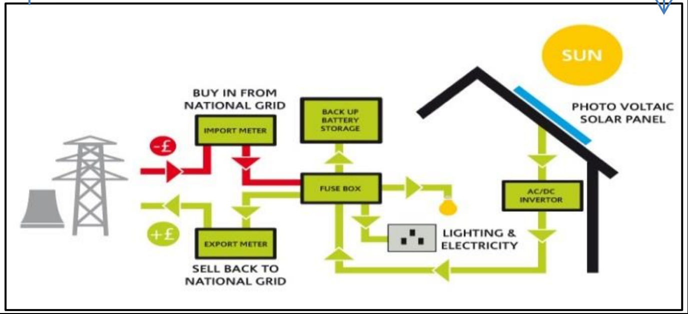
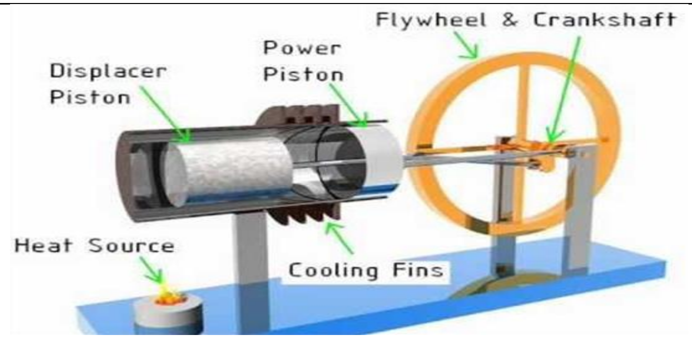
Micro-generation has been described as the production of electricity and/or heating in small scale by individual households and small businesses to meet their own needs, as alternatives or supplements to the traditional grid energy supply (University of Southampton, 2013; Micropower Council, 2010); usually from low carbon or renewable sources (Moren, 2011; Bergman et al, 2009). Pullen (2013) describes it as 'domestic scale renewable energy). Micro-generation is also defined under the *Energy Act 2004* as generating up to 50kWs micro-electricity and up to 45kWth heat, whereas the *Green Energy Act 2009* assumes 'up to 50kW for electricity and up to 300kWth for heat Moren (2011).

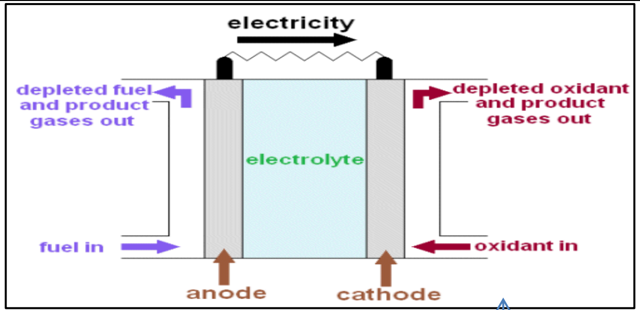
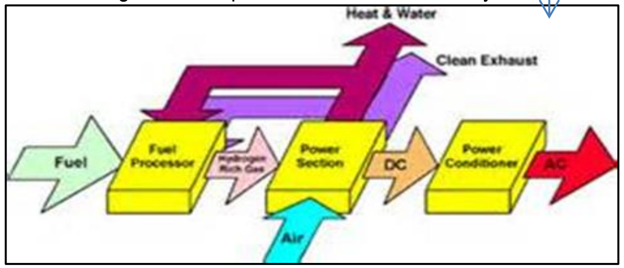
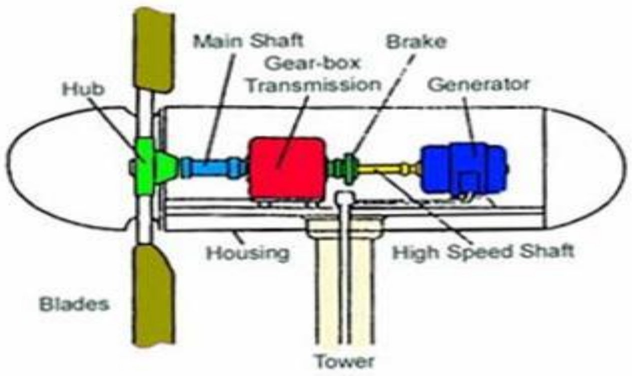
With the increasing emphasis on saving the environment and widespread patronage of energy based research, a number of low carbon and renewable micro-generation technologies have been developed and are still being developed. Some of these technologies include: solar photo-voltaic (PV) panels, solar thermal fat plates, solar collectors, combined heat and power (CHP) engines, micro-wind turbines, small hydro turbines, biomass systems, heat pumps, etc.

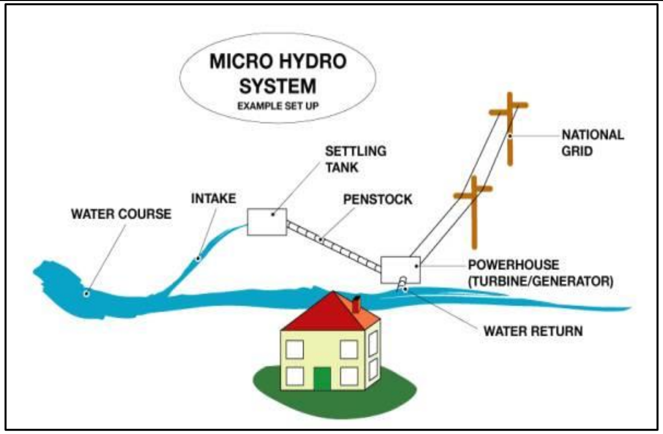
However, in this thesis, the micro-generation systems that are designed for heating and/or cooling are classified under the HVAC systems. So the renewable micro-generation technologies discussed are those that generate electric power or combine both power and heat in one system. Some examples are further discussed on table 5.4.

Table 5.4: Renewable Micro-generation Technologies

<table>
<tr><th>S/no.</th><th>Technology</th><th colspan="2">Description</th><th>Applications/Impact on Energy Demand/Environment</th></tr>
<tr><td>1</td><td>Solar PV Panels</td><td>

Typical PV Cell Construction How the System Works

</td><td>- Solar PV panels generate DC (direct current) electricity, using the sun light energy without any mechanical or moving parts.
- The DC is converted to alternating current (AC) by an inverter and stored in a backup storage battery system (for off-grid systems) and/or export meter.
- The size of a solar PV panels system is typically indicated in kWp Kilowatt-peak units; this indicates the maximum power it produces as recorded under laboratory conditions.
- An average domestic system in the UK is 2.2kWp
- A solar PV panel is constructed using individual solar cells made from layers of silicon semi-conductor materials; N-type (-ve) upper layer and the P-type (+ve) lower layer.
- When assembled together with metallic conductors, the silicon arrangement becomes a light sensitive PN-junction semi-conductor.
- Typical cell measures 100m^2 and produces about 0.58 volts DC. Several cells are grouped together to form a PV panel, to required size.</td><td>- For optimum performance, PVs are best situated to face southwards and unobstructed from the sun rays by trees or adjoining structures; usually on the roof tops, walls and undeveloped land spaces.
- The electricity generated from this natural source is used in the building, thereby reducing bills on energy, and/or exported into the national grid to earn money.
- By reducing need for energy from the grid, there is a reduction in CO2 that would have been emitted from production and supply of energy need of the building.
- The absence of mechanical or moving part in the energy conversion system reduces O&M cost greatly.
- However, PV surfaces require periodic cleaning.
- The efficiency of solar panels could drop with increase temperature, so it is advisable to install them with air gaps behind them to ensure good air circulation.</td></tr>
<tr><td></td><td></td><td colspan="3">Sources: Storr, 2012; Anicca Digital, 2010; Hall, 2008</td></tr>
<tr><td>2</td><td>Combined Heat and Power (CHP) Stirling Engine</td><td>
</td><td>- Often referred to as micro-CHP or cogeneration; it simultaneously produces both electricity and heat in the form of hot water or steam.
- It uses external combustion engine system to generate electricity and heat is recovered from the exhaust gases and cooling system.
- The gas is alternately heated and cooled in the combustion chamber. When heated, the gas expands and caused mechanical movement of the crankshaft which is connected to the displacer piston system. Heat is recovered from the motor's cooling water system and exhaust gases</td><td>- Used in small commercial and domestic buildings
- It has high energy conversion efficiency and low noise level and cleaner waste gases.
- It is fuelled by gas from renewable sources.
- reduces the primary energy consumption, compared to other independent generation of the heat and power by utilising the exhaust heat
- The outputs are about 1kWe and 8kW heat
- Its overall efficiency is > 80%, but has relatively high installation cost.
- Life expectancy is 15yrs or more.</td></tr>
<tr><td></td><td></td><td colspan="3">Sources: Pullen, 2013; Popscreen Inc., 2013; Bokalders and Block, 2010; Kuosa et al, 2007; CIBSE TM38, 2006; Kong et al, 2004;</td></tr>
</table>

3	**Fuel Cells**	 A typical cell of the fuel cells system Diagramatic expression of the fuel cells system 	- A device that involves reaction of two chemicals, usually hydrogen and oxygen, to produce electricity, heat and waste by-product – water. A form of CHP system. - Operates like a battery, but does not run down. - Consists of 2 metallic electrodes; anode and cathode, between which is an electrolyte which provides medium for the flow of hydrogen fuel protons from the anode to the cathode to produce direct current (DC) electricity. At the cathode, air is introduced as an oxidant which reacts with the protons and electrons to form water which drains as by-products. The process generates heat which is recovered and used for heating. - There are various types of electrolytes commonly used, which gives the name of the fuel cells. (Alkali fuel cells, Molten carbonate fuel cells -MCFC, Phosphoric acid fuel cells –PAFC, Proton exchange membrane –PEM fuel cells, Solid oxide fuel cells –SOFC, Polymer electrolyte membrane (PEM) fuel cells.	- Fuel cells can be sized to meet energy needs for a range of applications; from laptop computers to utility power plants for a single bldg. and up to a community. - Inverters are needed to convert the DC to AC (alternating current) - Generates electricity with very little pollution, by-product produced is water; a harmless substance - Vibration free, noiseless and no moving parts, so O&M cost is minimal. - Have > 2x the efficiency of traditional combustion technologies. - Life expectancy – 20yrs, but internal cells may need replacing every 5 – 6 yrs. - Fuel cells technology is still being developed; it is not as common as other renewable micro-generation systems in the UK.
		Sources: NIBS, 2013; Pullen, 2013; Hall, 2008; Smithsonian Institution, 2008		
4	**Micro-Wind Turbines**	 Internal Structure of a typical wind turbine	- Wind turbines use blades to build up a kinetic energy within an air stream, converting it into rotational movement which turns an electric generator mounted in a housing at the top of the mast. - The rotational movement of the blades turns the main shaft connected to the gearbox which increases the rotation speed of the generator. The rotational energy is then converted in the generator to electric energy as a result of the magnetic fields created by the rotation. - The output goes into a transformer which converts the voltage generated to the required voltage. - It is also popularly known as Wind Power. When a number of wind turbines are grouped together, it is	- Wind generated electricity is devoid of any harmful pollutants. - Cuts down on electricity bills once installed, it also exports energy to the grid, for which the householder will be paid. - Excess could be stored in a battery system and used on wind free days. - Building mounted systems are generally less expensive than the free standing pole mounted domestic turbines, and depending on the size also. E.g., 1kW micro-wind system costs £2000, while 2.5kW pole-mounted system costs £15000 and 6kW similar system cost £22000. - Life expectancy is 20yrs or more if well cared for.

			referred to as a wind farm. - Micro-wind turbines, also called small-scale wind turbines are usually not more than 6kW. - They could be mounted on roof tops or on free standing poles.	- O&M requirements are not as good as PVs, but better than the conventional power generating systems. - Requires maintenance checks every few years, the inverter may need to be replaced at some stage. For off-grid systems, batteries may also need to be replaced every 6 – 10 yrs.
		Sources: Energy Saving Trust, 2013; RUC, 2013; Clearlyahead.com, 2009; Hall, 2008		
5	**Small-Scale Hydropower**		- Hydropower is the electricity generated by converting the potential energy and some kinetic energy of flowing or running water to electric energy. - Hydropower is not a new technology. The first hydropower plant was commissioned in 1882 in the US. However, it is a renewable technology, and have been so developed in recent years that it could be used to provide power for a single dwelling and for several communities and cities, depending on size. - Small hydro is typically developed to serve a small community or industrial plant. The definition of a small hydro project varies but a capacity of 10 megawatts (MW) is generally accepted as the upper limit of what can be termed small hydro. This may be stretched up to 30 MW in the United States, and 50 MW in Canada - Small hydro can be further subdivided into mini hydro, for plants generating less than 1,000 kW, and micro hydro for those generating less than 100 kW. - The turbine uses the same principle as the wind turbine to generate electricity and export into the grid or used for a single home, in the case of micro hydro. However, instead of wind it uses water falling from a height to rotate the turbine	- Hydropower has been identified as the cheapest way to generate electricity. Although small scale hydropower plants are said to be uneconomical to build. - The fuel source is flowing water; a clean fuel source, with no pollutant to the environment. - Hydropower is also known to have provided about a fifth of the world's electricity, but only 2% in the UK. - However, one great disadvantage of the hydropower is the disruption to swim through of aquatic lives through the river course. - There could also be shortage of water during the summer for some small scale scheme.
		Sources: National Geographic Society, 2013; Shah, 2013; Bokalders and Block, 2010; Hall, 2008		

5.3.3 Heating, Ventilating and Air Conditioning (HVAC) Systems

HVAC has been defined as *'the technology of indoor and vehicular environmental comfort'; a system where safe and healthy building conditions are regulated with respect to temperature and humidity, using fresh air from outdoors'* (HVAC, n.d.). EPA (2012) also identified the purposes for HVAC systems as: helping to maintain good indoor air quality (IAQ) through adequate ventilation with filtration, and providing thermal comfort.

HVAC systems are said to be the major energy consumers in buildings (Ibid). Pullen (2013) discussed the results of two separate surveys on UK household energy consumption by the Department of Trade and Industry (DTI) in 2004 and Energy Saving Trust in 2007. The results; presented in figure 5.13 show that heating accounted for 84% of energy usage in 2004 and 73% in 2007.

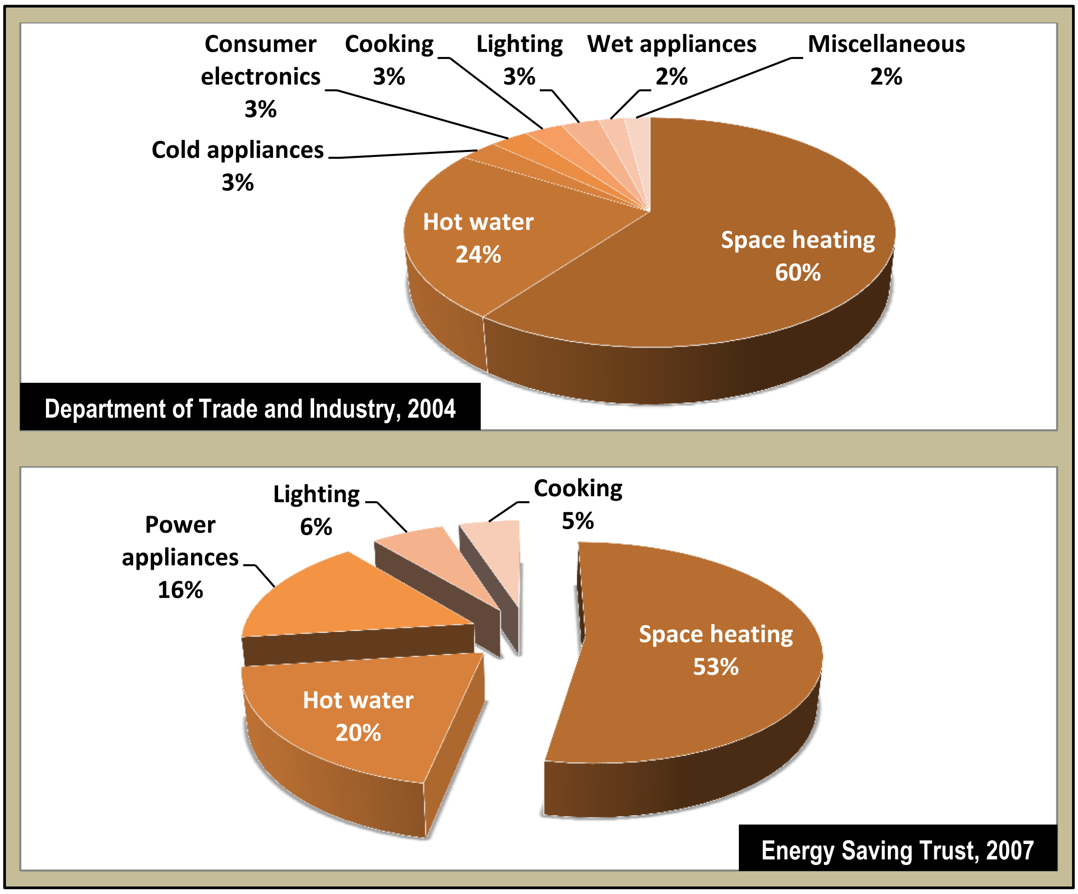


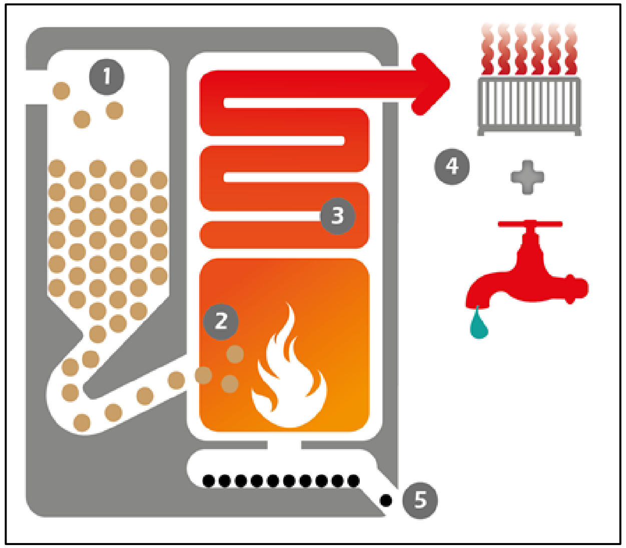
Figure 5.13: UK Typical Household Energy Consumption in 2004 and 2007
(**Source:** Pullen, 2013)

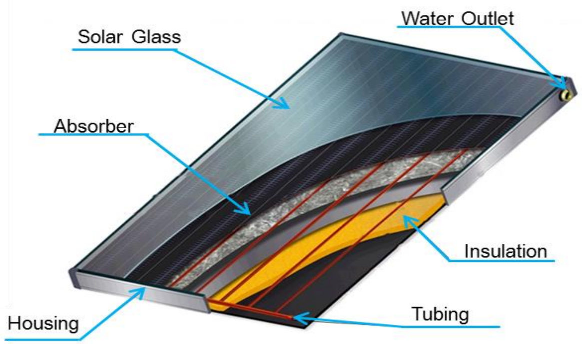
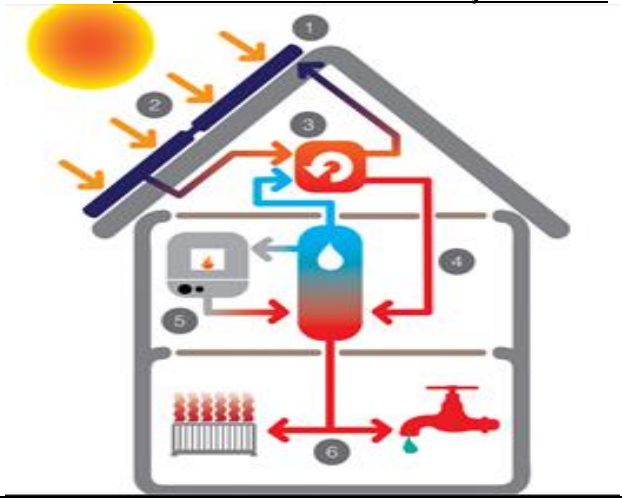
A lot of investment has been made in research and development of low carbon heating, ventilating and air conditioning systems/techniques in the UK, resulting to wide-range of HVAC technologies being innovated (DOE, 2013). This includes:

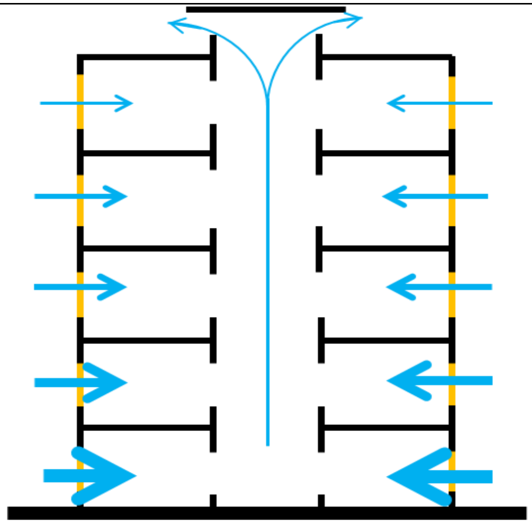
a) *Space/Hot water heating technologies* - Biomass boiler, Solar thermal collectors, Heat pumps, Heat recovery system, Under-floor heating, Solar sun-space, Solar sun-box, Earth thermal storage system, etc.
b) *Ventilating technologies* - Natural cross ventilation, Natural stack ventilation, Courtyard natural ventilation, Controlled venting and ducting, e-tube ventilation system, PV based extractor fan, etc.
c) *Air Conditioning technologies* - Adiabatic cooling system, Solar powered chillers, Air heating and cooling exchanger system

The list is inexhaustible, but just to mention a few as new technologies continue to emerge. Table 5.5 discusses some of these technologies listed above.

Table 5.5: Heating, Ventilating and Air Conditioning (HVAC) Technologies

S/no.	Technology	Description	Applications/Impact on Energy Demand/Environment
1	**Biomass Boiler**	 **<u>Schematic Diagram of how a Biomass Boiler Works</u>** See Description ⇒ - Biomass is described as woody material such as, logs, wood chips or pellets and other by-products from wood processing, supplied for fuel. - It is also referred to as 'solid biofuel'. It is a renewable source of energy. Wood can be grown and regrown. - Biomass boilers are therefore 'Wood burning Stove' for space and hot water heating. - The biomass fuel is usually processed into same shape and size, so that it can be used effectively and automatically and also to improve its combustion characteristics. - They come in the form of: firewood, wood chips, briquettes, pellets and wood powder. - The schematic diagram shows how the system works: - The fuel is fed into a storage hopper (1) -The automated system feeds the fuel from the hopper into the biomass furnace (2) - The heat energy produced is absorbed into a heat exchanger (3) - the heat exchanger feeds into home hot water and heating supply units (4) - Waste ash is periodically removed (5)	- Biomass fuel are renewable, they are not depleting the natural environment. - There are arguments that that carbon generated from burning biomass is taken back by other trees for their growth - A study reported by National Trust indicated that using wood chip biomass in comparison with oil boiler resulted in about 91% CO_2 reduction - However, there are recent arguments that whereas biomass is renewable, it is not a low carbon technology because: - the use of biomass plants could lead to clear cutting of forests and pumping more CO2 into the air than coal plants, thereby adding to global warming - Grant and Clark (2010) noted that 'biomass boilers are an expensive way to make climate change worse …' - Meg Sheehan in LeBlanc (2009) calls biomass "a false solution to the climate change". - Biomass technology is widely reported to issues with maintenance and reliability.
		Sources: East Tech, 2012; National Trust, 2011; Grant and Clarke, 2010; Bokalders and Block, 2010; LeBlanc, 2009; Richards, 2008; Hall and Hall, 2008;	

2	**Solar Thermal Collectors** *(Flat plates)*	 **A. A Typical Flat Plate Solar Collector** **B. How the Solar Thermal Collector Systems Work**  	- Solar Thermal Collectors are solar hot water heating technologies. They include the Flat Plate Collectors and the Evacuated Tube (also called vacuum tube) Collectors. - The flat plate collector consists of a toughened solar Glass Cover with low iron oxide content which act as a protector against loss of heat from the Absorber, which are typically black coloured to maximise it heat absorption capacity. Underneath is a high temperature insulation with fibre glass surface, sitting on a corrugated aluminium back plate. The metal tubing is provided to transport the refrigerant within the panel. - Figure B is a schematic layout of how the system works: - Refrigerant is pumped into the collector(s) on the roof (flat plate or vacuum tubes) (1). - As the refrigerant flows through the panel or tubes, it absorbs heat from the sun (2). - The refrigerant carries thermal energy back to the heat exchanger (3) where it is used to heat up cold water from the water tank (4). - The heated water is then pumped back to the water tank (4). - Short falls from hot water requirements are made up by the back-up home boiler (5) - the hot water is then sent to the space heating and hot water outlets as required.	- For optimum performance, solar collectors are best situated southwards and unobstructed from the sun rays by trees or adjoining structures; usually on the roof tops. - The energy generated from this natural source is used in the building, thereby reducing bills on energy. - By reducing need for energy from the grid, there is a reduction in CO_2 that would have been emitted from production and supply of energy need of the building. - The absence of mechanical or moving part in the energy conversion system also reduces O&M cost greatly. - However, the collector surfaces require periodic cleaning like PVs. - The Vacuum tube varieties are known to be easily overheated and so may require a shorter duration of periodic checks and maintenance for efficiency.
		Sources: East Tech, 2012; Bokalders and Block, 2010; Fred, 2010		

3	**Natural Stack Ventilation**	 **<u>Stack Ventilation System</u>**	- Stack ventilation is a natural ventilation system that operates of the principle of vertical pressure and thermal buoyance. - A common rule of the thumb for stack ventilation is that it works when there is a temperature difference of more than about 2^{o}C between the outdoor and indoor temperature. - The indoor air temperature is generally warmer that the outdoor, and warmer air are lighter the cooler outdoor air. So the lighter warm air is pushed upwards by the cooler air coming in from windows and doors opening. As this happens a low air pressure relative to outdoor condition is created. - The low indoor pressure draws in fresh air to the building as illustrated in the figure.	- Being a natural ventilation system, the building's running cost will be lower in comparison with a mechanical ventilation system - Energy consumption is zero, therefore carbon emission for ventilation will also be zero. - Low maintenance cost - Healthier building - Stack ventilation also functions even when there is no wind pressure, provided there is temperature difference in and out. - It can also operate in deep plan buildings - Stack effect could be typically weak, so large openings would enhance it.
		Sources: Baker, 2013; Heywood, 2012; Davies and Jokiniemi, 2011; Hall, 2008		

5.3.4 Day Lighting Systems

The concept of daylight has been discussed in section 5.3.1.2 to include the direct sunlight and the reflected skylight. However, the term skylight is also used to refer to roof windows (Szokolay, 2008) or roof lights as some authors would call it. Daylight is the preferred form of illumination in buildings; it provides the best colour rendering property of light sources and gives building occupants that natural connection with the natural environment (Hall, 2008).

Daylight provision has huge potential for energy savings in buildings. A study of how energy is being consumed in a typical naturally ventilated office building, reported in Hall (2008) shows that lighting provided by electricity accounted for 20% of total energy consumption as shown in figure 5.14

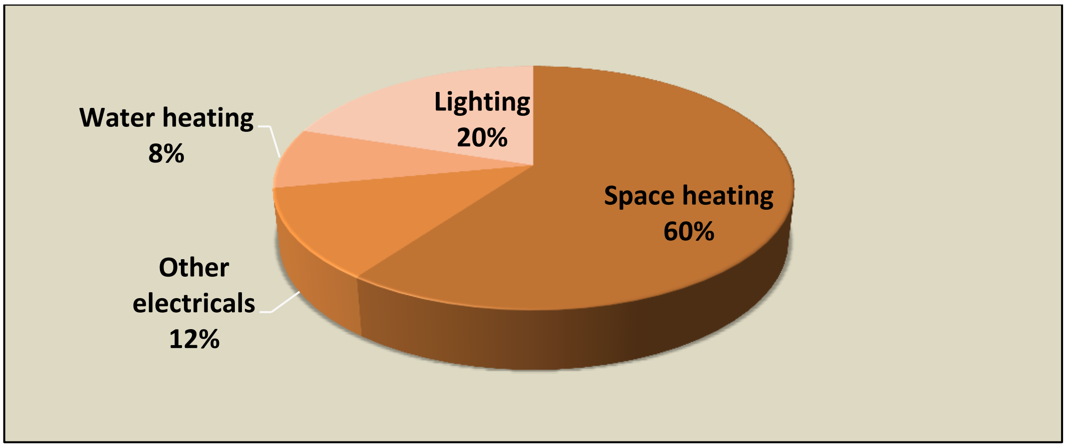


Figure 5.14: Breakdown of Naturally Ventilated Office Energy Consumption
(**Source:** Hall, 2008)

Traditionally glazed fenestration (openings on walls) have been the major medium for admitting daylight into buildings; usually glazed windows. Heywood (2012) provided that, where a room has windows only to one side, it can only provide effective lighting for room depth up to twice the window height (figure 5.15). Also, for a room depth not exceeding 7m, with windows on one side, that the total window area should be about 20% of the wall area to be effective, larger spaces should be increased to about 35%. Taller windows also help to through in light deeper into the space (Ibid, Hall, 2008).

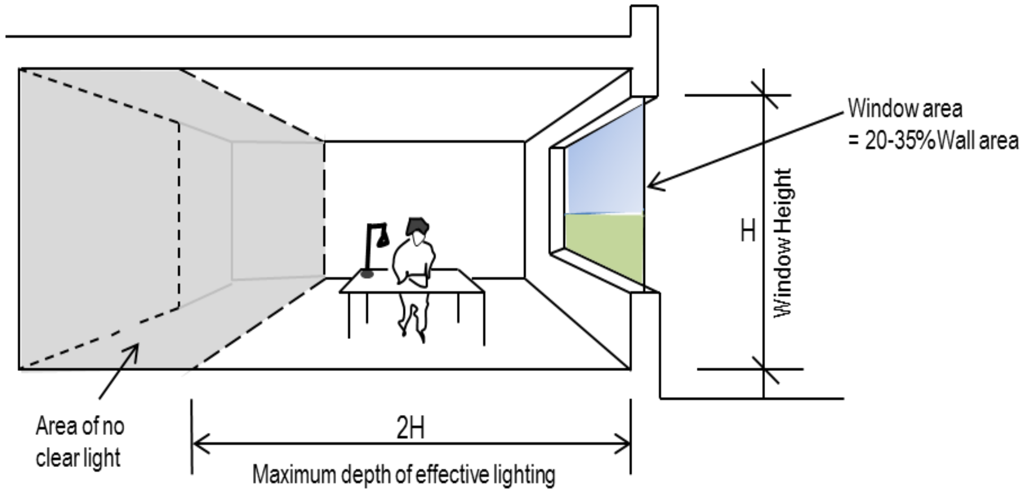
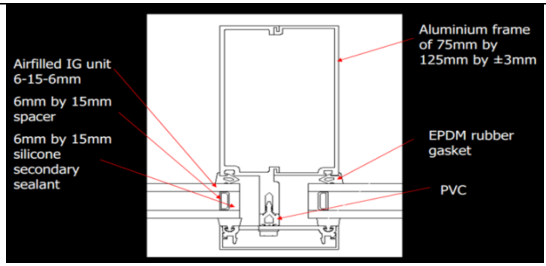
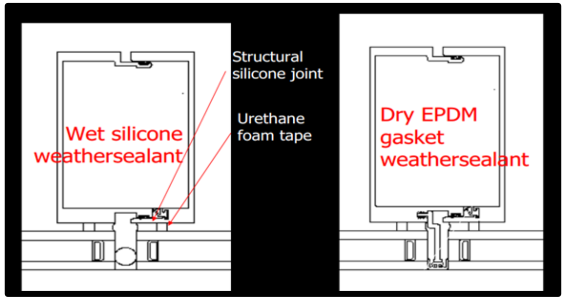
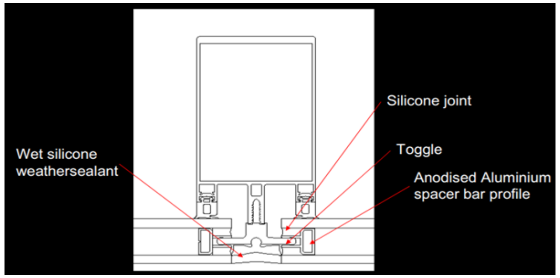
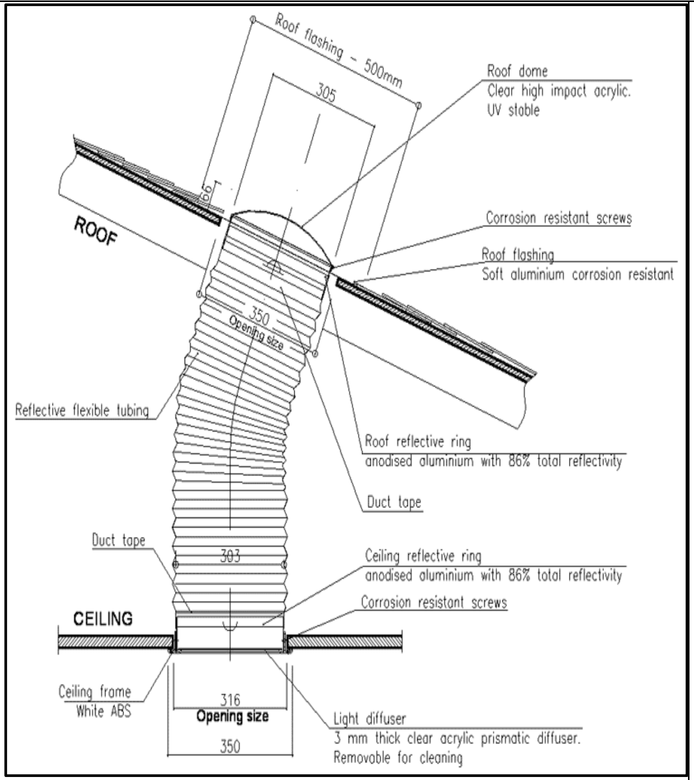


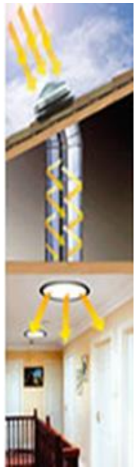
Figure 5.15: Maximum Effective Depth of Daylight through Window from one side (**Source:** Heywood, 2012)

However, there are other technologies and measures available in literature through which daylight could be enhanced. E.g. curtain wall, skylight (roof light), sun pipes, lightwell, atrium and artificial lighting. Table 5.6 highlights some of these technologies.

Table 5.6: Daylighting Systems

S/no.	Technology	Description	Applications/Impact on Energy Demand/Environment
1	**Curtain Wall**	 **A. Mechanically Fastened System**  **B. Structurally Glazed System**  **C. Hybrid Toggle System** - A curtain wall system is an outer non-structural light weight external wall, usually in glass. - The curtain wall allows natural light to penetrate deeper within the building. - The curtain wall transfers its self-weight and the horizontal wind loads that are incident upon it to the main building structure through connections at floors or columns of the building. - Curtain walls are designed to resist air and water infiltration, sway induced by wind and seismic forces acting on the building, and its own dead load weight forces. - Recent curtain wall systems are typically designed with extruded aluminium framings, in-filled with glass, which provides enhanced daylighting. - Other common in-fills include: stone veneer, metal panels, louvers, and operable windows or vents. - 3 detailing methods (in-fill to frames and gaskets) are identified in literature: - Mechanically fastened system (fig. A) - Structurally glazed system (fig. B) - Hybrid toggled system (fig. C)	- Also 4 main types classified according to how they are assembled were also identified: Ladder, Stick, Structural Glazing and Unitised. - In ladder systems the frames are made up as individual ladders in the factory and fixed together and glazed on site. - Stick systems are the most popular and cost-effective. Individual pieces are assembled and glazed in situ. - Structural glazing system is similar to the stick system - Unitised systems are completely assembled in the factory, including glazing or infill panels, before the curtain walling is brought to site. This allows the building to be made weather tight quickly. - Curtain walling are principally provided to capture the sunlight energy for daylighting and for heating up the indoor environment. So this contributes immensely to electricity cost as well as heating costs. - Savings on energy means a reduction in the building's carbon footprint.
		Sources: Mark, 2012; Dow Corning Proprietary, n.d.	

<table>
<tr>
<td>2</td>
<td>Solar Sun Pipe</td>
<td>


<u>A Typical Solar Sun Pipe Constructional Details</u>
</td>
<td>

- Also referred to as sun tubes or light pipes; used to provide natural lighting to interior spaces by guiding it along a light pipe.
- The system (shown on the detail drawing) consists of long flexible tubing with very reflective interior surfaces to guide the sunlight received by a clear high impact acrylic UV stable roof mounted dome. The reflected sunlight is diffused into the room space by 3mm thick clear acrylic prismatic diffuser at the terminal, held to the ceiling soffit by a removable ABS ceiling frame, to enable removal of the diffuser for periodic cleaning.
- The system can also be used at nights by installing a light kit.
- The animated photograph insert shows the reflections of the sun rays in the tube.
</td>
<td>
- The sun pipe is used to provide natural lighting to internal spaces that cannot be fitted with windows, e.g., internal lobbies, stairwells, dressing rooms, basements, etc.
- The system, if properly designed eliminates the need for artificial (electricity) lighting in such spaces in the day, and thereby contributing to huge savings in electricity bills, and by extension, total energy consumed by the building.
- This also contributes to reduction on the CO_2 that would have been emitted in generating energy required for the building.
</td>
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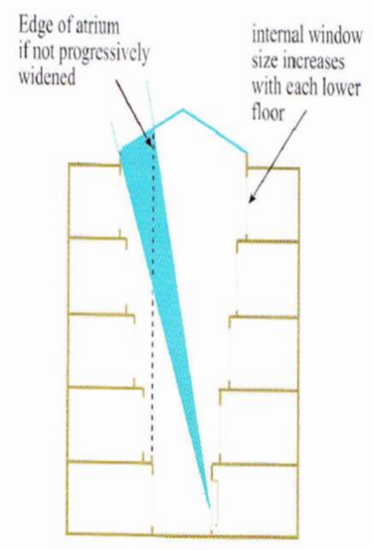
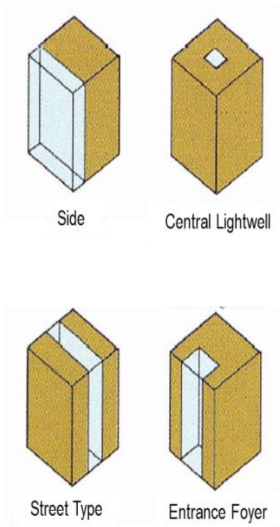
<tr>
<td></td>
<td></td>
<td colspan="3">Sources: LRS, 2013; Hall, 2008</td>
</tr>
</table>

3	**Lightwell**	 **A. Improving daylighting access in Lightwells**	 **B. Types of Lightwells**	- Lightwells are vertical ducts provided within a large multi-story building to provide lighting principally, and sometimes, ventilation to internal room spaces which would have otherwise been dark and unventilated. - It gives better view of the sky from lower windows if the width of the well is progressively increased towards the top, and better light effect if the area of windows are progressively increased from top to bottom (see fig. A). - Lightwells are usually narrow shafts within a building, it becomes an Atrium if widened so that it becomes a usable space, roofed with clear glass or glass blocks. - Walls are advisable to be in bright reflective surfaces to encourage better daylight distribution - 4 patterns of designs are usually employed as shown in fig. B.	- Lightwells also serves to reduce if not eliminate the necessity for electricity during the day. - it also provides an internal open space within the building - The system also reduces the need for artificial (electricity) lighting, thereby contributing to huge savings in electricity bills, and by extension, total energy consumed by the building. Cost of heating and cooling is also minimised as windows are opened to the well. - These also contribute to reduction on the CO_2 that would have been emitted in generating energy required for the building.
		Sources: Hall, 2008			

5.3.5 Renewable/Environmental Friendly Materials

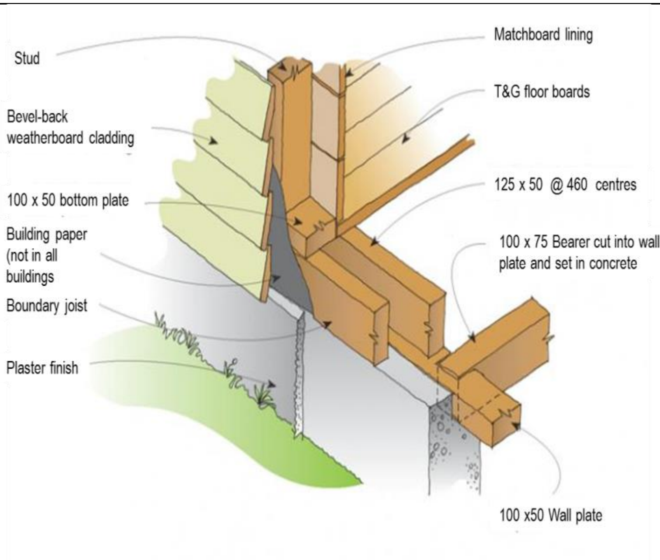
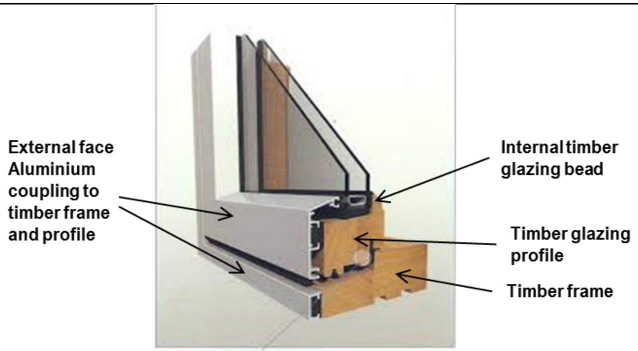
As discussed in section 5.2.2, there is very thin and often non-existing line between green, sustainable, low carbon and renewable technologies and they are often interchangeably used in literature to describe strategies or systems achieved with renewable or environmental responsible materials. They all refer to materials or systems that are adopted in response to concerns for climate change (eHow, 2013). This field of study is dynamic and still evolving. Therefore it will not be possible to capture all such materials in this section. Dick (2012) suggested the use of renewable building materials and products is so important and beneficial to building end-users because they help to:

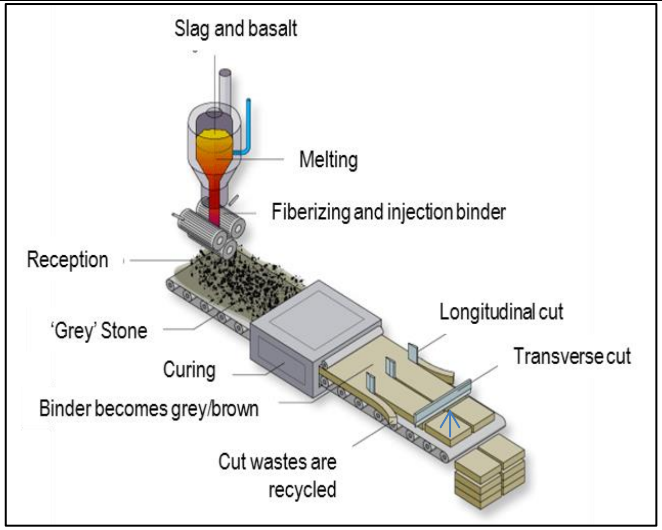
- Reduce maintenance/replacement costs through the building life
- Conserve energy
- Improve occupants health and productivity
- Lower the costs associated with the changing of space configurations
- Enhance greater design flexibility

Additionally, the use of renewable materials and products will encourage the conservation of the fast depleting non-renewable resources globally (Ibid).

The UK National STEM (Science, Technology, Engineering and Mathematics) Centre defines renewable building materials as materials based on plants; which are replaceable by growing them. They include a wide range of products ranging from unprocessed materials such as straw bales used for walling to more refined products such as floor finishes from renewable polymers (NSC, 2010). Some of the materials and products are described in table 5.7.

Table 5.7: Renewable/Environmentally Friendly Materials

S/no.	Technology	Description		Applications/Impact on Energy Demand/Environment
1	**External Timber Products**		- Timber can be classified as softwood and hardwood. - The soft woods grow to maturity in a relatively quicker time (about 30yrs), while the hardwood takes up to 100yrs and more. Unless treated. Hardwoods are denser and stronger and with less need for preservatives. - From ages timber and timber products have been used in several forms in buildings as structural members, furniture (fixed and moveable) and/or ornamental elements. - Contemporarily, timber is used externally as sustainable aesthetical elements, like window and door frames, wall cladding, solar shading, sit-out platforms, etc. thus requiring good detailing. - When timber is exposed to weather elements, irrespective of whether treated or not, they become more rapidly weathered and discoloured. - One of the very important factors affecting timber component durability is good design detailing and specification. Good detailing involves avoiding build-up of moisture on timber surfaces	- Timber is renewable; they are replaceable by growing them. - They are also easily recyclable; cost of recycling timber products in construction is far cheaper than most of its alternative. - timber is considered a low impact construction material if used wisely; if sourced locally, if used efficiently without chemical treatment and if detailed and constructed to be durable. - chemical treatment of timber makes it unsustainable, because these chemicals are harmful to man and other biological life. - However guidance on the need for preservative treatment in particular situations is available in BS 5268-5 and BS 5589
		Sources: Outdoor Structures, 2013; Morgan, 2008; TRADA Technology, 2002		
2	**Timber/Aluminium Composite Products**	 A typical Timber/Aluminium Composite Window	- As noted in (1) above, softwood timber which are the dominant wood found in the tropics are not very durable; when exposed to weather, they are readily discoloured and weathered, they are also not expected to have moisture build-up on them. - Aluminium (Al) and other weather resistant materials are sometimes coupled to external timber doors, windows, curtain walling frames to enhance performance/durability of the component. - This method reduces the quantity of aluminium used and also protect the timber from weathering effects	- Although aluminium is neither renewable nor environmental friendly in its production (very energy intensive production and emits poisonous fluorine and other pollutants), most of the aluminium products today are recycled and re-melted products from scrap metals, which disposal would have been of great environmental consequences. - Only a small quantity of Al is used, compared to using Al for the entire panels. - This method of prolonging the life of renewable and environmental friendly timber reduces the use poisonous timber treating chemicals.

<table>
<tr><td></td><td></td><td colspan="3">Sources: Bokalders and Block, 2010; Morgan 2008;</td></tr>
<tr><td>3</td><td>Stone Wool Products</td><td>
<u>Typical Production Process of Stone Wool</u>
<u>Stone Wool being used for insulation</u>
</td><td>- Stone wool, a type of mineral wool is made from volcanic rocks and recycled materials. Also referred to as rock wool. Slag, a by-product from the metallurgical industry and other solid minerals like basalt, etc.
- The raw materials are mixed and melted at 1350-1500°C.
- The melted droplets exiting the furnace are spun into fibres. Some amount of binding resins are added to the fibres and cured to required density in a curing oven at about 200°C, then cut to required size/shape
- Standard sizes (in mm) are 400 x 1000 and 600 x 1000; thickness varies between 25, 50, 75 or 100. Density also varies between 45kg/m³, 60kg/m³, 80kg/m³, 100kg/m³ or 140kg/m³.</td><td>- It possesses good acoustic and thermal insulation quality with high fire rating, and used for a wide range of acoustic, thermal and fire insulation requirements.
- Its thermal quality makes the building to be less dependent on energy for heating and cooling, thus contributing to a reduction in carbon footprint.
- Waste products are recyclable and do not contribute to any environment challenge of waste management. The material itself is reusable in their forms, provided they have not been expose moisture.</td></tr>
<tr><td></td><td></td><td colspan="3">Sources: Rockwool, 2013; Bokalders and Block, 2010; Eurima, 2011</td></tr>
</table>

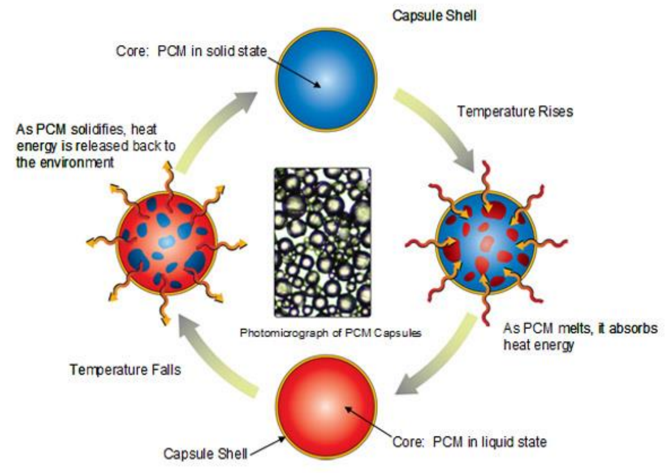
5.3.6 Energy Efficiency and Conservation Systems

By energy efficiency, it means *'using less energy to provide the same service'* while energy conservation is *'reducing or going without a service to save energy'* (EETD, 2013). Szokolay (2008) argued that although many authors may apply the term 'energy conservation' to all forms of energy, but that is specifically referred to 'the conservation of conventional, non-renewable energy sources. However, the commonalities between the two phraseologies are that in both cases, energy is used prudently and resourcefully while still achieving indoor comfort, and consequently, the carbon emission resulting from energy use is reduced.

Section 5.3.1 has addressed several approaches that could be adopted to minimise the use of energy (renewables and non-renewables). However, a few technologies developed based on the principles discussed in section 5.3.1 are here discussed. Some of the technologies include: phase change insulation, web-brick technology, insulated concrete framework, loft insulation, e-window glazing, thermal mass, low energy bulbs, double skin façade (as energy efficiency systems), motion activated lighting, Thermostats and diverse forms of intelligent systems (energy conservation systems). A few of these systems are discussed in table 5.8.

Table 5.8: Energy Efficiency and Conservation Systems

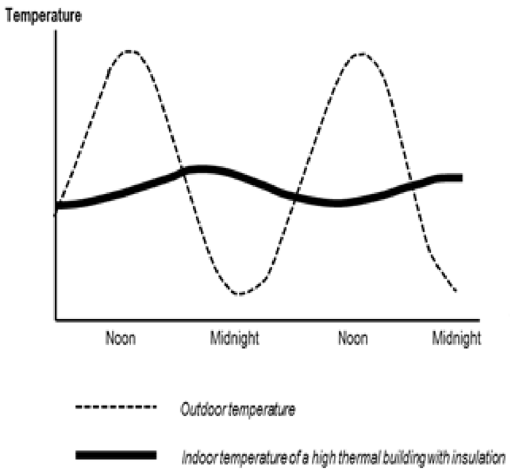
<table>
<tr><th>S/no.</th><th>Technology</th><th colspan="2">Description</th><th>Applications/Impact on Energy Demand/Environment</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Phase Change Insulation</td><td>



<u>**Schematic Diagram of How PCM Works**</u>
</td><td>

- The phase-change material (often abbreviated PCM) is characterised by its high heat fusion; melts and solidifies at a certain temperature due to its content of some microscopic polymer which contain wax storage medium in their core.
- A rise in temperature over a defined threshold (21oC, 23oC or 26oC), causes the wax to absorb the excess heat, stores the heat in the material and melts to a liquid state.
- When the temperature falls below the given temperature threshold, it solidifies, releasing the stored heat
- PCM is described by BASF (2013) described PCM as intelligent temperature management material
</td><td>

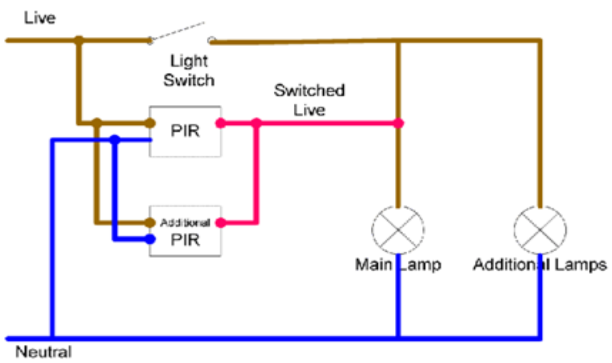
- It is usually microencapsulated into a plaster boards and diverse construction materials to help regulate the indoor temperature.
- PCM is a fabric integrated technology, so it lends itself as a passive temperature control technology.
- PCM has been proven to offer substantially enhanced indoor comfort due to their passive temperature regulation mechanism
- Using PCM could also substantially save energy demands, and by extension, greenhouse gas emission.
</td></tr>
<tr><td colspan="3">**Sources**: BASF, 2013; Hall, 2008</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Thermal Mass</td><td>



</td><td>

- Thermal mass is a term used to refer to heavy walls or floor slabs with high thermal storage capacity.
- Thermal mass differs from thermal insulation; insulators do not store heat well, they resist its flow (high thermal resistance), while the thermal mass stores the heat (or 'coolth') and has a low resistance to heat flow).
- It absorbs the heat slowly and stores it then releases it slowly.
- In high thermal mass buildings, the highest indoor temperature will occur in the early hours of the morning; many hours after the highest outdoor temperature was reached
- It absorbs the heat gained from the sun in the day and internal sources as well, and releases slowly during the cooler overnight period
</td><td>

- In high thermal mass buildings, highest indoor temperature will occur in the early hours of the morning; many hours after the highest outdoor temperature was reached or when the outdoor temperature is coldest.
- They keep internal temperature near steady through the day as shown in the graph.
- They work better when combined with insulation
- Non-domestic buildings could be designed to use nocturnal (night time) ventilation when the building is unoccupied
- In cool and temperate climates, thermal mass is particularly useful in west-facing walls, which are subject to the greatest exposure to solar radiation.
</td></tr>
<tr><td colspan="3">**Source:** Heywood, 2012</td></tr>
</table>

3	**Motion Activated Lighting**	 **<u>Circuit Diagram of a Two-way switching system with PIRs</u>**	- Motion activated lights also referred to as 'occupancy dictation lighting' is an automated lighting system that uses passive infra-red (PIR) dictators to sense body heat, or ultrasonic dictators to sense movement. - Light is turned on automatically by a PIR or an ultrasonic dictator only when movement is noticed - Typically, the system operates with more than one dictator controlling a lighting circuit, particularly for large spaces or for spaces with multiple access. - The system also consists of a conventional lighting control switch shown in the circuit diagram of a typical two-way PIRs switching system. - The control switch can force the lights to remain switched on, but will leave them on PIR automatic mode with it is in off position as shown in the circuit diagram.	- The system is intended to contribute to savings in lighting bills by turning off lights when not needed. - However, there arguments that the system may be adding to energy spend because: - lights come on even in the day when there is still brightness - frequent switching on and off of fluorescent lights reduces the life of the lamp - Another disadvantage of this system is that when occupants are seated, lights turn off, so occupants will need to wave their hands to activate the sensors. This causes dissatisfaction to occupants - Generally, automated lighting control system enable personal security when used as security lights and car pack spaces in buildings.
		Sources: DIYWiki, 2013; Hall, 2008; Carbon Trust, 2007		

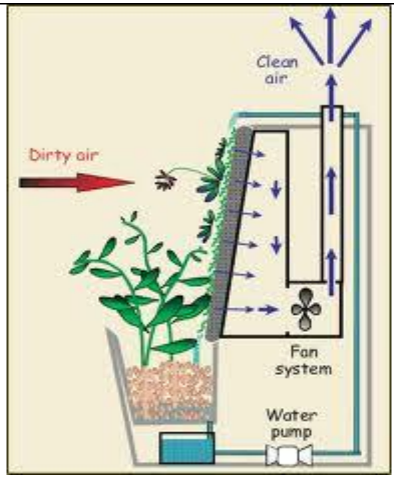
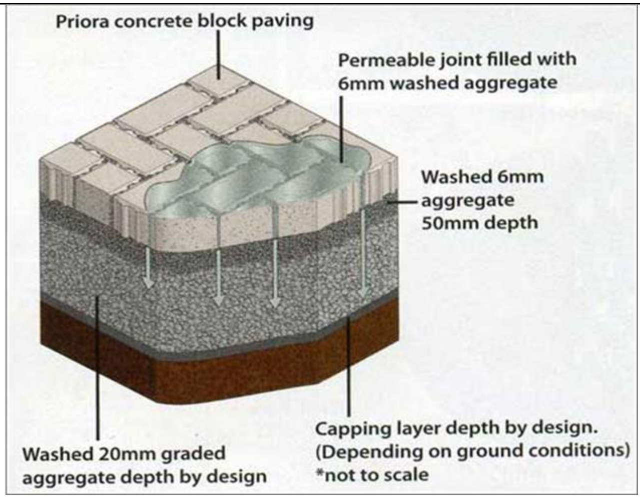
5.3.7 Bio-diversity Technology

The term biodiversity in its broad sense is used to describe the number, variety and variability of living organisms. It is a contraction of two words, 'biological diversity'; variety within the living world (UNEP, 2013). Biodiversity is often being discussed in terms of genetic diversity, species diversity and ecosystem diversity (Ibid). However, it has become popular to define biodiversity in the built environment in terms of 'urban biodiversity' (RIBA, 2013); encouraging urban developers to see wildlife, plants and their habitats as being a vital component of 'healthy, well-functioning ecosystems' that sustains life on the planet (UKGBC, 2009). Recent researches highlight the fact that *'the well-being of man is fundamentally and directly dependent on ecosystem services'* (EC, 2008). Brown and Grant (2005) posit that there are strong documented indications of links between human health and nature, particularly in the urban setting.

Urban biodiversity, its integration and maintenance has become an essential part of sustainability in architecture as planning authorities now expect biodiversity benefits from projects (RIBA, 2013; BSG Ecology, 2012). A number of initiatives have been introduced in response to the need to integrate and maintain biodiversity in the urban set ups. Some of these initiatives include: green roofs, brown roofs, earth buildings, Green (living) walls or vertical gardens, sustainable urban drainage, artificial lake, etc. Table 5.9 discusses a few of them.

Table 5.9: Biodiversity Systems

S/no	Technology	Description		Applications/Impact on Energy Demand/Environment
1	**Green Roof**	 **Sectional Detail of a Typical Green Roof Construction**	- Green roof technology is not new, but became popular in the 1960s by the increasing concerns about the rising decline of green spaces in urban areas. It is now become a sustainable solution to mitigate and adapt to climate change. - There are basically two types; 'Extensive' (50 – 150mm build-up height) and the 'Intensive' (150 – 1500mm build-up height) - A typical constructional detail as shown: - The top Vegetation layer; types of plant depends on the depth of the growing medium and other factors. - The Growing medium (the soil) needs to be stable, not prone to settlement, well aerated even with water saturation and free of weeds. - Underneath is the Drainage layer which controls and drains off water from the roof, protects the root proof layer from being mechanically damaged, retains water during drought and provides the substrate with a balanced supply of water and air. - Lastly, the Root Barrier which prevents roots from damaging the waterproofing. The membranes specification depends on the planned landscape and the slope of the roof.	- Has high water retention capacity, thus helps to reduces run-offs rainwater and consequently, sewer overflow - helps to cool and humidify the surrounding environment - the plants help to absorb greenhouse gases (CO_2). - Absorbs air pollution and dust - Provides safe habitat for wild lives. - protect the roof from rapid deterioration - reduces heat loss, thus providing extra insulation for the building - has high thermal mass, so it slows the passage of heat by at least 12 hrs - also helps to bring down noise levels - uses mostly recycled materials
		Source: Pullen, 2013; GreenSpec (2013); Heywood, 2012; Bokalders and Block, 2010		
2	**Brown Roof**	 **Pictorial view of a Typical Brown Roof**	- Also known as biodiversity roof - Has the features and constructional details of an extensive green roof, with 150mm maximum thickness of soil - It is designed for the purpose of recreating natural habitats for wildlife; insects, birds and wild plants; the flora and fauna that inhabited the site before the building was constructed. - It uses the by-products of the construction project such as rubbles and soil (usually soil from immediate surroundings and scraped off top soil).	- Provides similar benefits as green roofs. - Additionally, the vulnerable species of plats and animals species are protected from human interference.
		Source: Pullen, 2013; GreenSpec (2013); BrownRoofs.co.uk, 2013; Bokalders and Block, 2010		

3	**Green Wall**	 **A Typical Green/Living Wall system**	- A green wall is a wall that is partly or fully covered with plants. - Also called living wall, biowall or vertical garden - They could be used indoors or outdoors, attached to an existing wall or free-standing - The wall consists also of a growing medium such as soil in different moulds or panels - It also consists of a recycled watering system as indicated in the diagram	- When used indoors, they aesthetically moisturise the space. - Plants on walls can lower temperature in the wall by 3-4°C and also help to cool and humidify the surrounding environment - The plants also help to absorb CO_2, other pollutants and dust - It creates a high thermal mass, so that the passage of heat through the wall is slowed - also helps to bring down noise levels - uses recycled water
		Source: Vriksha Nursery, 2013; Greenroofs.com, 2013; Bokalders and Block, 2010		
4	**Sustainable Urban Drainage System (SUDS)**	 **Permeable Paving System; An example of SUDS**	- A system aimed at slowing down the rate of storm water run-off through the urban hard impervious surfaces of the urban environment into water ways - The system is a water management practice involving: 1) creating permeable paving so that rainwater soaks through into the ground; 2) use of green roofs to absorb rainwater as discussed above; 3) use of rainwater collection system over the entire site area, not limited to only water from the roof; 4) rainwater soakaways; 5) grass paving	- The principal aim of SUDS is to reduce flooding, by reducing the rate at which rivers and other water ways swell. - It also help to provide water for other uses within the site – gardening, biodiversity (aquatic habitat), etc. - Also helps to humidify the environment and provide fresh air.
		Source: Wilkinson, 2010; Hall, 2008; NBS, 2007; SEPA, n.d.		

5.3.8 Water Management Systems

The management of water is often associated with 'conservation of water' and linked to energy conservation (Hall, 2008); the energy cost of treating and piping water to individual consumers as well as energy cost of heating water (Pullen, 2013; Hall, 2008). Utility charges for water supply and sewerage will be reduced if water consumption in buildings is reduced. Hall (2008) posits that other benefits of water conservation could include:

- The environment is protected by reduction in the use of water, eg., protecting the marine ecosystem by preventing the drying up of rivers resulting from ground water table falls.
- Reduction in the amount of water treatment chemicals
- Reduced stress on supply infrastructure

The need for conserving water and the associated energy cannot be over emphasised. Pullen (2013) argued that if every household in the UK got a standard water butt (100 – 300 litres capacity) to collect rainwater for gardening and other outdoor water usage, this would save about 30billion litres of water each summer. A report by DEFRA and Waterwise quoted in Pullen (2013) indicates that the average person in the UK uses about 150 litres of water per day, and that this has been on a steady annual increase by 1% since 1930. Figure 5.16 shows a breakdown of typical water usage in a typical home in the UK.

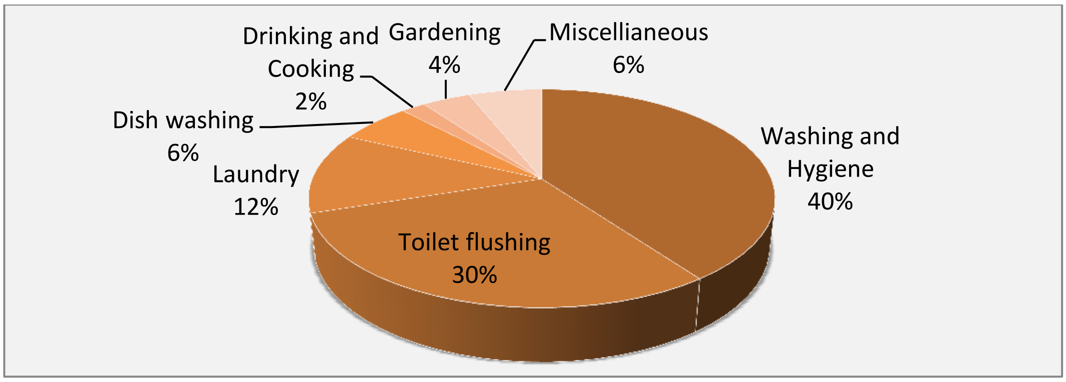


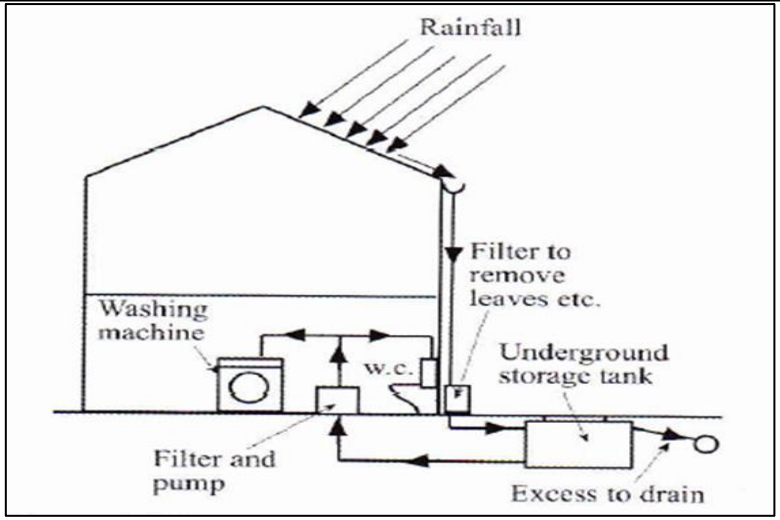
Figure 5.16: Breakdown of Water usage in a typical Household (**Source:** Hall, 2008)

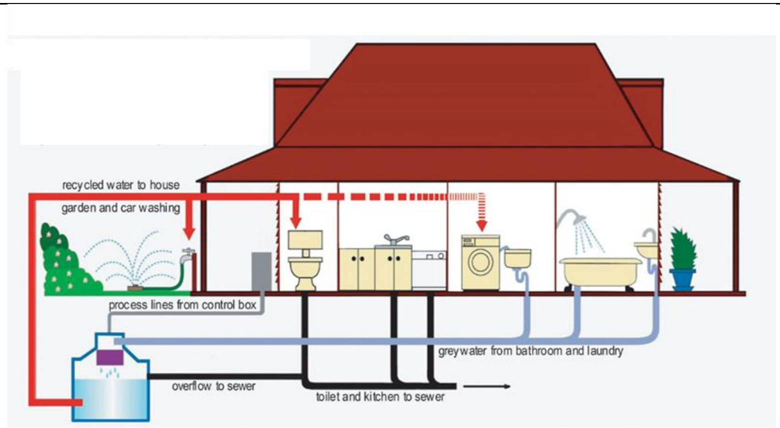
In recognition of the benefits of water conservation, the government has produced a waste strategy up to 2030 which aims among others to reduce water consumption from 150 litre to 120 litre/day/person. Also, several conservation or management strategies have been introduced; available in literature include:

1) Taps (Self closing taps, Reducing flow rate, Tap restriction)
2) Pipe Layout
3) Toilets (vacuum toilets, composting toilets)
4) Urinals (hydraulic systems, detector/Solenoid valve systems, waterless urinals, Barrier systems, contact disinfecting system)
5) Water recycling systems (Greywater recycle, Re-bed filtering system)
6) Rainwater harvesting
7) Monitoring and Metering
8) Sustainable urban drainage system (already discussed under biodiversity)

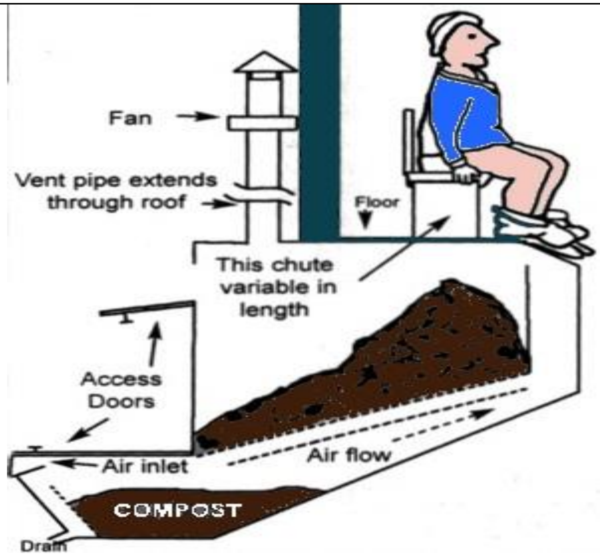
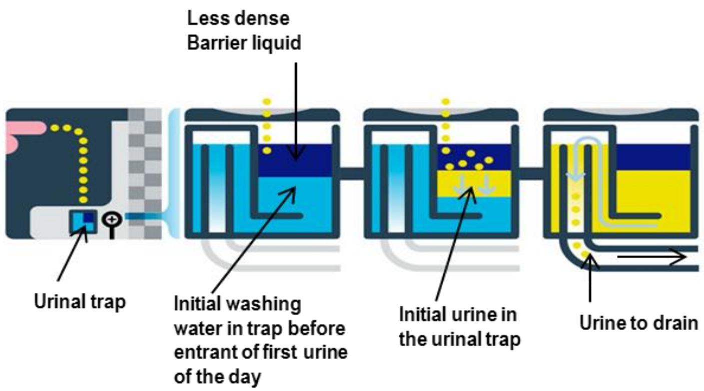
Table 5.10 discusses a few of these systems.

Table 5.10: Water Management Systems

<table>
<tr><th>S/no</th><th>Technology</th><th colspan="2">Description</th><th>Applications/Impact on Energy Demand/Environment</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Rain Water Harvesting</td><td>

<u>**Rainwater Collection and Utility Schematic Diagram**</u></td><td>- The system collects rainwater from the roof through a spout or gutter, draining through a pipe to a ground filter tank
- The filter tank is provided to filter off leaves and some unwanted particles washed down from the roof. The water is then syphoned through a pipe to an underground storage tank from where it is pumped using a surface pump to the outlets.
- In some cases, an additional storage tank could be provided within the roof space into which the underground tank supplies before it is supplied to the outlets (this system is referred to as indirect water distribution system.
- The underground storage tank is designed to be accessible through a manhole for maintenance</td><td>- Rainwater from the sky is relatively but could be polluted by some atmospheric pollutants and even bird and reptile droppings from the roof, so it is considered non-potable and not suitable for human consumption, but limited to use for washing machines and flushing toilets
- It could also be used gardening and other outdoor uses like car-wash
- It could be thoroughly filtered and purified/ sterilised using a standard purifying system prescribed by an expert, before it be used for drinking and/or cooking
- Harvesting rainwater reduces stress on utility systems as well as other benefits discussed in section 5.3.8</td></tr>
<tr><td colspan="3">**Source**: Hall, 2008</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Grey Water Recycling System</td><td>

<u>**A typical Greywater system**</u></td><td>- Greywater is originally potable water from the mains and has been used for bathing and washing (cloths, plates and hands). It does not include water from toilets, urinary or kitchen sink (referred to as foulwater, blackwater or soil waste), but could also include water from dishwasher.
- Like the rainwater collection system, the storage tank is underground and designed to be accessible through a manhole for maintenance purposes.</td><td>- Recycled greywater is reused for washing machines, toilet flushing and outdoor usage.
- Outdoor usage includes carwash, garden watering and irrigation.
- They could contain chemicals, organic suspended solids and contaminants. Eg. oil and greases. These could cause maintenance problems, without a form of cleaning system.
- About 60 – 80% of outflow water from homes are greywater, its reuse can amount to potential savings on water bills, pressure on utility lines and in turn savings on emissions.</td></tr>
<tr><td colspan="3">**Sources**: The Environment Writer, 2011; Hall, 2008</td></tr>
</table>

3	**Composting Toilet**	 **A Typical Composting Toilet System**	- It is a dry toilet which uses aerobic decomposition processing system that treats excreta, typically with little or no water. - The system involves the sitting fixture opening directly into the composting chamber through a 150mm diameter silver pipe, through which the excreta passes to the chamber. Underneath the chamber is the humus tray into which the decomposed mater or compost falls and is stored. Excess liquid is also drained out through a drain pipe at the bottom of the system and diverted through a blackwater system. - The waste is usually mixed with sawdust, peat moss or coconut coir to support aerobic action; absorbing the liquid and reducing odour. - To facilitate the aerobic process, the waste chamber is properly ventilated through a vent pipe, through the roof. It is sometimes fitted with an extractor fan.	- It can be used as an alternative to flushing toilet where there is no adequate or suitable water supply and treatment facility available. - The nutrients in the human excreta can be harnessed and used as manure (referred to as humanure). - The decomposition process is usually faster than the anaerobic system used in the water based toilet system. - the energy involved supplying water from the mains and transporting and treating waste is reduced, thereby reducing emission also. - Typically, 30-40% of potable water supplied to homes is used to flush toilets.
		Sources: Neill Lewis Architects, 2009; Hall, 2008; EPA, n.d.		
4	**Waterless Urinals**	 **Barrier System Waterless Urinal Schematic Diagram**	- Two varieties exists; the barrier system and the contact disinfecting system. - The barrier system uses a low density fluid, tipped into the trap, so that it floats over the denser urine, which in effect is pushed down the trap. The liquid is typically a mixture of oil and disinfectant, thus acting as barrier to urine odour - The trap requires daily toping up by the cleaner and 2-6 times yearly complete replacement. - The contact disinfectant system deodorises and disinfects the urine as it leaves the urinal. A disc or rod impregnated with disinfectant is inserted into the upper part of the trap weekly to provide a disinfectant and deodorising effect as urine passes through it.	- The use of water is completely eliminated except during regular cleaning by the cleaner. - Conventional urinals in the UK operate in an automatic mode, it flushes at regular intervals, irrespective of whether it is used or not, therefore putting stress on the demand for water. The waterless system could contribute substantially to water and associated energy demand and emissions saving.
		Sources: Hybrid H_2O, 2013; Hall, 2008		

5.4 PRINCIPLES OF LOW CARBON BUILDING DESIGN

Designing buildings to conform to the zero carbon emission requirements requires a paradigm shift for designers who were trained and had long practiced the act of designing buildings the traditional way. They are now required to design buildings that are energy efficient and using ambient or renewable source. The buildings are also expected to conform to other standards or principles of sustainable practices. However, in a more general term, low carbon buildings are buildings designed to produce significantly low carbon dioxide emissions than others, with a view to mitigate climate change (RIBA, 2009d).

5.4.1 Design Principles Proposed by RIBA

Over the past decades, some experimental and exemplar low carbon buildings have been developed, monitored and extensively evaluated (RIBA, 2009c), which resulted in creating a knowledge base of well-established, key principles that designers should adhere to in order to achieve a low carbon design. The Royal Institute of British Architects (RIBA) published some principles to guide the design of low carbon buildings. They are discussed as follows (Ibid):

i) *Understanding Energy Use in the Building Type* - A clear understanding of the breakdown and pattern of energy use for the building type is very vital; at least by fuel type and ideally by end-use, e.g. heating, cooling, lighting, etc. Knowledge of this will aid design decisions on how to minimize emissions by focusing on the most important issues, particularly when renewable energies are being considered.

ii) *Minimising Energy Demand through the Form and Fabric Design* – Exploiting the knowledge of the role that form and fabric (the building envelope) play in modifying the environment is also key in low carbon building design. Proper use of this skill could help to minimize demand on heating and lighting.

iii) *Insulation and Air Tightness* – A key element of a low carbon design is its ability to reduce unwanted heat losses and gains to the barest minimum possible. To identify the appropriate standard that will aid insulation and air tightness, it is important to understand the heating and/or cooling balance of the building.

iv) *The Use of High Efficiency Building Services with Low Carbon Fuels* – The selection of building services system should consider efficiency and the use of fuels with low CO_2 emissions factors. Designers are to ensure that heating controls are as responsive as possible so as to facilitate the use of solar and internal heat gains from humans and equipment, for example, without overheating the building.

v) *Energy Management System within the Building* – The employment of energy management systems is also advocated for low carbon buildings; system like appropriate metering, censoring devices, etc. The occupants should also be well informed about how the systems work.

vi) *Renewable Energy Systems* – Low carbon buildings harvests its energy from renewable technology systems to reduce CO2 emissions associated the provision of heat and power needs of the building.

It is worthy of note that the RIBA document did not delve into how maintainability consideration could influence the choice of any services system, whereas, it is evidently clear that *"no matter how sustainable a building may have been in its design and construction, it can only remain so if it is operated responsibly and maintained properly"* (NIBS, 2010).

According to RICS (2000) building maintenance is said to be the "*key to sustaining the built environment*". So if maintenance is not imputed into the design of these buildings with so to say 'strange' technologies, it will be difficult to achieve an efficient maintenance practice during operation.

5.4.2 Low Carbon Building Standards

In England and Wales, Part L of the Building Regulations set minimum standards for energy efficiency in both new and refurbished buildings, providing the basis for many low carbon standards that exist. These standards are expressed in terms of improvements over the minimum requirements of the Building Regulations (RIBA, 2009d). Part L of the Regulations is divided into:

i) Part L1A – dealing with regulations for new domestic buildings
ii) Part L1B – dealing with regulations for existing domestic buildings
iii) Part L2A – dealing with regulations for new non-domestic buildings
iv) Part L2B – dealing with regulations for existing non-domestic buildings (Logickworks, 2010)

It is also important to note that the policy on low carbon standards is still evolving and some uncertainty remains (Zero Carbon Hub, 2013). Low carbon research is also a growing area. In 2012 the Cabinet Office consulted widely amongst industry key players concerning the review of the Building Regulations. It proposes changes to the 4 parts of Part L, to meet with plans for the ultimate zero carbon target of 2016 and 2019.

5.4.2.1 Code for Sustainable Homes – The code for sustainable homes is described as the national standard for the sustainable design and construction of new homes in England, Wales and Northern Island (Planning Portal, 2012; GOV.UK, 2013d). It is a measure aimed at reducing carbon emissions and promoting higher standards of sustainable design above the current minimum standards set out by the building regulations. The code deals with more than energy use and carbon emissions; it provides 9 measures of sustainable design, such as: Energy/CO_2, Water, Materials, Surface water runoff (flooding and flood prevention), Waste, Pollution, Health and well-being, Management and Ecology (RIBA, 2009d; GOV.UK, 2013d)

It is classified into 6 levels of compliance; levels 1 to 6, differentiating the rating of the overall sustainability performance of a new home against these 9 categories. However, the CO_2 performance is rated against the 2006 level as provided in Part L of the Building Regulations (RIBA, 2009d). They are classified shown on Table 5.5.

Table 5.11: Code level Classification

s/n	Code Level	Reduction in CO_2 emissions compared with Bldg. Regs., Part L (2006)
1	Level 1	10%
2	Level 2	18%
3	Level 3	25%
4	Level 4	44%
5	Level 5	100%
6	Level 6	'Net Zero Carbon'

Adapted from RIBA (2009d)

For levels 1 – 5, the emissions reduction are assessed based on the Target Emissions Rate (TER) which deals only with emissions related to energy use for heating, hot water and internal lighting. Level 6; net zero carbon was assessed based on all energy use, including energy used for cooking and all electrical appliances, through entirely on-site generation (Zero Carbon Hub, 2013). However, in 2011, 'zero carbon' was redefined by the government to exclude energy use for cooking and electrical appliances (Ibid; UKGBC, 2013).

5.4.2.2 Zero-Carbon Standards – In 2008, the Zero Carbon Hub was established to define and to facilitate the delivery of a single zero carbon standard by 2016 (RIBA, 2009d; Zero Carbon Hub, 2013). In her recent publication of February 2013, the Zero Carbon Hub published 3 criteria, based on the Government's zero carbon home policy shown on the hierarchical triangle in Figure 5.3. These criteria are:

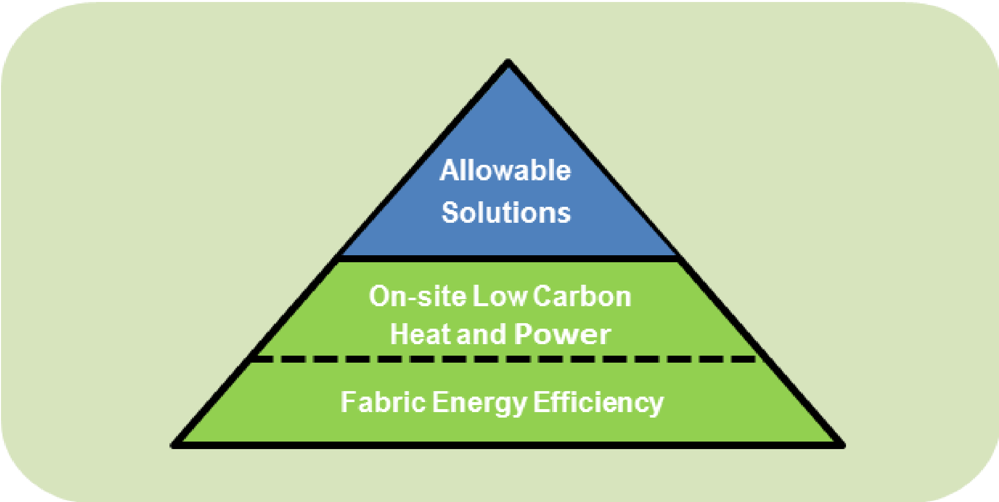


Figure 5.17: The Three Parts of the Government's Stepped Policy Approach to Zero Carbon (Source: Zero Carbon Hub, 2013)

1. the fabric performance, at a minimum, need to comply with the defined standard known as the Fabric Energy Efficiency Standard (FEES) *and*
2. whatever carbon emissions remain after consideration of heating, cooling lighting and ventilation, should be less than or equal to the Carbon Compliance limit established for zero carbon homes, *and*
3. the remaining carbon emissions (after requirements 1 and 2 have been met) must be reduced to zero.

5.4.2.3 The PassivHaus Standard – Also spelt as 'Passive House' in some literature (BRE, 2011a). The concept was developed originally in Germany in the early 1990s by Professors Bo Adamson of Sweden and Wolfgang Feist of Germany (Ibid; RIBA, 2009d). It has also received the support of the

European Commission, and the concept is rapidly becoming a pan-European standard for low carbon homes (RIBA, 2009d).

The main focus of the standard is to effectively reduce the demand for space heating and cooling, whilst also creating excellent indoor air quality (IAQ) and comfort levels (BRE, 2011b). Building Research Establishment calls it *'the world's leading fabric first approach to low energy building'* probably because of its very high level of insulation requirement (BRE, 2011a; BRE, 2011b; PassivHaus Trust, 2013b). BRE (2011a) proposed a functional definition of the PassivHaus as;

> *"a building for which thermal comfort can be achieved solely by post-heating or post cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without additional recirculation of air".*

Summarily, PassivHaus standards require:

- A maximum heating and cooling demand of < 15 $kWh/m^2/year$ or a maximum heating and cooling load of $10W/m^2$.
- A maximum total primary energy demand of 120 $kWh/m^2/year$
- A maximum air exchange rate of 0.6 air changes per hour @ 50 Pa. (Ibid).

<u>5.4.2.4 The Energy Saving Trust: Best Practice Energy Standards</u> – These standards have been incorporated within the Code for Sustainable homes and the Advanced Practice Standard is akin to PassivHaus standard. It has three levels: Good Practice, Best Practice and Advanced Practice Standards (RIBA, 2009d). The *Good Practice Standard* provides similar conditions for meeting Code level 1 of the Code for Sustainable Homes, while the *Best Practice Standards* is also similar to the conditions for meeting Code level 5 (Ibid). Detail requirements of the 3 standards are shown in table 5.6.

Table 5.12: The Energy Saving Trust Standards Requirements

Good Practice Standards	Best Practice Standards	Advanced Practice Standards
10% improvement on 2006 Bldg. Regs.	25% improvement on 2006 Bldg. Regs.	60% improvement on 2006 Bldg. Regs.
No trading off the thermal properties of the bldg. fabric	No trading off the thermal properties of the bldg. fabric	No trading off the thermal properties of the bldg. fabric
Maximum air permeability of 5 m^3/m^2h at 50 Pa	Maximum air permeability of 3 m^3/m^2h at 50 Pa	Maximum air permeability of 1 m^3/m^2h at 50 Pa
		Energy demand for space heating limited to 15kWh/m^2/yr.
		Total primary energy use (for heating, hot water, cooking and appliances) limited to 120kWh/m^2/yr.
Maximum U values	Maximum U values lower than in the Good Practice standard	Lower maximum U values than the Best Practice standard
40% of fixed lighting to only accept energy efficient lamps	75% of fixed lighting to only accept energy efficient lamps	100% of fixed lighting to only accept energy efficient lamps
All domestic appliances supplied to be energy saving	All domestic appliances supplied to be energy saving	All domestic appliances supplied to be energy saving
No mechanical cooling required	Mechanical extract ventilation (MEV) or whole-house mechanical ventilation with heat recovery (MVHR) must be used	Whole-house MVHR must be used and specific fan power must not exceed set limits
	Mechanical cooling system, not required	Mechanical cooling not to be used.

(Adapted from RIBA, 2009d)

5.4.2.5 BREEAM Assessments – Building Research Establishment Environmental Assessment Method (BREEAM) is said to have won an award as *'the worldwide best programme for environmental assessment'* at the World Sustainable Building Conference, 2005 in Tokyo Japan (BRE, 2009). It aim to assess the environmental impacts of buildings with respect to: energy, health and well-being, water, transport, materials, land-use and site ecology, waste, pollution and management (Ibid). Projects are assessed using a form of credit awards according to afore mentioned issues. These issues are assigned weightings in terms of percentages as shown on table 5.7, in order to give an appropriate balance of assessment (RIBA, 2009d). They are assessed against recognised best practice benchmarks and standards (BRE, 2010).

Table 513: BREEAM Weighting Distribution

S/n.	Category	Weighting
1	Management	12%
2	Health and Well-being	15%
3	Energy	19%
4	Transport	8%
5	Water	6%
6	Materials	12.5%
7	Waste	7.5%
8	Land Use and Ecology	10%
9	Pollution	10%

Source: RIBA, 2009d

The weightings are summed up and the resulting score is then used to identify the overall BREEAM rating for the project, using the following ranges shown on Table 5.8:

Table 5.14: BREEAM Rating Scale

Rating	BREEAM Score
Pass	≥ 30%
Good	≥ 45%
Very Good	≥ 55%
Excellent	≥ 70%
Outstanding	≥ 85%

Source: RIBA, 2009d

BREEAM assessment can be carried out using a number of standard methods for different building types; offices, educational, retail, industrial, prisons, courts, multi-residential, etc.

RIBA (2009d) also recommends that a BREEAM Assessor be engaged in the design team early in the design process if a BREEAM standard needs to be met. This will enable the team benefit from the Assessor's early advice on which credits are likely to be readily achievable or challenging. The assessor will also assist with identifying the best and cost effective options for meeting the required standard. BREEAM Assessment can be carried out at the design, construction and/or refurbishment stages of a building (BRE, 2013).

5.5 CONCLUSION: Addressing Climate Change through Sustainable Maintenance

This chapter has been able to establish the fact that the consequences of climate change on the human environment is enormous and perilous and that governments of the world have shown great concern and taken several measures to mitigate and adapt to this phenomenal change, with the UK government playing a leading and exemplary role.

Sustainable development is also discussed in the light of being a vehicle to drive mitigation and adaptation as it balances concerns for the environment with economic and social developments. In the UK particularly, and through the developed nations targets have been set for all buildings (not just new ones, but also old ones that needed refurbishing or extension) to be low carbon. This is seen as a sustainable approach to minimizing emissions. Consequently, the fossil fuel driven building service systems needed to give way to what is considered as 'Clean Technology' or low carbon technologies which are not just new and innovative technologies, but use low energy and/or energy from renewable sources.

However, there seems not to be sufficient or equitable measures in place to ensure that buildings are fitted with systems that are operable and maintainable long into the future in a resource efficient manner. Evidences in literature and results of this research presented in chapter 6 show that building occupants and managers are very often dissatisfied with either under-performance or operation and maintenance difficulties of these new technologies.

The US Green Building Council (USGBC) as its overview statement states that, *'the design and construction of a building is only the beginning of the building's environmental impact; implementing green building operations and maintenance (O&M) practices ensures that building systems achieve maximum efficiency over the life of a building'* (Cassidy and Pinkard, n.d.). McDonald (2007) in his graphical illustration of what he referred to as Sustainable 'Green' Buildings, shows that Good Maintenance practice is one of the six cardinals of sustainable or green buildings. See figure 5.4.

Similarly, Liddell (2008) posits that:

> *"If we are serious about making our buildings green, then it is crucial that we don't get carried away by the trends and the fads. A green building needs to be economic to run, simple to maintain and gimmick-free*".

This implies that buildings designed in response to climate change mitigation and adaptation, like green buildings need to be operated and maintained efficiently. In section 3.2.4, it is argued that sustainable building maintenance is a maintenance process planned and carried out in ways that are resource efficient, exerting little or no impact on the environment, the building and/or its users, and ensuring continued comfort, utility and beauty of the facility, through its life cycle. This implies that sustainable maintenance practice will encourage less need for new build or refurbishment and the accompanying energy needs, emissions, materials, water and associated wastes. Thus saving and coping with the environment (mitigating and adapting to climate change.

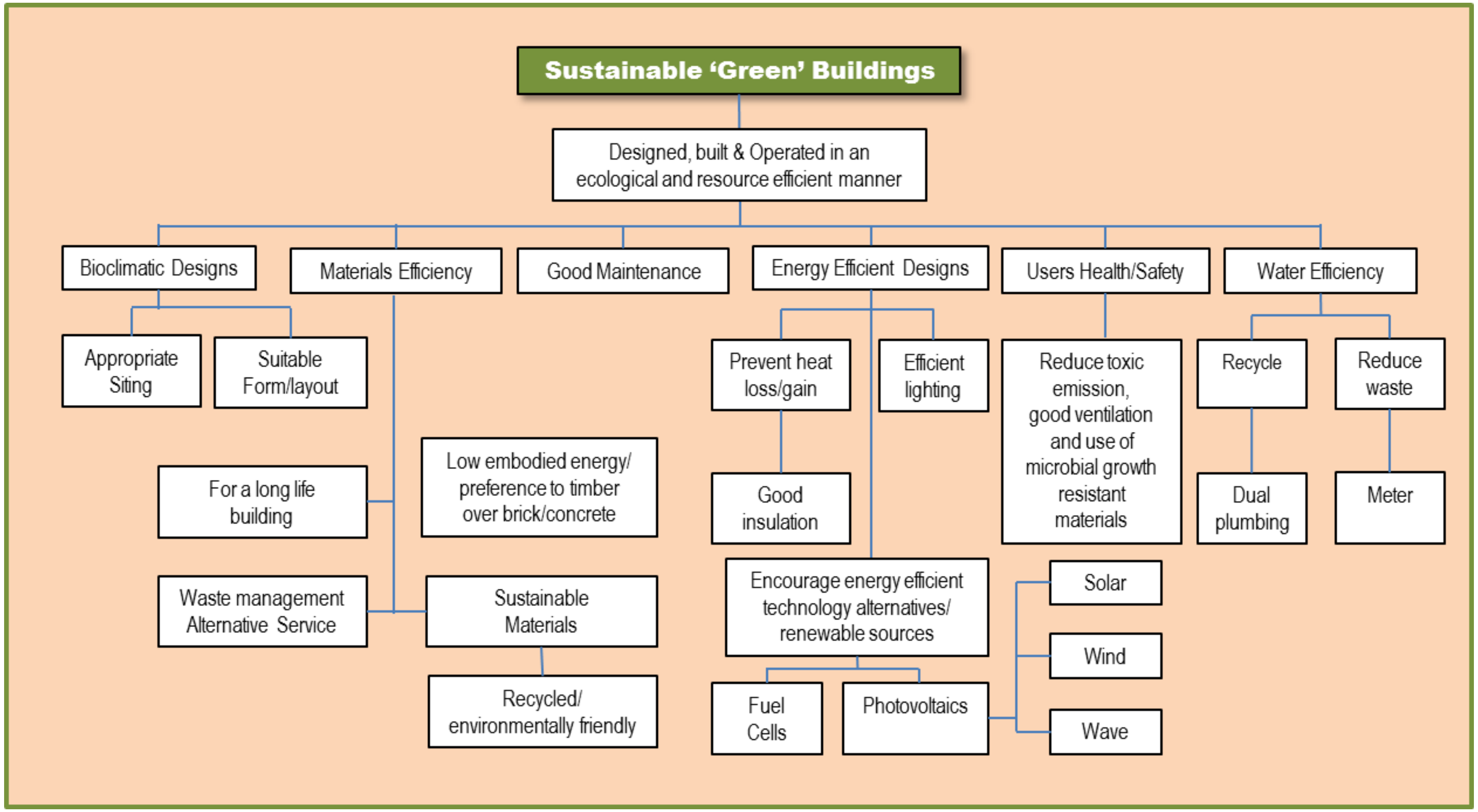


Figure 5.18: Illustration Diagram of a typical Sustainable Building, Incorporating Good Maintenance Practice (Source: McDonald, 2007)

Chapter 6:

OPERATION AND MAINTENANCE CHALLENGES OF LOW CARBON BUILDINGS

6.0 INTRODUCTION

This chapter presents the results and analysis of data gathered from interviews and surveys. The surveys comprise of an online questionnaire intended to complement the interview data, and a hard copy format intended to explore the O&M manual regime in the UK. Details of the methodology used in building up and analysing the data are discussed in chapter 2.

The interview provided opportunities for detailed probing into key projects which the interviewees were involved with, and considered to be exemplary low carbon buildings. The main aim of the interviews was to discover possible case studies and explore the associated challenges with LCBs as well as taking a broad overview of the O&M regime in UK. Information obtained from the interviews and the two surveys were analysed qualitatively and quantitatively and the results are discussed in this chapter.

6.0.1 Executive Summary of Data

1. Data sources include extensive literature search discussed in chapters 3, 4 and 5, preliminary interviews and site visits to the Creative Energy homes and the BedZed mixed-use development in Wallington. The main data sources involving detailed study and analysis reported in this chapter include:

- ❖ Interviews (5 participants – who have been involved in developing, designing, managing or researching about LCBs)
- ❖ Online Questionnaire (15 participants – who have also been involved in developing, designing, managing or researching about LCBs, whom meeting them for a one-on-one interview proved difficult)
- ❖ Hard Copy Questionnaire – Circulated among Facilities Managers and also among members of the Nottinghamshire Construction Forum.

2. Twenty exemplar Low Carbon Buildings (LCBs) within the UK were identified from the interviews and online survey for which the participant have been involved with in developing, designing, managing or researching.

3. About fifty (50) low carbon technologies were identified. The statistics indicate that the micro generation system, solar PV panels were used more than all other technologies. 55% of the 20 buildings identified were fitted with solar PVs. Following next were the HVAC systems; the flat plate collectors were identified in 35% of the 20 buildings. Biomass systems also recorded 35%. Heat Pumps (including Ground Source and Lake Source) were also in 35% of the buildings. Curtain walling was the most popularly used day-lighting enhancement technique. Timber elements were also identified to have been used in various forms on building external façades. The study also identified fabric insulation as the most commonly adopted method for energy efficiency and conservation, and very few buildings adopted a biodiversity strategy like green roof, vertical garden, etc. Lastly, 45% of the buildings identified adopted one system of water management or the other.

4. Most of the technologies were identified with one operational challenge or the other, unique to the respective technologies. Key challenges identified are with the biomass technology where 100% of buildings fitted with the biomass technology reported at least one issues, ranging from temporary out of use, difficult to operate and maintain to outright failure of the system; leading to the system being taken out of use. In one case where the re-bed water filtration system was used, after the retirement of an individual who was manning the system, no one could operate it and the system became moribund. Another case was the recycled water sprinkler to the living wall (vertical garden) which failed, ultimately leading to the death of the plants, and the living wall died.

5. The study also identified that there may be more low carbon development in residential buildings compared to commercial, recreational, educational and mixed-use buildings. This shows to an extent that there is progress towards achieving the 2016 target for zero carbon in the UK home building sector.

6. There were indications that there were fewer tall buildings that are fitted with low carbon technologies in the UK at the time this research was conducted.

7. There were strong indications suggesting that more low carbon buildings may have been built in the UK between 2007 and 2010, and that this may have been influenced by the Low Carbon Building Programme that ran from 2006 - 2010.

8. Results also show that the life cycle cost of low carbon buildings is higher than that of ordinary (non-LCBs) buildings. However, there are valid arguments suggesting that the impacts of fossil fuel on the environment and human health greatly outweigh the difference in cost for renewable technologies. So in creating a balance between Cost vs. clean + ‘cutting edge technologies’ low carbon building designers need to carefully select their specified technologies in line with how they blend with the design overall in order to reduce the operation and maintenance snags.

9. Results of the online survey populated by nearly 70% Architectural professional, and the hard copy survey populated by 50% Facilities manager show that most architects or building designers pay less attention to maintenance and operation issues during design. The interview result also corroborates these findings.

10. It was concluded that in most cases clients were never aware of the O&M implications of their proposed buildings before construction, however, in some cases they were.

11. To make architects think maintenance while designing, 60% of the interviewees said it could be necessary to prove how the building will be operated and maintained, before it is constructed. About 93% of the study population for the hard copy survey also corroborates this.

12. It is already a requirement by law for designers to think through maintenance, however, one of the interviewees questioned; "*the issue is how well do they do this?"*

13. When looking at the issue of how well the building design law is being obeyed suggests that the best solution to improving designers' attitude to operability and maintainability should not end in legislation, but should extend to a cultural or process change (*cultural shift in work attitudes and thinking* on the part of both clients and designers).

14. In July 2011, BSRIA asserts that that construction industry has a poor reputation with regards to O&M manual quality and timeliness of delivery. The reasons for this poor reputation were investigated in this study and the results suggest that:

1) Most O&M manuals lack adequate details that could aid effective operation and maintenance

2) The manuals are just compilations of manufacturers manuals
3) They are being provided just for legal purposes and not fit for purpose
4) The time of delivery does not aid maintainability
5) The manuals in most cases are not transferred to the actual operators in case of lease or re-sale of property
6) Most O&M manuals lack information about the building fabric
7) The Time of delivery does not give clients opportunity of alternative choice of materials, equipment and/or technology
8) The quality of most O&M manuals is poor
9) Most O&M Manuals contain too many details and technicalities that make them too difficult to be useable
10) Most O&M Manuals are not user-friendly

15. Further findings about the O&M manual regime show that preparation of the first draft of the manual is usually commenced from the construction or during handover and commissioning stage of the project. The final draft is then handed in while the building is in operation or during handover/commissioning and in few cases, still within the construction period.

16. The intended purposes of O&M manuals for buildings in the UK: as prescribed by the 1965 Committee on Building Maintenance of Ministry of Public Building and Works which included:

- ❖ enabling the property manager to organise the repair and maintenance of the building, its services and surrounds effectively and economically;
- ❖ enabling the occupier to clean and operate its services efficiently and reduce losses of time and production;
- ❖ establishes a link between the project design team and the client and his maintenance organisation to their mutual benefit;

- ❖ provides basis for improved future design through lessons learnt from previous projects.

The results returned below average rating on the extent to which O&M manuals has met these expectations.

17. 100% of the respondents in the online survey agreed to the statement that 'if properly prepared, the O&M manual can act as a bridge to the existing gap between designers and operators of buildings'; while a total of nearly 80% of the hard copy survey respondents agreed that the O&M manual is an indispensable document for LCBs. 100% of interviewees also believed the O&M manual remains a needful document for the effective and efficient operations of buildings with new technologies.

18. Findings also show that the way forward for the O&M manual regime in the UK will entail:

- ❖ Integrating the O&M Manual Process into the Design Process
- ❖ Involving O&M Manual Specialists from the Design Stage
- ❖ Develop a first Draft of the O&M Manual at the Design Stage
- ❖ Providing Information in User-Friendly Formats
- ❖ Separate Technical Details from Users' Operation and Maintenance Guide
- ❖ Physical Examples of where Products have been Used

6.1 DATA COLLECTION AND ANALYSIS METHODS

6.1.1 Preliminary Data

Besides the extensive literature search discussed in chapters 3, 4 and 5, the preliminary studies also involved some informal unstructured interviews and site visits to The Creative Energy Homes, here in the department of Architecture and Built Environment, University of Nottingham as well as The BedZed mixed-use development in Wallington, South-London. The purpose of these preliminary studies was to inform a better understanding of the role of an O&M manual in informing maintainability, as well as informing a tangible perception of low carbon buildings and low carbon technologies and their associated Operation and maintenance challenges.

6.1.1.1 Preliminary Interviews

At the early stage of the research, informal interviews were conducted with two senior officers in the University's Estate Department. The interviews were informal without any set of outlined questions (unstructured interview format). However, the aim of the interviews were to determine how a typical O&M manual influences the maintenance of building and if there are any legal demand for a manual for every building. One of the interviewees was a senior building surveyor and the other, an administration/business systems manager.

During the Interview notes were taken, and some of the findings are:

- The Surveyor expressed surprised that a researcher with architecture background thinks of maintenance.
- The respondent conjectured that most Architects do not give attention to maintainability, giving instances of some of his site and commissioning experiences, where the architects confessed of not

given a thought on how the elements or components in question would be maintained.

- And that in some cases, this lack of maintenance consideration by the designers had led to building owners acquiring expensive machineries for maintenance purpose even for cases of changing ordinary lighting bulbs.
- When asked if there are legal compulsion demanding for the production of the O&M manual or if it was just a tradition? The answer was; *"Yes, it is a legal requirement for building owners to be provided with a description of how to operate and maintain the building".*
- The Building Files for the Sustainable Research Building (SRB) building was brought from the archives as a typical O&M manual. It consists of 8 volumes of files made up of Health & Safety file with Operating & Maintenance Manuals.
- The Estate department do not regularly make reference to the document for maintenance or operation, that is why it was put out to the archives, rather electronic software are being used to monitor, regulate and order maintenance works.
- The PPM (Planned Preventive Maintenance) manager uses the manual at the initial stage by extracting the relevant PPM information from the O&M section of the document and feeds it into the maintenance system operated by the department

Further probe of the CDM Regulation was also made and it was noted that the CDM Regulation 2007 Approved Code of Practice (ACoP) was the latest version at the time. Relevant outcomes are discussed in the result and discussion section of this chapter.

6.1.1.2 Creative Energy Homes

This preliminary study involved one-on-one interview with occupants of the respective buildings and with a colleague (PhD researcher) working on one of houses that is un-occupied; the EON house. A guided walk-through physical identification of the technologies in the buildings was also carried out for each of the five buildings. Further information about the creative energy homes were also sourced from the University's website. Feedbacks from the creative Energy Homes study are also included in the final results analysed for this research.

The Creative Energy Homes project was said to be one of the most outstanding achievements in the University's sustainability success story (Nottingham Science City, 2012). The project is sited on Green Close at the University Park campus, close to the University's North entrance, off the A52, Derby Road axis. The development was also said to be a showcase of innovative state-of-the-art, energy efficient homes for the future, addressing concerns over global warming, fuel poverty and CO_2 emissions (Ibid). The Creative Energy Home Project aims to stimulate sustainable design ideas and promote new ways of providing affordable, environmentally sustainable housing that are innovative in their design (UoN, 2011a). They are being developed and managed by The Institute of Sustainable Energy Technology of the Department of Architecture and Built Environment of the University in collaboration with industrial partners like: BASF (building materials manufacturers), E.ON (Power generation and supply company) and TARMAC (Contracting firm).

They were designed and built to various degrees of innovation and flexibility to allow the testing of different aspects of modern methods of construction and sustainable/renewable energy technology systems (UoN, 2011b).

They not only provided students from the department with the opportunity to be involved with the design, construction and research elements of live zero carbon housing projects, but also serve as reference cases to the wider industry. Prof Mark Gillott, in a podcast (19 Oct., 2011) titled 'Sustainable Futures – Creative Energy Homes' noted that for industries to meet the UK's ambitious target of reducing carbon emission to zero in all new homes by 2016, *"it is important to understand what technology works and where solutions lie and where they could come from"*. So these homes provide such opportunities to designers, developers (private/public) and component manufacturers. The project won the Civil Engineering Award at the Engineer Technology and Innovation Awards in December 2009 in recognition of its relevance and industrial collaboration (UoN, 2011a).

The project consists of 7 houses, two (2) of which were still under construction at the time of this study. The five (5) houses that were completed at the time of this research include:

- ❖ David Wilson Millennium Eco-House
- ❖ BASF House
- ❖ TARMAC Masonry Home (Built to Code 6 standards)
- ❖ TARMAC Masonry Home (Built to Code 4 standards) and
- ❖ E.ON 2016 Research House.

The David Wilson House was being used as offices for research staff of the department at the time of the study, while the rest were rented out to research students of the department, except the EON house that was unoccupied at the time.

6.1.1.3 Beddington Zero Energy Development (BedZed)

A field trip was organized by the department of Architecture and Built Environment for Master's degree students to BedZed factory at 21 Sandmartin

Way, Wellington in Surrey, South of London. The researcher seized the opportunity to be part of the trip with the aim of developing and broadening knowledge in low carbon technologies and their associated O&M challenges. At the BedZed two architects who were at the time of study, also part of the management team, led a guided tour of the facility. Questions and answers were entertained intermittently through the tour, and relevant notes taken in the process. The information gathered also formed part of the data analysed for the research.

The BedZed was said to be built in 2002 on a brownfield site, and was one of UK's largest mixed-use, zero carbon development, at the time. It houses 82 homes comprising of flats, maisonettes and town houses, and up to 2500m^2 let-able work/office spaces. A combination of several low carbon technologies were used here; including Biomass, PV for combine heat and power (CHP), Water recycling and filtration system, Green roofs, Thermal mass, Natural ventilation and Timber wall cladding. Some problems were also identified and discussed later in this chapter.

6.1.2 Interviews

The *semi-structured* type of interview was used in preference to structured or unstructured interviews for this research to enable probe for further insights and clarification while maintaining some structure in the views collected and to facilitate a reasonably stress-free analysis.

6.1.2.1 The Purpose of the interviews

The interviews created platform to discover possible case studies; explores the low carbon technologies in the cases and their associated operation and maintenance challenges. Flyvbjerg (2006) argued that selection of subjects for a case study is better based on information-oriented sampling than based on random sampling. This was why it became necessary to first talk with professionals who have been involved in design, construction, management and research of low carbon buildings, to enable collection and analysis of information that could lead to choosing suitable case(s) for in-depth study.

The participants' experiences with respect to the operation and maintenance challenges faced by users in the building, as well as their individual experiences of procuring, designing, managing and researching low carbon buildings generally; including the feedbacks they got from direct users of the property, were also explored. The interviews were also tailored as to tap from the wealth of experience of participants, what in their opinion could be the place of the O&M manual in buildings fitted with new and low carbon technologies and a best practice approach to its drafting and use.

6.1.2.2 The Process of collecting and analysing the interview data

A semi-structured qualitative interview format was adopted; using the interview protocol discussed in Creswell (2009) and also in line with the University research ethics discussed in chapter 2. Sample questions along with general information about the research and interviewee consent form were sent in advance to the interviewees. The questions are in semi-structured format, with structured open ended questions. The model was designed to allow participants the flexibility of expressing themselves in their own words. Questions were also not restrictive to the outlined set of questions and in some cases not following the outlined order as further probing also emanated from responses of the participants. The reasons were to enable detailed exploratory and in-depth probe into the maintainability ethos in the UK. The interviews were conducted on a one-on-one basis with the individual participant alone at venues, times and dates chosen by the participants.

The discussions were recorded in a digital voice recorder and transcribed with the aid of transcription software, '*Express Scribe*'. The transcribed document in Microsoft word were sent along with the original recoding in a window media audio format to respective participants to confirm that the transcribed documents were true transcriptions of the interviews. They were also at liberty to retract any statement they so wish with no reason given, by editing the transcribed document. The reviewed copies from the participants coupled with notes taken at time of the interview became the raw data for analysis.

The interview data were analysed using the thematic content analysis method which has been discussed in detail in section 2.4.1. This involved coding the data by themes drawn from existing theoretical knowledge (deductive coding) and from the data itself (inductive coding). The deductive themes were based on the set objectives of the interviews. This method of analysis also involved some numerical analysis; what is referred in literature as partial quantitative method as discussed in section 2.4.1.

6.1.2.3 The Population Characteristics

Over 40 requests for interviews were sent out by emails, only 5 interviews were granted as most of those contacted were either too busy to find convenient time or declined out-rightly for reasons of not being involved with LCBs. However, most of the participants are very experienced professionals and sit at the topmost management level of their respective organisations. 80% of them (4 out of 5) had over 30 years' experience in their respective fields of practice. See summary on Table 6.1.

Although the interviewed population was small, it provided detailed insight into the subject. Similar work reported in Dawood et al, 2013 which was directed at understanding current architectural design practices with respect to low carbon designs in the UK was also informed by interviews involving five participants drawn from large architectural practices in the country.

Table 6.1: Summary of Building Professionals who took part in the Interviews

S/no	Code No. of Participant	Years of Experience	Professional Background	Professional groups according to the nature of job
1	001	30	Engineer	Client & Facilities Manager
2	002	Less than 10	Planning & Development Surveyor	Client
3	003	30	Building Surveyor	Facilities Manager
4	004	30	Architect	Building Design Practitioner & Academic Researcher
5	005	37	Architect	Academic Researcher

In terms of their professional disciplines, 2 of the interviewees (40%) were architects, while the rest 3 spread across the disciplines of building surveying, engineering and planning/development surveyors; each accounting for 20% of the population. Although the spread did not go through all the built environment professional disciplines, it covered a wide spectrum of stakeholders in the built environment; clients, Designs, facilities managers and built environment researchers. Secondly, the vast years of experience they have acquired in working with other building professionals provides a good level of reliability in their opinions. In addition, most of the participants sit at the top decision making bodies of their organization, where they receive feedbacks from other experts. By research ethics, it is not possible to indicate the position held by the participants in order not to infringe on the anonymity rules. However, appendix C Shows details of the interview analysis, which also gives a brief description of each participants.

6.1.3 Structured On-Line Questionnaire

After the interviews were collated and analysed, the structured questionnaire in web format was developed and sent to some professionals who were not able to make out time for a one-on-one interview and other professionals identified at various professional forums.

6.1.3.1 Purpose of the Online Survey

The online survey was intended to reach a wider population of participants and also to allow for quantitative analysis of data. It was also designed to complement the results of the interview; to further explore possible case studies and their associated O&M challenges of the specific buildings the participants may have been involved with.

6.1.3.2 Process of Collecting and Analysing the Online Survey

The Interview questionnaire provided the structure for the survey questions. It was revised from open ended questions to a structured format, where options were given to reduce the length of time participants could spend on the questionnaire. Multiple choice and ranking questions were therefore developed; the interview feedbacks gave the clue for the options provided on the survey. However, there were also few open ended questions.

The web based survey was developed using the Survey Monkey tools, results collected and preliminary analysis done using the Survey Monkey. The results were further analysed quantitatively using the Microsoft Excel software. Link to the survey is: https://www.surveymonkey.com/s/LCB-OandMMsurvey.

The link was sent through email communication to contacts made at the Ecobuild 2011 and 2012, ThinkFM Conference in 2011 and the ACA Debate, 2012.

6.1.3.3 Proofing/Validating the Questionnaire

Before sending out the online survey to the participants, a test case was first circulated, also using the Survey monkey software. The reasons of this test case were:

- ❖ to test for understanding and usability of the software
- ❖ to test the effectiveness of the software as an analysis tool
- ❖ to test respondents reactions to the questions put to them

- ❖ to ensure that questions are sound and do make sense
- ❖ to gain experience of colleagues and some member of staff of the department on questionnaire design
- ❖ to test the average length of time it will take to complete the survey
- ❖ to test/ensure that results are analysable

Participants chosen for testing the survey included colleagues and staff in the research group, colleagues in the department and some academics outside the University of Nottingham. The number was restricted to selected few in order to avoid resending to the same people again during the actual survey.

7 respondents participated; some sent their comments through email and some through telephone conversation. These comments helped in reshaping the final questionnaire sent out online. The test survey could be assessed through the link: https://www.surveymonkey.com/s/lcb-OandM.

6.1.3.4 The On-line Population Characteristics

A summary of the population characteristics shows that Architects still topped the list with about 58%, others include building surveyors, facilities managers, urban planners and architectural technologists as shown on figure 6.1. When grouped according to the nature of job they perform as in figure 6.2, the result shows equal percentage of design practitioners and researchers; each forming one-third of the population. This indicates a possible balance in academic and practical opinions. Those who engage in managing facilities rose to nearly 17%. More diverse building professionals took part in the study; including urban planners, project managers and architectural technologists. This diversity provided opportunity for wide range of views.

Grouping the participants according to the type of organization they work for shows a near equal distribution between those who work in private consulting firms and those who work in academic research bodies as shown on figure 6.3. This further stressed the potential of the result yielding a balance between academic and real practice perspectives.

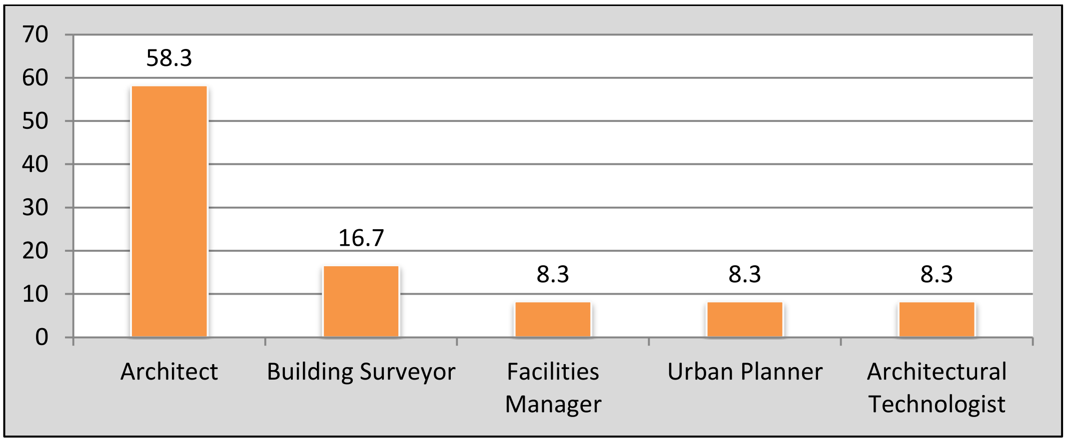


Figure 6.1: % Distribution of Building Professionals who took part in the Online Survey

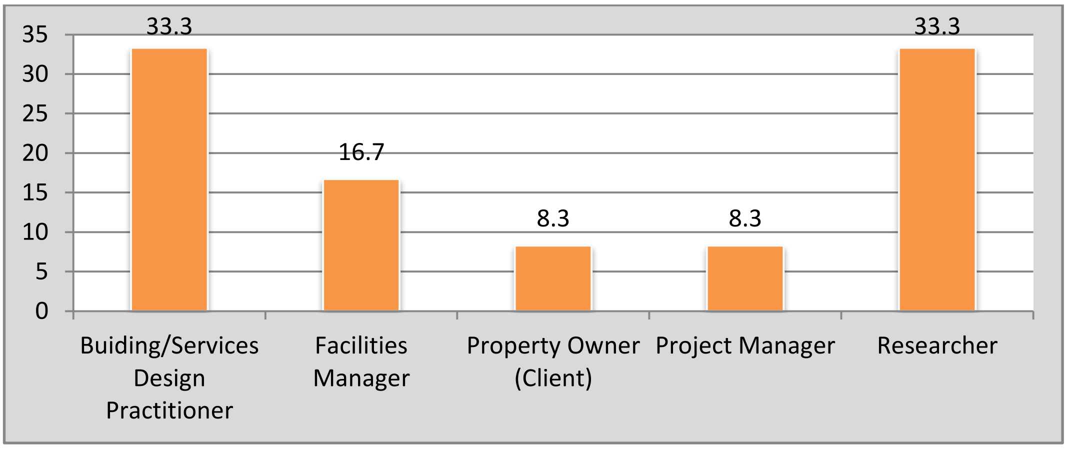


Figure 6.2: % Distribution of Professional groups (according to the nature of job) who took part in the Online Survey

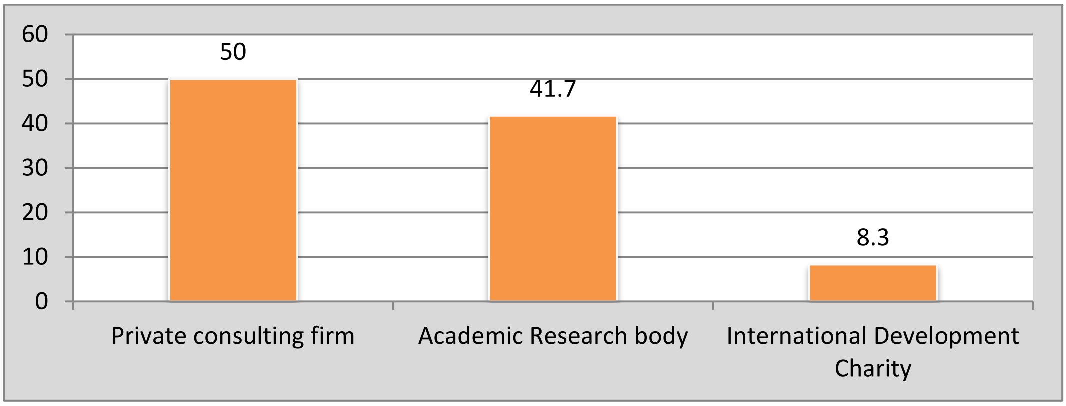


Figure 6.3: % Distribution of Professional groups (according to type of organization) who took part in the Online Survey

6.1.4 Hard Copy Questionnaire

The result of earlier web-based Survey showed that the actual people who manage buildings; facilities managers did not participate much in the survey; just about 8% only, while Architects and architectural technologists were 58.3% and 8.3% respectively. The interview also returned more participation of architects than other built environment professionals. Wider participation was therefore sought through meeting professionals at a one day conference of the British Institute of Facilities Management (BIFM) - 'ThinkFM, 2012', held in London. Views were also sort at the Nottinghamshire Construction Forum (NCF) at The Basford New College's CPD Centre in Nottingham. Nottinghamshire Construction Forum is a pan-industry organisation for construction in Nottinghamshire (NCF, 2012).

6.1.4.1 The Purpose of the Survey

This survey was particularly aimed at trying to understand the O&M manual regime in the UK. This second survey was not restrictive to low carbon buildings and was not focused on any particular building. The main purpose of this survey was to have clearer understanding of the O&M manual regime in UK and what the people who manage buildings (the facilities managers) think about it; including contractors' opinions. Although the interview and online survey also explored the O&M manual regime in addition to their main objectives of identifying LCBs and their O&M challenges, the percentage of facilities managers involved was small, contractors were also not involved.

6.1.4.2 The Process of Collecting and analysing the Survey Data

A total of 58 questionnaires were handed out at the two events; ThinkFM and NCF as discussed in section 6.1.3 with a self-addressed stamped envelope included in the pack for return of questionnaire. 14 responses (about 24%) were received and analysed quantitatively. The open ended comments were analysed using the thematic content analysis method adopted for the qualitative interviews.

The returned questionnaires were manually and carefully fed into the survey monkey for analysis. The final results were now presented using the Microsoft Excel software. The open ended questions were analysed using the thematic content analysis method discussed in section 2.4.1.

6.1.4.3 The Population Characteristics

In this survey, a grouping of the participants according to the organizations they represent reveals a very wide variety, including: private contracting firms – 35.7%, private consulting firms and academic research bodies were 21.4% each, public client organizations and construction charities recorded 14.3% and 7.1% respectively, as shown in figure 6.4. Grouping according to their professions shows that facilities managers constitute 50% of the population of participants. Other participants include architects, building services engineers, chartered builders, Health and Safety officials, quantity surveyors and value engineers, as shown in figure 6.5.

A further grouping according to their status in their organizations as shown in figure 6.6 reveals that over 80% of the respondents here sit at the management level of their respective organizations. This is made up of nearly 60% as senior management staff, 21% CEOs and 7% management staff. Again, this population distribution shows that most of the participants in this survey may have considerable experience in managing buildings and building works, and holds out a potential of reliability in their opinions.

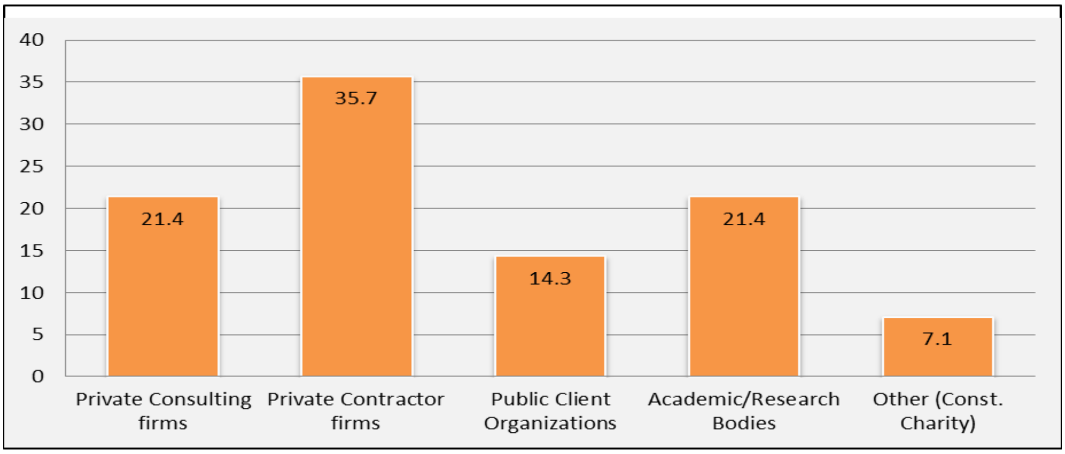


Figure 6.4: % Distribution of Building Professional Organizations Represented in the survey participants

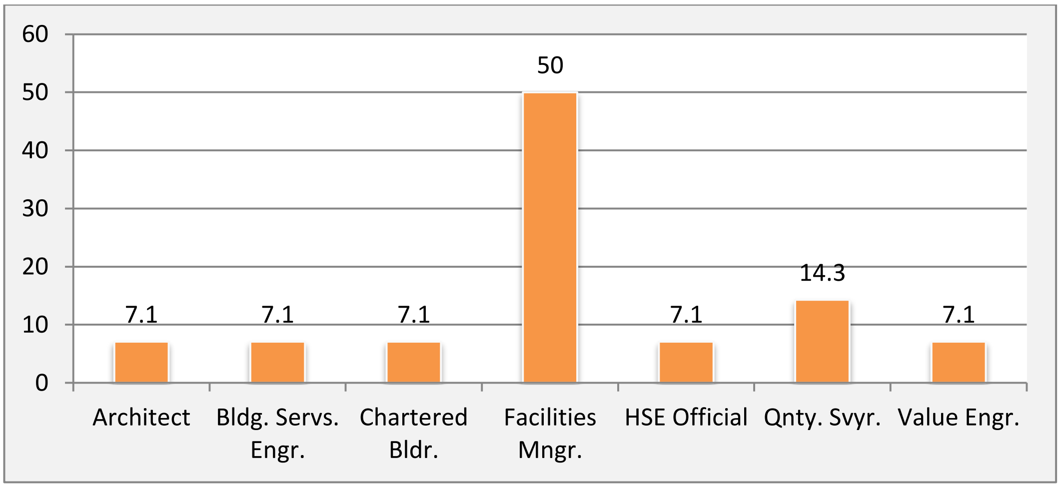


Figure 6.5: % Distribution of Professionals who took part in the survey

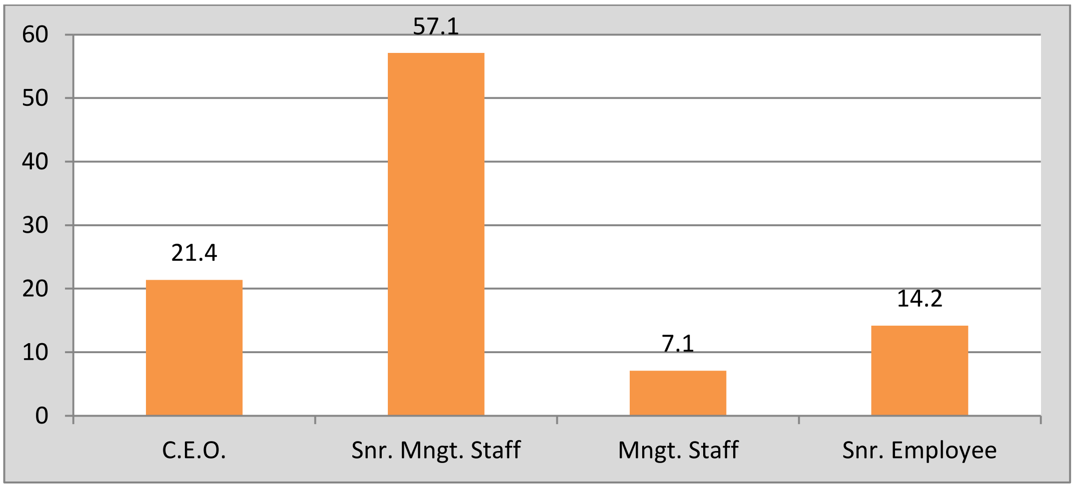


Figure 6.6: % Distribution of Status of Personnel who participated in the Survey

6.2 LOW CARBON BUILDINGS AND TECHNOLOGIES IDENTIFIED IN THIS STUDY

Table 6.2 is a summary of the twenty exemplar low carbon buildings identified from the results of the interviews and online survey. Few cases were also identified from preliminary studies and online web search. A few of the buildings are also shown pictorially on figure 6.7.

Table 6.2: List of Exemplar Low Carbon Buildings Identified in the Study

S/n.	Name and Address of Building	Building Type & (Height)	Total Floor Area and (Age)	Sources of Data
1	**No.1 Nottingham Science Park** Jesse Boot Avenue, Nottingham. NG7 2RU	Commercial (low-rise)	5,109.67m² (2 – 5yrs)	Interview
2	**Creative Energy Homes** Green Close, University of Nottingham NG7 2RX: David Wilson Millennium Eco-House	Residential (low-rise)	137m² (Over 10yrs)	Questionnaire;
3	**Creative Energy Homes** Green Close, University of Nottingham NG7 2RX: BASF House	Residential (low-rise)	112m² (5 – 10yrs)	Interview with occupants
4	**Creative Energy Homes** Green Close, University of Nottingham NG7 2RX: Tarmac Masonry Home 1 (Code 6)	Residential (low-rise)	99m² (2 – 5yrs)	Interview with occupants
5	**Creative Energy Homes** Green Close, University of Nottingham NG7 2RX: Tarmac Masonry Home 2 (Code 4)	Residential (low-rise)	86 m² (2 – 5yrs)	Interview with occupants
6	**Creative Energy Homes** Green Close, University of Nottingham NG7 2RX: E.ON 2016 Research Houses	Residential (low-rise)	106m² (2 – 5yrs)	Interview with a project researcher
7	**Sustainable Research Building** DABE, University of Nottingham.	Educational (low-rise)	1,762m² (10 yrs)	Questionnaire; Pilot Studies
8	**Zedfactory,** Sandmartin Way, Wallington, Surrey	Mixed Use (low-rise)	No Information (5 – 10yrs)	Site Visit
9	**Jubilee Wharf** Penryn, Cornwall	Mixed Use (Mid-rise)	3,000m² (5 – 10 yrs)	Questionnaire
10	**The living wall** Paradise Park, Children Centre, Islington, London	Recreational (low-rise)	No Information (5 – 10 yrs)	Email correspondence; Web search
11	**Bio-Energy Building** Sutton Bonington Campus, Unv. of Nottingham	Educational (low-rise)	3,100m² (below 2 yrs)	Questionnaire
12	**Sir Colin Campbell Building,** Jubilee Campus, University of Nottingham	Educational (low-rise)	4,534m² (2 – 5yrs)	Questionnaire
13	**Private Residential Building** High Wycombe, London	Residential (low-rise)	No Information (over 10yrs)	Questionnaire
14	**Romero House** 55 Westminster Bridge Road, London.	Commercial (Mid-rise)	33,000m² (2 – 5yrs)	Questionnaire
15	**Green Street Development,** Meadows, Nottingham	Residential (Low-rise)	No Information (below 2yrs)	Interview
16	**Phoenix Square** Midland Street Leicester	Mixed Use (Mid-rise)	No Response (2 – 5yrs)	Interview
17	**Julian Marsh Private Residence,** Meadows, Nottingham	Residential (Low-rise)	No Information (2 – 5yrs)	Interview
18	**Peveril House** West Bridgeford, Nottingham	Residential (low-rise)	No Information (2 – 5yrs)	Interview
19	**CSET Building** China Campus, Univ. of Nottingham	Educational (Mid-rise)	1,300m² (2 – 5yrs)	Interview; Web search
20	**The Gateway Building** SB Campus, University of Nottingham	Educational (Low-rise)	3,253 (below 2yrs)	Interview

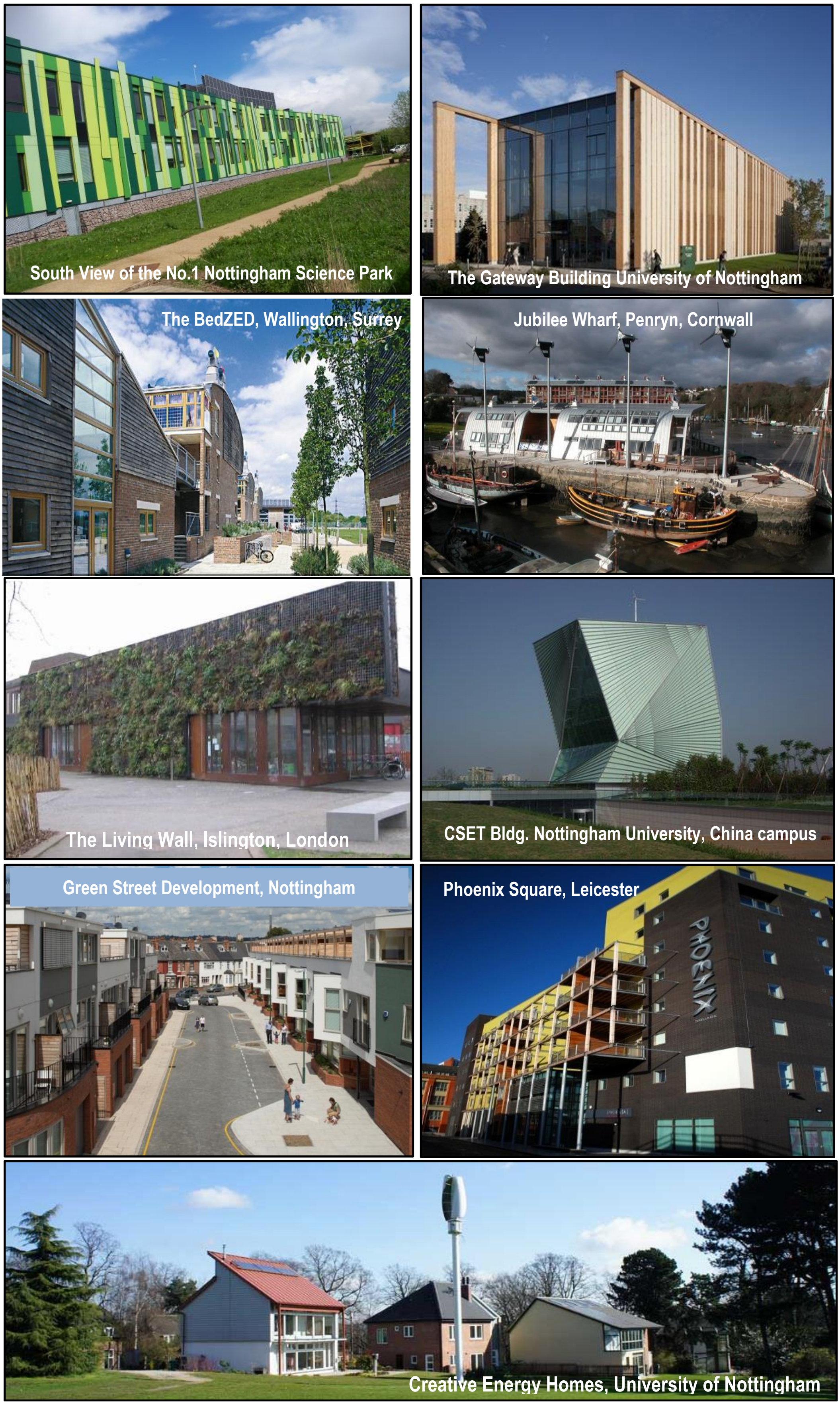


Figure 6.7: Pictures of some of the Exemplar Low Carbon Buildings in the study

6.2.1 Low Carbon Technologies

The study identified some of the low carbon technologies that are fitted to the buildings under investigation. They represent small scale low carbon technologies that are commonly used in low carbon buildings in the UK, although some are innovative and unique to the buildings they are identified with. Table 6.3 is a summary of the identified technologies. In some cases, additional online search about the buildings where little was reported in the questionnaires was also carried and the list updated. An example is the CSET building of the China Campus of the University of Nottingham. The interviewee only mentioned the fact that it was an award winning exemplar low carbon building. Internet search and further email correspondence with a staff directly overseeing activities in that building were explored.

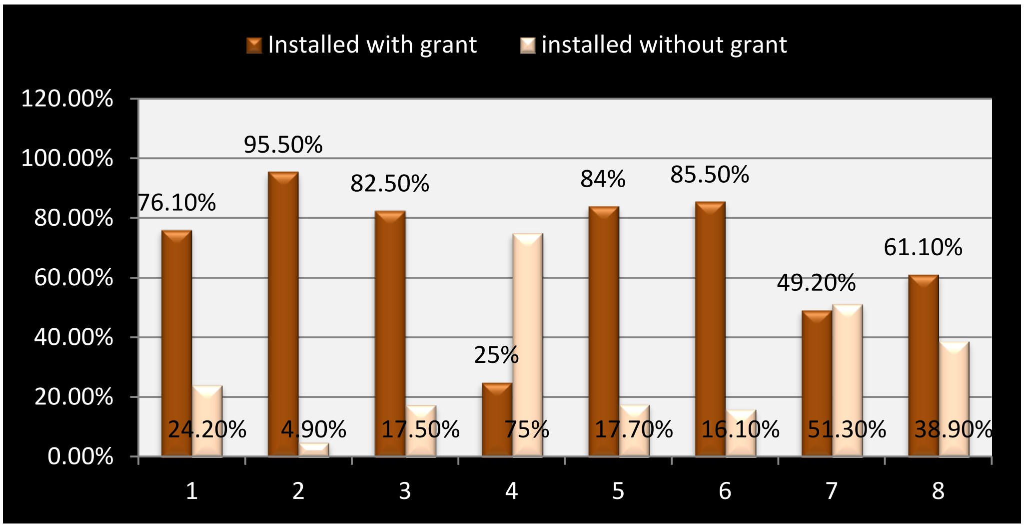
On the whole, about fifty (50) low carbon technologies were identified and grouped according to their broad type of technology; e.g., Renewable micro-generation systems, Heating, Ventilation & Cooling (HVAC) systems, etc. as shown on table 6.4.

The result shows that among the ***micro generation system*** solar PV panels are used more than the others. 55% of the 20 buildings identified were fitted with solar PVs. This result can be compared with the statistics of the LCBP published in Gardiner et al (2011). The statistics is based on their customer satisfaction survey which ran from 2009 – 2011. See figure 6.8, which shows that Solar PV received more funding in terms of number of grants than any other technologies. This suggests that more people may have installed solar PVs in the UK than any other technologies being funded by the LCB Programme.

Table 6.3: Some Low Carbon Technologies in the Buildings Highlighted in the Study

<table>
<tr><th>S/n.</th><th colspan="2">Name and Address of Building</th><th>Some Low Energy Techs in the building</th></tr>
<tr><td>1</td><td colspan="2">No.1 Nottingham Science Park Jesse Boot Avenue, Nottingham. NG7 2RU</td><td>Biomass boiler; Solar PV; Adiabatic cooling/natural vent; Motion activated lighting; Brown roof; Composite Window/Curtain Walling frames, SURDS.</td></tr>
<tr><td>2</td><td rowspan="5">Creative Energy Homes Green Close, University of Nottingham NG7 2RX</td><td>David Wilson Millennium Eco-House</td><td>Solar PV; CHP-sterling engine; Vacuum tube collectors, Wind turbine, Solar thermal (FP); Sun pipe; PV based extractor fan; Timber Window Frames</td></tr>
<tr><td>3</td><td>BASF House</td><td>Passivhaus standard conformity; Biomass boiler; Ground Air Heat and cooling exchange system; natural ventilation; Phase change material; Web-Brick technology; Insulated concrete framework; Sun space; Rain water harvesting; BASF paint on roof, GSHP</td></tr>
<tr><td>4</td><td>Tarmac Masonry Home 1 (Code 6)</td><td>Biomass boiler; Heat recovery system; Solar thermal (FP); Solar PV; Sun space; Rain water harvester</td></tr>
<tr><td>5</td><td>Tarmac Masonry Home 2 (Code 4)</td><td>Biomass boiler; Heat recovery System; Rain water harvester</td></tr>
<tr><td>6</td><td>E.ON 2016 Research Houses</td><td>Built as 1930 houses and retrofitted with: Double glazing; Wall insulation; floor ceiling; Loft insulation; Low Energy bulbs; Electric car charging devices</td></tr>
<tr><td>7</td><td colspan="2">Sustainable Research Bldg. University of Nottingham.</td><td>Solar PV; Micro wind turbine; Timber framed windows; Motion activated lighting; Skylight; e-window glasses</td></tr>
<tr><td>8</td><td colspan="2">Zedfactory, Wallington, Surrey SM6 7DF</td><td>Biomass boiler; Solar PV; Timber cladding; Thermal mass; Green roof; Re-bed water filtering system</td></tr>
<tr><td>9</td><td colspan="2">Jubilee Wharf Penryn, Cornwall</td><td>Solar thermal (FP); Biomass; Thermostats; e-window glasses; wind turbines; Timber cladding; Timber framed windows</td></tr>
<tr><td>10</td><td colspan="2">The living wall Paradise Park, Children Centre, Islington, London</td><td>Flowering plants on wall with automated watering system</td></tr>
<tr><td>11</td><td colspan="2">BioEnergy Building Sutton Bonington Campus, University of Nottingham</td><td>Biomass Heating; thermostats; Motion activated lights; High insulation walls; Skylight; light pipes; curtain walling</td></tr>
<tr><td>12</td><td colspan="2">Sir Colin Cambell Building, Jubilee Campus, University of Nottingham</td><td>GSHP (lake source); Controlled venting & ducting; High insulation walls;</td></tr>
<tr><td>13</td><td colspan="2">Private Residential Building High Wycombe, London</td><td>Solar PV; High insulation walls; Thermostats; Curtain walling; Composite windows</td></tr>
<tr><td>14</td><td colspan="2">Romero House Westminster Bridge, London.</td><td>Solar PV; Solar thermal (FP); GSHP; Motion activated lighting; Thermostat; e-window glasses; Skylight; Timber cladding</td></tr>
<tr><td>15</td><td colspan="2">Green Street Development, Meadows, Nottingham</td><td>Solar PV; Natural stack ventilation; Timber solar shades; High insulation walls; Mechanical heat recovery; Automated blinds.</td></tr>
<tr><td>16</td><td colspan="2">Phoenix Square Midland Street Leicester</td><td>Solar Thermal (FP); GSHP; Solar shading; Nat. ventilation; Rain water harvesting; low energy bulbs;</td></tr>
<tr><td>17</td><td colspan="2">Architect Julian Marsh Private Residence, The Meadows, Nottingham</td><td>A passivehaus; GSHP; Solar thermal (FP); Solar PV; Compost toilet; Rain water recycling; night cooling;</td></tr>
<tr><td>18</td><td colspan="2">Peveril House West Bridgeford, Nottingham</td><td>Solar thermal (FP); GSHP; Evacuated tubes; Solar Sun-Box;</td></tr>
<tr><td>19</td><td colspan="2">CSET Building China Campus, University of Nottingham</td><td>Solar PV; Green roof; Wind turbine; Solar powered chillier; GSHP; E-tube ventilation system; Double skin façade; Radiant thermal slab; Weather station, Water harvesting/grey water recycling;</td></tr>
<tr><td>20</td><td colspan="2">The Gateway Building SB Campus, University of Nottingham</td><td>Straw bale insulation; Timber external fenestration; Curtain walling</td></tr>
</table>

Q. Which renewable technologies have you had installed? Which did you receive an LCBP grant for?



Alternatives		No
1	Solar Thermal Hot Water	1,495
2	Solar PV	1,501
3	Wind Turbine	63
4	Small Scale Hydro	4
5	Ground Source Heat Pump (GSHP)	175
6	Air Source Heat Pump (ASHP)	379
7	Wood Fuelled Boiler	187
8	Pellet Stove	18
TOTALS		**3,822**

Figure 6.8: LCBP Statistics (Source: Gardiner et al, 2011)

Among the ***HVAC systems***, the flat plate collectors, biomass and Heat Pumps (including Ground Source and Lake Source) take the lead with 35% each. The two most popular solar hot water systems are the flat plate solar thermal system and evacuated solar collectors. The evacuated collectors returned 10%, so total percentage of buildings fitted with solar hot water systems would be 45%. This is next to the solar PV of 55%, and also agrees with the LCBP statistics which presents solar thermal hot water beneficiaries in second position to PVs. Solar thermal hot water had 1,495 beneficiaries while Solar PVs had 1,501 beneficiaries (figure 6.8).

Day-lighting enhancement system featured 3 technologies, with the traditional curtain walling being the most popularly used. 20% of the buildings identified in the study adopted curtain walling system, while sky-lighting and solar sun pipes were 15% and 10% respectively.

The study noted that ***timber elements*** are being used in various forms on building external façades as wall claddings, window frames and solar shades. They are also combined with Aluminium or other weather resistant materials to form composite frames for windows and curtain walling. In all, about 60% of the buildings identified adopted the use of timber in one or more of these forms.

The study also identified fabric insulation as the most commonly adopted method for ***energy efficiency and conservation***. Also common is the use of motion activated lighting system and thermostats with 20% each.

Buildings which adopted a ***biodiversity strategy*** were relatively few. Only two buildings were found with green roof and another one with brown roof, accounting for just a total of 15% of the buildings. The building with the brown roof also adopted a drainage system referred to as SUDS – Sustainable Urban Drainage System which also enhanced biodiversity by encouraging the growth of bulrushes and aquatic lives. One building also adopted a Green wall system, what is referred to as the 'Living Wall'. It was said to be a pioneering green concept which developed a system of rooting different species of plants on walls and watered with a recycled water pumping system (Bar-Hillel, 2009).

30% of the buildings adopted a ***system of water management*** in one way or the other. 10% recycles sullage (greywater), while another 5% adopted a re-bed water filtration system which is another form of harvesting and recycling rainwater and greywater. In total, 45% of the buildings identified in this study adopt one form of water recycling or the other.

Table 6.4: % of Technology Distribution amongst the Buildings Identified

s/n	Class of Technology	Type of Technology	Buildings fitted No.	Buildings fitted %
1	Renewable Micro Generation Systems	Solar PV	11	55%
2		CHP Sterling Engine	1	5%
3		Wind Turbine	4	20%
4	Heating, Ventilation & Cooling Systems	Adiabatic Cooling System	1	5%
5		Solar Powered Chillier	1	5%
6		Solar Thermal Flat Plate	7	35%
7		Biomass	7	35%
8		Evacuated Tubes /Vacuum Tube Collectors	2	10%
9		Ground Air Heating & Cooling exchange System	1	5%
10		BASF paint on Roof	1	5%
11		Heat Recovery system	3	15%
12		Solar Sun-Space	2	10%
13		Solar Sun-Box	1	5%
14		Ground Source/Lake Source Heat Pump	7	35%
15		Radiant Thermal Slab	1	5%
16		Natural Stack Ventilation	3	15%
17		Courtyard Natural Ventilation	1	5%
18		Controlled Venting & Ducting	1	5%
19		e-Tube Ventilation System	1	5%
20		PV Bases Extractor Fan	1	5%
21	Day lighting Systems	Solar Sun Pipes/Light Pipes	2	10%
22		Skylight	3	15%
23		Curtain Walling	4	20%
24	Renewable/Environment Friendly Materials	Composite window frames (Timber + Al.)	2	10%
25		Timber Window Frames	3	15%
26		Timber Cladding	3	15%
27		Timber Solar Shading	2	10%
28		Straw bale Insulation	1	5%
29		External Timber Fenestration	1	5%
30	Energy Efficiency & Conservation Systems	Phase Change Insulation	1	5%
31		High Insulation Fabric	5	25%
32		Web-Brick technology	1	5%
33		Insulated Concrete framework	1	5%
34		Motion activated lighting	4	20%
35		Loft Insulation	1	5%
36		e-Window Glazing	3	15%
37		Good Thermal Mass Slab	2	10%
39		Thermostats	4	20%
40		Low Energy bulbs	2	10%
41		Double Skin Façade	1	5%
42	Bio-diversity	Brown Roof	1	5%
43		Green Roof	2	10%
44		Green Wall (green plants on wall)	1	5%
45		Sustainable Urban Drainage System (SURDS)	1	5%
46	Water Management System	Rain Water Harvesting	6	30%
47		Re-Bed Water Filtering System	1	5%
48		Grey Water Recycling	2	10%
49		Automated Plant Watering using recycled water	1	5%
50		Composting Toilet System	1	5%

6.3 OPERATION AND MAINTENANCE ISSUES IDENTIFIED

The study also attempted to identify some of the operation and maintenance (O&M) challenges associated with the use of low carbon technologies and a number of these challenges within the respective buildings were identified as listed in table 6.5. Figure 6.9 compares the number of cases with issues against the total number of buildings identified with the technologies.

As shown in table 6.4, about 50 LCTs were identified, but figure 6.9 shows that only 12 technology types (24%) have been reported to have operation and maintenance issues. The reasons for the shortfall are that some of the respondents skipped the question relating to O&M challenges in the questionnaire, probably because they were not involved in the O&M stage of the building and had no feedback about how the buildings were being run. In some cases, the buildings or the retrofitted technologies were less than 2 years old, and as such may not have experienced noticeable problems with the technology. There is also one of the cases where the building has not been occupied since it was completed.

So for some of the technologies, it was not possible to identify what their probable operational challenge would be. However one of the interviewees' responses to the question 'if there were any technology in the building that has challenges with maintenance' was:

> *"They've all got challenges with maintenance. No building remains low-carbon if you don't look after them".*

Therefore, the result presented in this section is not to conclude that the technologies which O&M challenges are not reported do not have O&M challenges.

Table 6.5: O&M Challenges identified with the LCTs

S/n.	Name and Address of Building		Operation & Maintenance Challenges
1	**No.1 Nottingham Science Park**		Biomass boiler; Heating and cooling system; O&M manual;
2	**Creative Energy Homes** Green Close, University of Nottingham NG7 2RX	David Wilson Millennium Eco-House	CHP retrofitted to replace Vacume tube collectors; Wind turbine not in use due to noise; PV slates efficiency reduced by about 50%
3		BASF House	Biomass failed; Water pump for the water harvester broken down in the past 2wks to the time of survey; GSHP out of function and replaced with Air Source exchanger.
4		Tarmac Masonry Home 1 (Code 6)	Water pump not 100% reliable; Biomass boiler not functioning at the moment, and has broken down in the past and took about 6 months before it was fixed
5		Tarmac Masonry Home 2 (Code 4)	Water pump not 100% reliable; Biomass boiler not functioning at the moment, and has broken down in the past and took about 6 months before it was fixed
6		E.ON 2016 Research Houses	Not inhabited
7	**Sustainable Research Building**		Wind turbine out of function; Timber window frames re-varnished twice in less than 12 months
8	**Zedfactory,**		Biomass tech failed; H_2O filtering system also failed when the maintenance staff retired; Weathering effects on timber cladding
9	**Jubilee Wharf**		Biomass boiler require specific maintenance
10	**The living wall**		Problem with watering and plants died off.
11	**BioEnergy Building**		Problem with Biomass boiler
12	**Sir Colin Campbell Building**		Lake source heat pumps freezes when air temp is below -10 ^{0}C
13	**Private Residential Building**		No information
14	**Romero House**		Availability of servicing personnel for GSHP
15	**Green Street Development,**		No information
16	**Phoenix Square**		No information
17	**Architect Julian Marsh Private Residential House**		Lack of maintenance personnel for the GSHP
18	**Peveril House**		No information
19	**CSET Building**		No information
20	**The Gateway Building**		No information

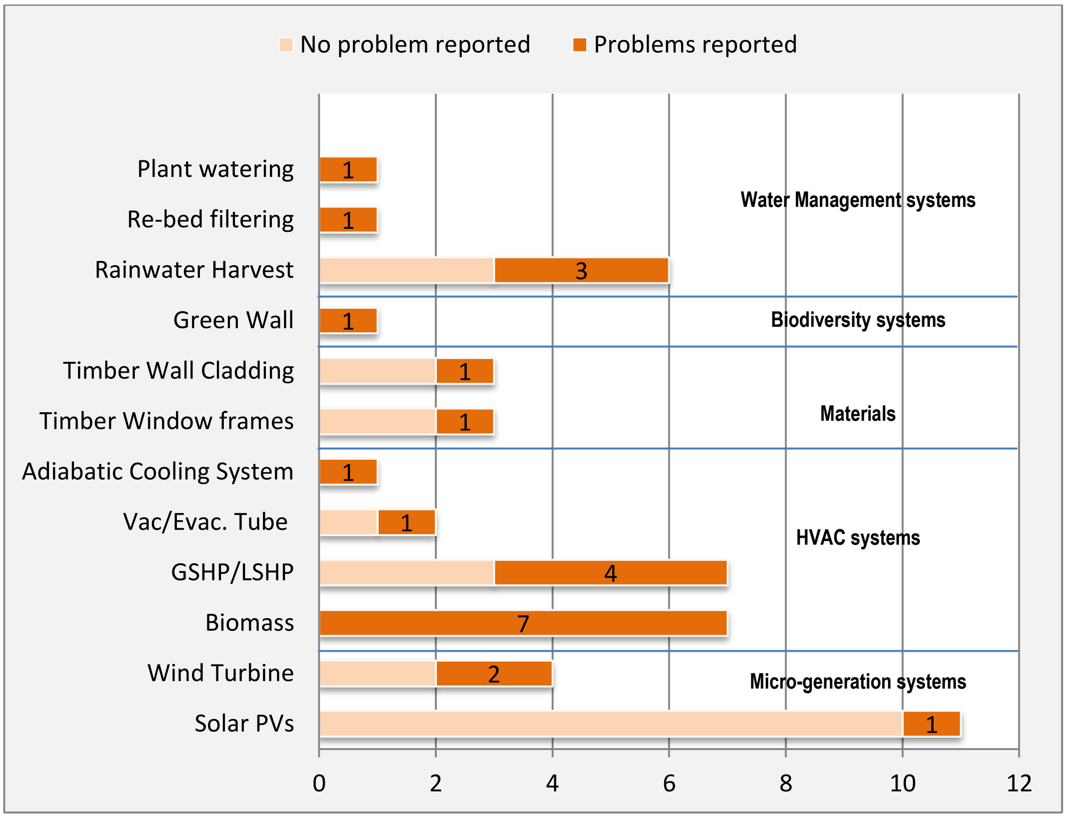


Figure 6.9: Number of cases with O&M challenges that were reported for each technology type in the study

6.3.1 Micro-Generation Systems

Three (3) micro-generation systems were identified in the study. On a general note, their O&M performance seem impressive. Although no issue was reported about the only ***CHP sterling engine*** identified in the study, interestingly, the ***Solar PV*** which is the most widely used as evidenced from this study, reported only one case with a challenge out of the eleven (11) buildings found with Solar PVs; i.e., less than 10%. It noted that the efficiency of the PV slates on the roof has dropped to about 50% of what it was, when it was installed. 20% of the buildings studied also were fitted with ***micro wind turbine*** and 50% of this number reported issues with the technology. In both cases, the issue was that the system/technology was 'too noisy'.

In the preliminary studies carried out at the Creative Energy Homes, these 3 micro-generations; Sterling engine CHP, Solar PV slates and Micro Wind turbine were use. Figure 6.10 shows the creative use of PVs as slates on the roof and the old and new wind turbines.

Figure 6.10: David Wilson Millennium Eco-House showing PV slates, the Old and New Wind Turbine

Interview with occupants of the building revealed the PV slates may have experienced the depreciation in output due to:

- Age; the building was commissioned in year 2000
- Accumulation of dust and bird droppings
- Lack of care (one of the occupants noted; "*PVs are supposed to be cleaned periodically for guaranteed efficiency, but one does that here, so you can't expect it to still perform as when it was new*").

The occupants also reported the first Wind turbine installed with the building was changed because of the noise it generates, and that the replacement model was not any better, so they had to stop putting it to use.

Some questions which the author may ask are: could the issue of noisy system not have been tackled at the design stage if the designers and clients were fully informed of the system's operational mode? Or could the drop in performance of the PV slates not have been minimized by an appropriate design or specification and even a simple maintenance regime?

6.3.2 HVAC Systems

Among the Heating, Ventilation and Air Conditioning systems, the ***biomass technology*** seems to have reported the poorest findings. Seven buildings representing 35% of the total number of buildings in the study were identified to have been fitted with biomass technology as shown on table 6.4; all seven buildings (100%) reported one issue or the other with the biomass technology as shown on figure 6.9. The issues range from temporary out of use, difficult to operate and maintain to outright failure of the system and out of use.

Also, seven ***heat pumps*** were identified in the study and about 57% of this number (4 out of 7) reported some form of challenges with the technology. The only case fitted with Lake Source, reported that the pump freezes in winter when air temperature falls below -10^{o}C. This could really be a very serious challenge if there are no other backup sources, because that is when the heating is most needed. In one case, the heat pump failed and has been replaced with the ground air heating & cooling exchange system. The two other cases reported difficulty in finding maintenance personnel. It is also possible that the one that was replaced with the Air exchanger system may not have been unconnected with lack of maintenance personnel.

In the case of the ***Evacuated tube Solar collectors*** also known as the ***Vacuum tube Solar collectors,*** results show that one (1) out of two (2), (50%) was out of use and has been replaced with flat plate collectors in the building identified. The system was said to have failed due to overheating, which may have resulted from the operational control system.

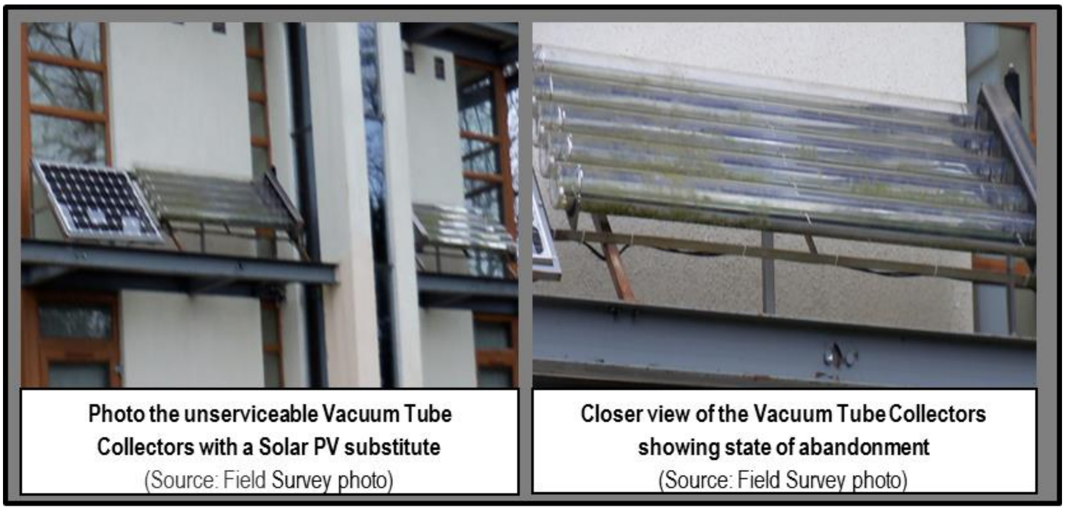


Photo the unserviceable Vacuum Tube Collectors with a Solar PV substitute
(Source: Field Survey photo)

Closer view of the Vacuum Tube Collectors showing state of abandonment
(Source: Field Survey photo)

Figure 6.11: David Wilson Millennium Eco-House showing the abandoned Vacuum Tube Solar Collectors and a replaced Flat Plate Collectors

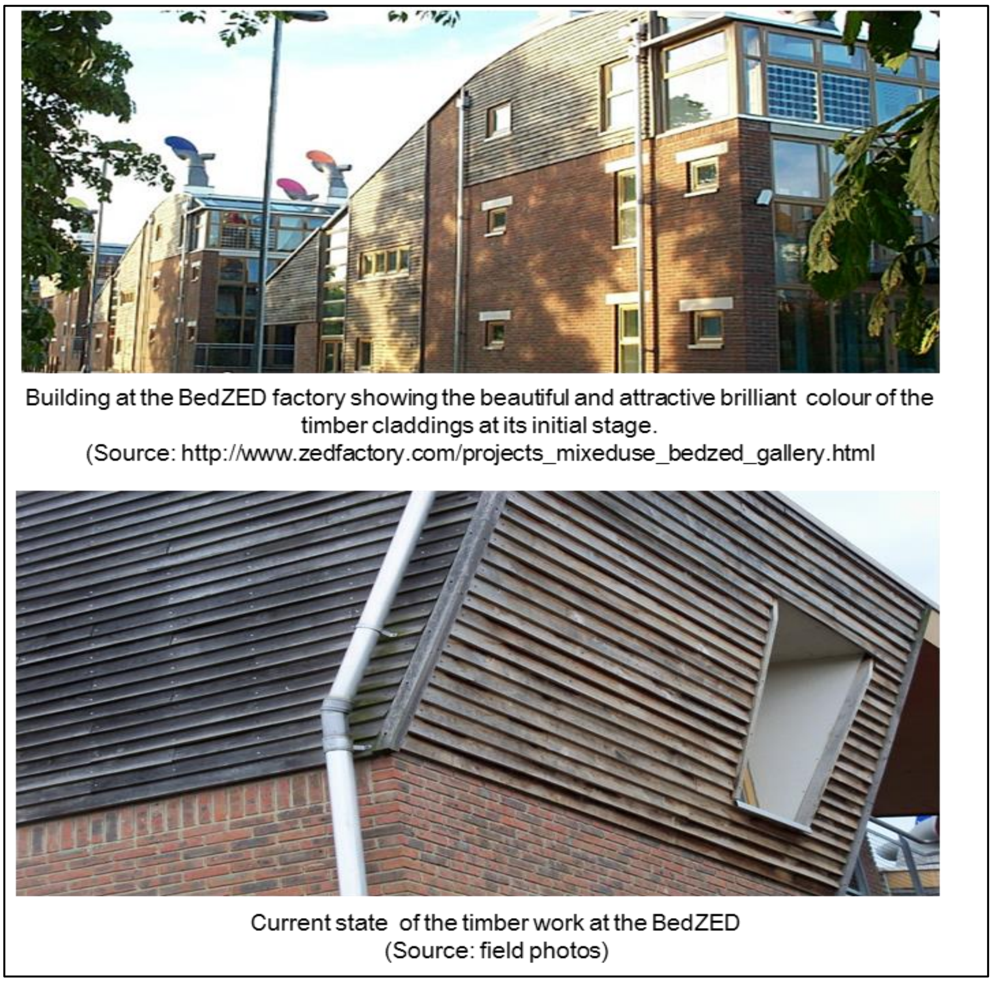
Like the CHP, out of the 35% of buildings fitted with ***flat plate collectors*** none reported any O&M challenge.

The ***Adiabatic cooling system*** challenge noted in the study was purely that of operational challenge. Operators of the system were not sure of how it works with other systems; whether to close or open the windows as reported by one of the interviewees. It is possible that a good user friendly O&M manual should have been able to assuage that confusion early enough. This case is discussed further in chapter 7.

6.3.3 Renewable & Environmental Friendly Materials

Timber and timber products appears to be one of the commonly used renewable and environmental friendly materials in building construction today. About 60% of the buildings (12 buildings) as evident on table 6.4 have used timber in one forms or the other. Figure 6.9 show that only two of these buildings show evidence of weathering on the timber materials. This is probably because most of these buildings are either relatively new or have used the timber in a more sensible way.

The study shows that when timber is exposed directly to the vagaries of weather (rainfall, snowfall, dewdrops, sunshine, etc), irrespective of whether treated or not, they become more rapidly weathered and discoloured. This finding is also corroborated by Outdoor-Structures (2013). Figure 6.12 shows the BedZED wall timber cladding in its early stage after construction as shown on the company website. The second photo shows the current state of the cladding; with a noticeable decay in the timber. Although sustainability practices seems to advocate against chemical treatment of timber (Morgan, 2008), it encourages sensible designs. In figure 6.13, on the Sustainable Research Building, all the windows were constructed by the same contractor and probably constructed using the same type of timber and about the same period and given the same type of treatment. However, a clear difference was noticed between the upper level windows that are directly exposed to the elements of weather and those that were protected from direct contact with elements of precipitation.



Building at the BedZED factory showing the beautiful and attractive brilliant colour of the timber claddings at its initial stage.
(Source: http://www.zedfactory.com/projects_mixeduse_bedzed_gallery.html

Current state of the timber work at the BedZED
(Source: field photos)

Figure 6.12: The BedZED factory Timber Cladding; Comparing the Initial state with Current state

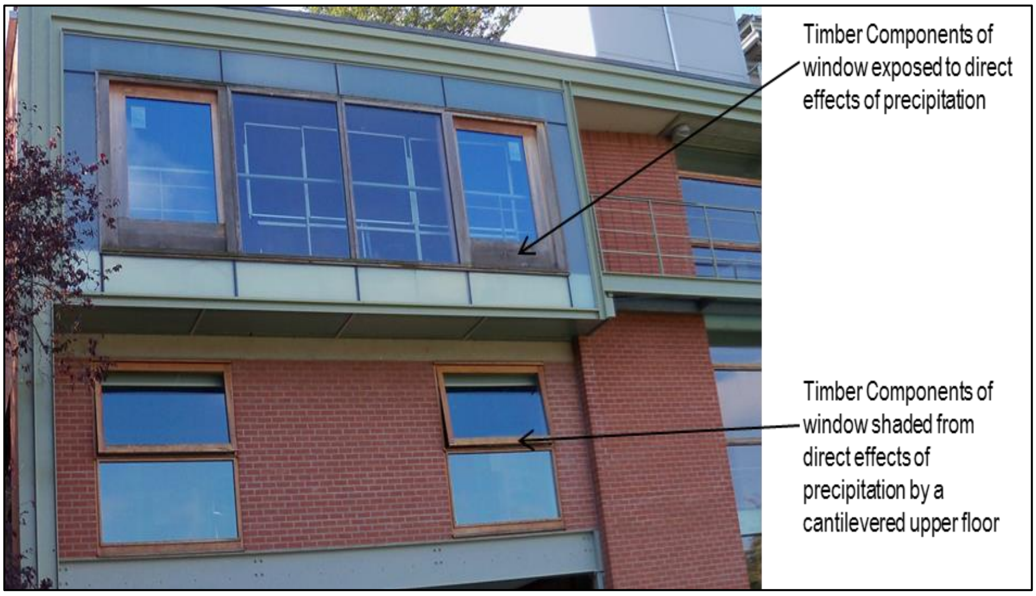


Figure 6.13: Sustainable Research Building (SRB) Showing two different ways timber was used and the resultant effects

Timber elements in buildings are expected to enhance the beauty of the edifice. They are ornamental; "something employed to adorn, beautify, or embellish, or that naturally does this" (Fredrick Gibson + Associates Architecture, 2010). At the BedZED factory for instance, the tour guide who was one of the designers for BedZED was asked about the effect of the timber claddings in terms of indoor temperature or comfort level of the building. The answer was; *"No significant effect, they are for aesthetic purpose";* beauty. Leon Battista Alberti, one of the Renaissance architects of the 15th century conjectured that *"beauty was to be found not only in nature – it was the main purpose for building"* (Ibid). Alberti also defined beauty as:

> *"The adjustment of all parts proportionately, so that one cannot add or subtract or change without impairing the harmony of the whole"*

This conjecture and definition presuppose that visible building elements are supposed to be essentially beautiful and must remain in its beautiful state to ensure harmony with the whole.

So the operational challenge here is that the timber elements will need to be re-varnished more often than it is necessary, exposing occupants and passers-bye to the danger of pollutants from the varnish chemicals or the timber elements will need to be replaced sooner than it would have been necessary if used or designed sensibly. For instance, the SRB windows were re-varnished twice in 2012 alone. An informal chat with the project supervisor on site revealed that the right chemical was not prescribed in the first instance and so the finishing was not what was expected, so they were called back to scrape off the former coating and apply with the proper one.

One question here is who pays for the re-work? Secondly, staff and students in the department had been exposed to the effects of these chemicals twice in a space of less than a year. Other effects include the noise generated by the scraping machine which had its own toll on concentration for research work in the research building.

6.3.4 Water Management Systems

Ten buildings were identified using one form of water management system or the other, including composting toilet system. 50% of these buildings reported one issue or the other. In one case where the ***re-bed water filtration system*** was used, after the retirement of an individual who was operating/maintaining the system, no one could operate it and the system became moribund. It is possible that if there were to be a good user-friendly O&M manual, with little training another person could have been able to operate the system effectively.

A second case was the recycled ***water sprinkler to the living wall*** which failed, thus starving the plants of required nourishment and the plants withered. The news of the failed system made national headlines in August 2009; £100,000 of tax payers' money was claimed to have been wasted by untested design (Daily Mail Reporter, 2009). The 30ft (9m) high wall of the Children's Centre built in the Paradise Park by the Islington Council was a pioneering green concept which critics called *'green extravagance'*; accusing the council of wasting public money, using *'untested technology'* (Bar-Hillel, 2009).

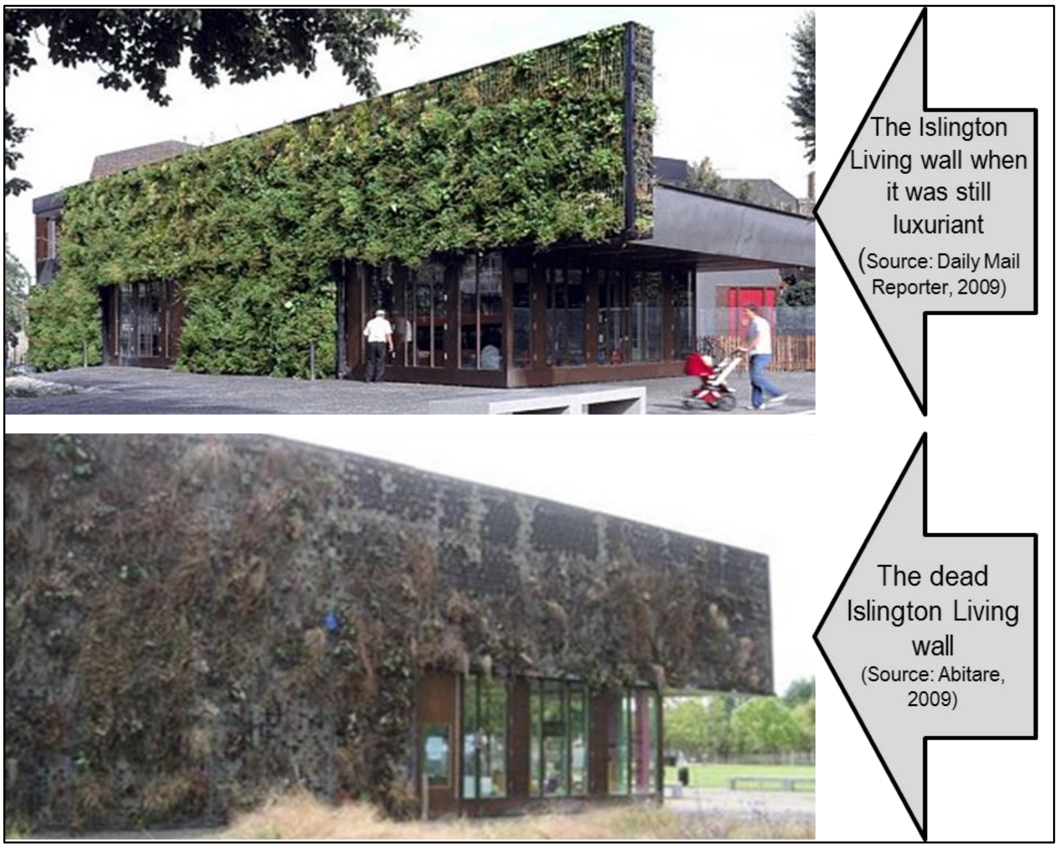


Figure 6.14: The Dead Living Wall of the Islington Paradise Park Children's Centre; showing the luxuriant and dead stages of the wall

Some of the published comments about the Islington living wall include:

> *"The so called vertical Garden was a costly waste of money. The architects should have worked out all the problems before it was installed"* (Tim Newark of Islington Taxpayers' Alliance in Bar-Hillel, 2009).
>
> *"The council should not experiment with taxpayers' money"* (Tim Newark of Islington Taxpayers' Alliance in Bar-Hillel, 2009).
>
> *"When the installation went up it looked wonderful…. Since then we've had problems. Now the wall seems pretty well dead. The fancy watering system has never quite worked; either it overwatered or it underwater the plants"* (Labour ward Cllr Barry Edwards in Bar-Hillel, 2009).
>
> *'It would have been better to let someone else try it first, experience all the problems and find a solution before trying it here.'* (Labour ward Cllr Barry Edwards in Daily Mail Reporter, 2009).

> *'The wall was the first of its type to be installed in the UK and, as with anything new, carried a certain element of risk* (Council spokesman in Bar-Hillel, 2009).
>
> *The disaster threatens the immediate prospects of living walls. 'The failure of this particular scheme is going to raise doubts in people's minds about the viability of living walls as a valid technique for cladding* (Chris Churchman, partner at Churchman Landscape Architects in Fulcher, 2009).
>
> *The death of London's first living wall has led to questions about their viability – and sustainability (*Fulcher, 2009).

Inference drawn from these comments is that the society's expectation of new technologies in buildings is 'a tested and proven technology', because every new and untested technology bears an element of risk. This risk could be so costly as in this case. So there may be the need for clients to demand proof of viability and sustainability of innovative exploits of building designers.

6.3.5 Efficiency of the Technologies Overall

Preliminary studies show that the efficiency of some renewable energy technologies, particularly the solar based technologies drops over a period, due to lack of proper maintenance. According to Ritec (n.d.), to maintain the performance of solar energy systems (PV and thermal panels) is dependent on the quality and cleanliness of the glass surfaces used to collect the power. In some cases dust accumulation and bird droppings, growth of algae, etc. could inhibit a clear surface area and thereby reduce efficiency of the system considerably.

So this study set out also to find out how efficient the installed technologies are at the time of study, in comparison to its installed efficiency in the exemplar buildings. It was not intended for detailed examination, but understanding the users or handlers perception. The online survey participants were asked to rate the efficiency of any one technology in their exemplar buildings, in comparison to its installed efficiency on a scale of 1 –

5, where 1 is unsatisfactory and 5 is very satisfactory. The result returned a rating average of 3.86 with about 57% of the participants rating it at 4.0, as shown on figure 6.15.

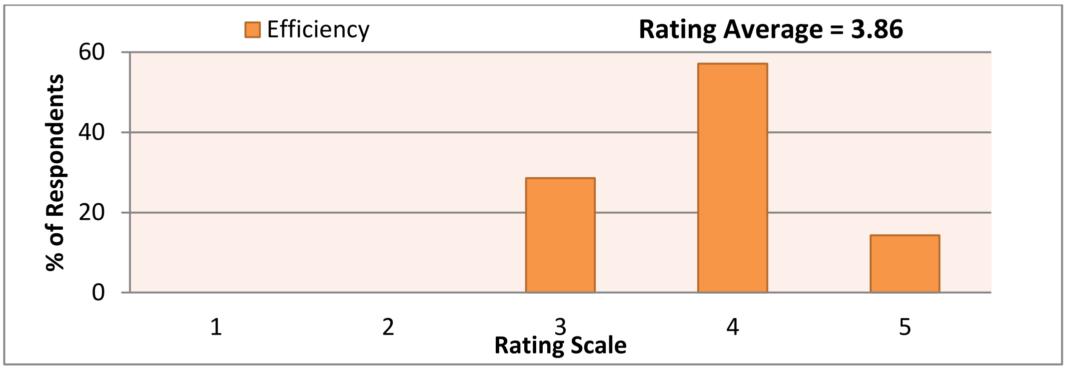


Figure 6.15: Efficiency of the Technologies Overall

This means that the average efficiency of low carbon technologies in the buildings surveyed is just about satisfactory. This no doubt may be because most of the buildings were just about 2 -5 years old. From table 6.2, majority of the buildings identified in this study (50%) were between 2 – 5 years old. However, there are indications that some of the technologies has drastically dropped in efficiency as about 30% indicated a rating of 3.0 which is just average.

6.3.6 Functional State of the Technologies Overall

It was also necessary to investigate if these technologies were still in their good functional state, because preliminary findings during visits to the ZedFactory in Wallington, Surrey and the Creative Energy Homes here in the University of Nottingham revealed that some of the technologies were no longer functional. Participants in the online survey were also asked to rate the functional state of any of the technologies they found challenging, on a scale of 1 – 5, where 1 is unsatisfactory and 5 is very satisfactory. The results as presented in figure 6.16 returned a rating average of 3.33, indicating that the technologies are not in their full functional capacity. Only about 50% of the respondents rated the technologies to be in a satisfactory functional state (4.0 rating average).

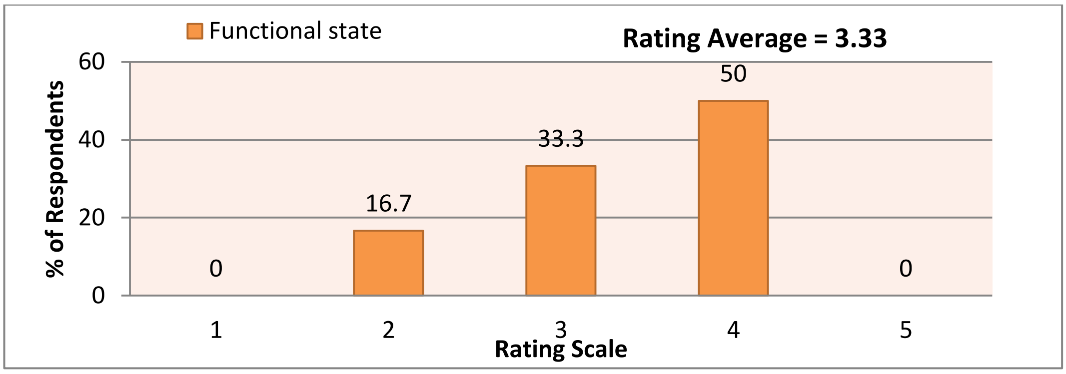


Figure 6.16: Functional state of the technologies overall

In section 6.4.3 it has been identified that 50% of the buildings were between 2 – 5 years old, and about 85% are 10 years old and below. This means that the buildings in this study are relatively new buildings and the expectation is that every part of the building should be in a satisfactory functional state. So a rating average of 3.33 out of 5 will not be said to be impressive for the functional state of low carbon technologies in the buildings identified.

6.3.7 Accessibility for Cleaning and Repair of the Technologies Overall

CIRIA (2009) noted that in maintenance and repair works, getting materials, equipment and personnel to the place of work safely is very critical. The authors noted that often, designers overlook this consideration as they design. However, in this study, the result as presented in figure 6.17 shows an impressive return for access to cleaning and repair works to the LCTs. It returned a rating average of 3.83 out of 5; with about 83% rating it above average satisfaction. This means that on the overall, there is no challenge with accessibility for cleaning and repairs of the technologies in the buildings under study, or that the respondents are satisfied with the level of accessibility. However, it must be noted that most of the participants in this survey are not directly involved with the maintenance and repair works as most of them were designers. Their judgement may have been based on their design experience and feedback from users.

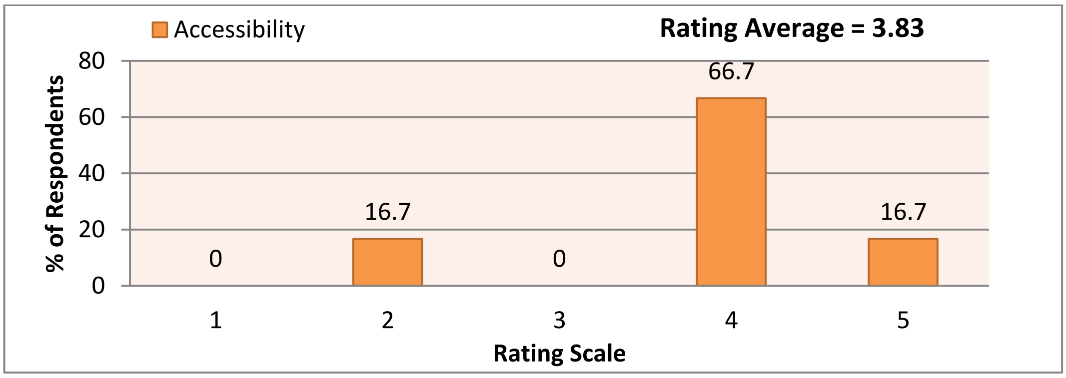


Figure 6.17: Accessibility for cleaning and repairs of the technologies overall

6.3.8 Availability of Servicing Personnel for the Technologies Overall

One problem that was highlighted during the preliminary studies and the interview stages was the difficulty in finding maintenance personnel for these new and innovative technologies in LCBs. However the study results show that on the overall, there was no issue with finding service personnel. 43% rated the availability of service personnel for the technologies in their buildings as average, while a total of 57% rated it as being above average. No one rated it below the average (3.0) scale (figure 6.18). However, as noted in section 6.8.7, most of the participants in this survey are not directly involved with the maintenance and repair works and their judgement may have been based on their design experience and feedback from users.

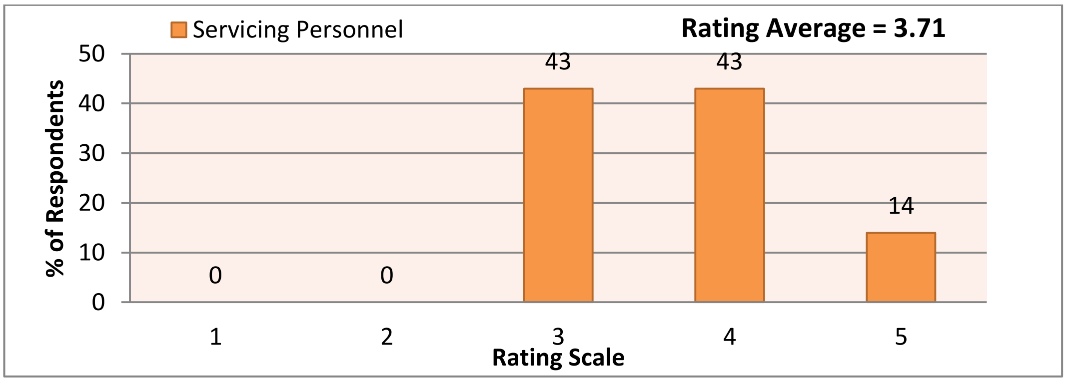


Figure 6.18: Availability of Servicing Personnel for the technologies overall

6.3.9 Frequency of Maintenance Works on LCTs Overall

It is only rational to think that when the need for maintenance is less frequent, the life cycle cost will be minimized. However, this may not always be the case. Getting up to the roof top to clean your PV panel at least every 3 – 4 months could save you the problem of reduced efficiency at the long run, for example. Reduced efficiency might mean changing the panels and thereby result in more cost. However, if the panels are installed in a way that they could be self-cleaned, may be by using a steeper angle of inclination, which may warrant cleaning just once in a year. This definitely will save you more money in the long run. Better still, a form of self-cleaning technology for PVs could be explored because of the risk and cost involved in getting to the top of roof particularly for tall buildings (see recommendation 3, section 9.4).

So the study also investigated how satisfied the respondents were with the maintenance frequency of the technologies they have identified in their respective buildings. Figure 6.19 summarises the result.

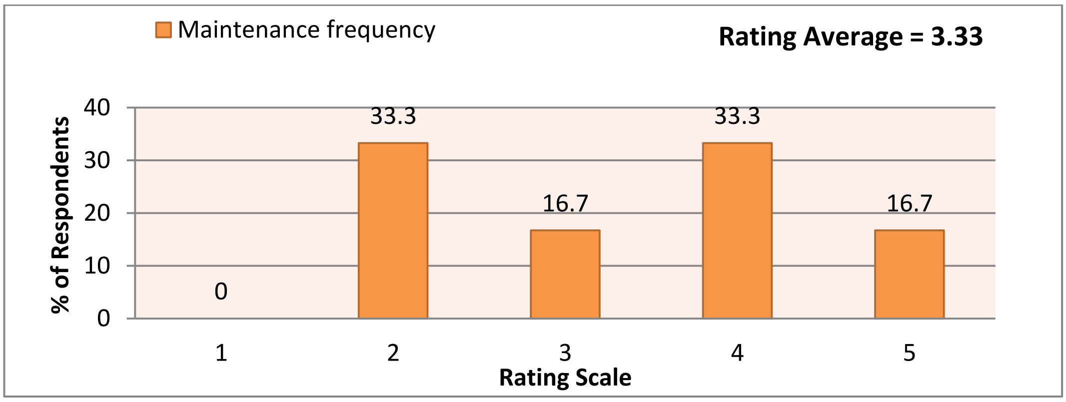


Figure 6.19: Frequency of Maintenance for the technologies overall

It showed a rating average of 3.33, which is just a little above average satisfaction. About a third of the respondents rated their satisfaction level at 2 out of 5, which is unsatisfactory. Although this is the opinion of a smaller fraction of the respondents, but it still matters and calls for the need to put in place, measures that help reduce maintenance frequencies in facilities, particularly, low carbon facilities.

6.3.10 Operating Costs of the Technologies Overall

The study also examined how satisfied the respondents are with the operating cost of a typical low carbon technology they have chosen. Figure 6.20 summarises the findings. A total of about 66% of the respondents were satisfied with the operating cost. The study also returned a rating average of 3.67 out of 5.

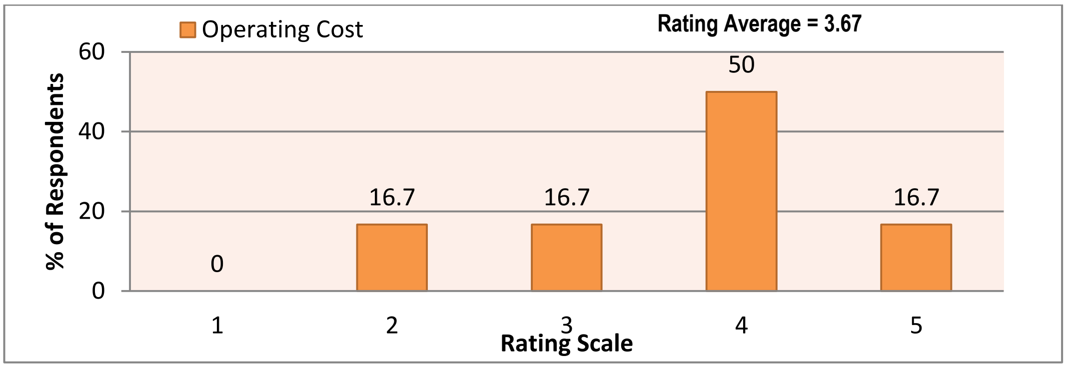


Figure 6.20: Cost of Operating the technologies overall

However, this does not indicate that the operating cost is low, rather it shows that majority of the respondents were happy with the operating cost. As stated in previous sections, most of the respondents here are architects and architectural educators; they are neither engaged with the day to day operation of the facilities nor involved with making funds available for the day to day operation. However the 2011 Government Construction Strategy is hinged on cost savings, though conscious of not relegating value. It noted that; *"This will ensure that cost becomes a lead driver in the delivery of projects, without sacrifice of whole life value" (*Cabinet Office, 2011*).* The key objective of the strategy is to save 15 -20% on cost of government projects by the end of the current parliament. Para.2.23 of the document also added that:

> *"…, cost benchmarking is not to be restricted to construction work. It should cover all project on-costs (consultants" fees, departmental administrative costs, etc) so that the efficiency of total project delivery cost is also plotted" (*Ibid*).*

It therefore follows that although the respondents in the study were happy with the operating cost of the technologies, any reasonable strategy that could help in reducing operating costs would be a welcomed idea.

6.3.11 General Image of the LCTs

Respondents were also asked to rate their perception of the current overall image of the building in comparison with the initial state (immediately after practical completion). The result here was very impressive, as this returned a rating average of 4.38 out of 5. No respondent rated it as unsatisfactory. Three quarters of the respondents rated it as either satisfactory or very satisfactory and the rest one quarter rated it as average. See figure 6.21.

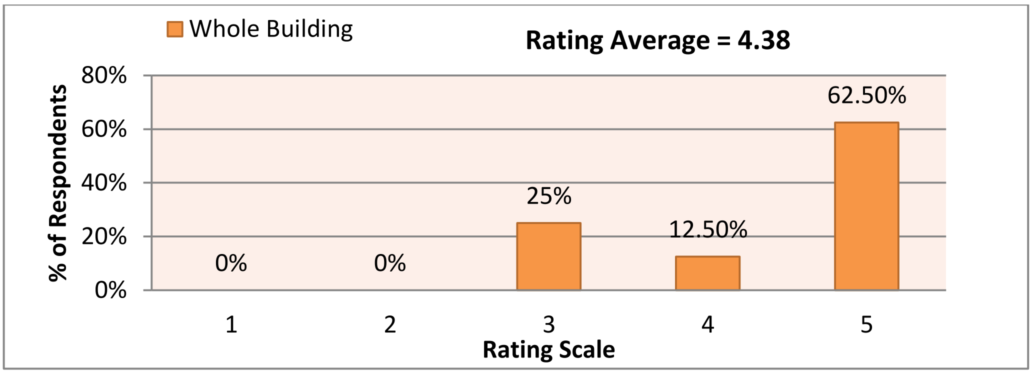


Figure 6.21: Image of buildings to public view in comparison to their initial states

This implies that the buildings are still in their good aesthetic looks. This however was not unexpected since the buildings are relatively new, and most of them appear to be state of the art designs.

6.4 OTHER FINDINGS ABOUT LOW CARBON TECHNOLOGIES

This section features other deductive findings about low carbon buildings from the data, which are not primarily the target of the research. The information were intended to support other details in this research, however the findings were found to be interesting and capable of supporting future research in low carbon technologies.

6.4.1 Low Carbon Technologies Growth in Residential and Non-Residential Buildings

The study also identified the buildings according to their typology. It is noted that 9 of the 20, representing 45% of buildings identified are residential buildings as shown in figure 6.22. This suggests that there may be more low carbon development in residential buildings in the UK than in any other building type. This is not strange, perhaps because of the 2016 target for all new residential buildings in the UK to be zero carbon and 2019 for other buildings (DCLG, 2007). Following closely with 25% is educational buildings; also probably because until it was changed by the sitting government in the UK, educational buildings (school buildings) were also required to be zero carbon by 2016 (UKGBC, 2013). This shows to an extent that there is reasonable progress towards achieving the 2016 'ambitious target' for zero carbon in the UK home building sector.

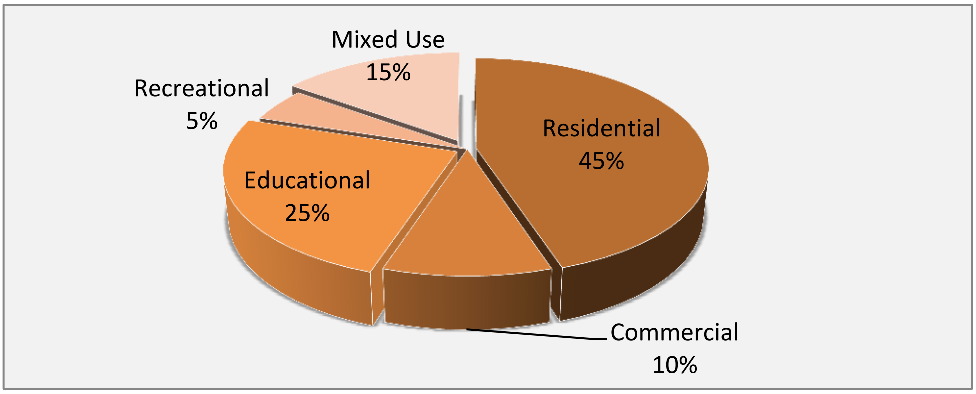


Figure 6.22: LCBs identified according to their Typology

6.4.2 Low Carbon Technologies and Tall Buildings

The study also tried to identify the buildings according to their height classifications; low-rise – buildings of 1 – 3 floors, mid-rise – 4 – 11 floors, high-rise – 12 – 39 floors and skyscrapers – 40 floors and over. Table 6.2 shows that 16 of the 20 or 80% of the buildings identified in this study are low-rise buildings and the rest 20% are mid-rise. Interestingly no high-rise or skyscraper identified. See figure 6.23.

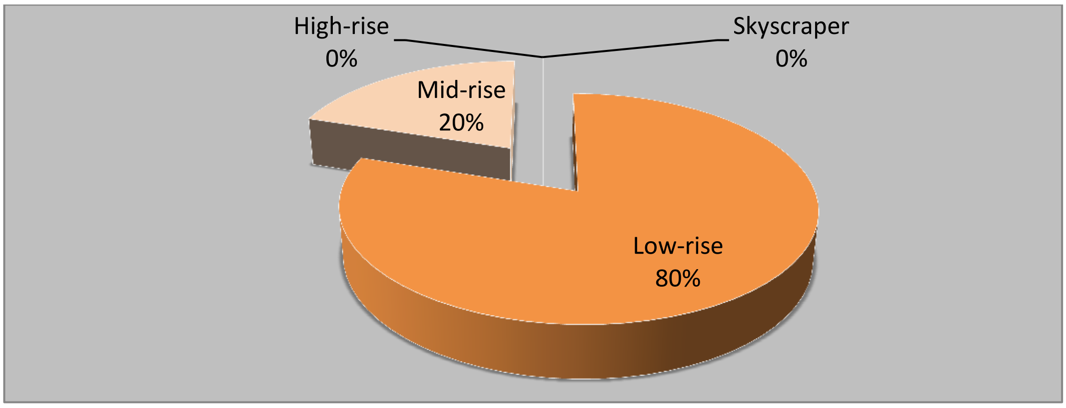


Figure 6.23: % Distribution of Buildings Identified in the Study by Height

This perhaps could be an indication that there are fewer tall buildings that are fitted with low carbon technologies in the UK at the time this research was conducted. Whitelaw (2007), quoted Joe Summers, Arup project director on the Britain's tallest building, 'The Shard' that renewable energy would not work productively for tall buildings set in an urban environment. This perhaps could account for why this study could not capture tall building, and also why there are fewer tall low carbon buildings in the UK. This finding is not an indication that there are no tall buildings fitted with low carbon technologies, it indicates that tall buildings fitted with low carbon technologies are fewer compared to low-rise and mid-rise buildings in the UK.

6.4.3 Influence of the LCBP on the Growth of LCBs

There are strong indications suggesting that more low carbon buildings may have been built between 2007 and 2010 as the result of this study shows that 50% of the low carbon buildings identified were between 2 – 5 years old as at 2012, when the data was collected and analysed. See figure 6.24. The LCBP

(Low Carbon Building Programme) as discussed in section 5.1.3.7 was a grant programme under the auspices of the Department of Energy

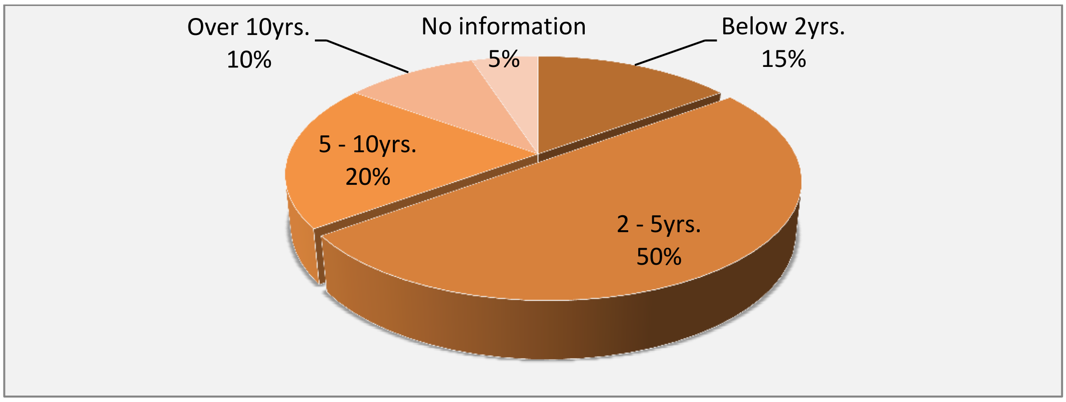


Figure 6.24: % of Age Distribution of Buildings Identified

& Climate Change (DECC), aimed at supporting individuals or organizations to partially cover the cost of purchasing and installing a range of micro-generation technologies in their buildings. This programme ran between January 2006 and May 2010 (Gardiner et al, 2011). This may have accounted for more low carbon buildings being built between 2007 and 2010 (a space of 3 years). Buildings that were built before 2002, over 10 years accounted for just 10% and improved to 20% between 2002 - 2007 (5 – 10 years old); a space of 5 years. This improvement may not be unconnected with the 'early birds' beneficiaries of the LCBP in 2006 – 2007. The result shows that there was a drop between 2010 and 2012 to 15%. These 15% are likely those who received the grant at its ebbing period. Gardiner et al (2011) indicated that "all payments were intended to be completed by 31st March 2011 which was largely achieved". It therefore seems conclusive that the introduction of the LCBP encouraged developers to opt for Low carbon buildings.

6.4.4 Life Cycle Cost of Low Carbon Technologies

The concept of maintainability as discussed in section 3.3 is hinged around life cycle cost of project. The operation and maintenance cost constitute the bulk of this cost. Bokalders and Block (2010) argued that the capital cost of a project usually comprises of just about 10% of the life cycle cost calculated over a 50 year life cycle. It therefore became imperative to assess building practitioners opinions about the operation and maintenance (O&M) cost of buildings fitted with low carbon technologies, in comparison with normal (non-low carbon) buildings. It appears very logical to say that renewable technologies save 'energy bills', but this study tries to look at a holistic cost which include the initial cost of building, maintenance and other operational costs.

The results of the interviews and the survey, both suggest that the project cost (construction + pre-construction cost) would have been lower if the building being referenced were to be a normal (non-low carbon building) as shown on figure 6.25. None of the interviewees opined that the cost would have been higher, and only 25% of the survey respondents believed it would have been higher. 40% of interviewees and 37.5% of survey respondents were indifferent. Another 37.5% of the survey respondents opined that the project cost would be lower for a normal building, similarly, another 40% of interviewees also agree that the project cost would have been lower. In the words of one of the interviewees (see appendix C - Code No. 004 – general comments), he said;

> *"In construction, low energy housing is a bit more expensive than ordinary housing, but on a building where you got some quite big spaces and you will normally have lots of plants any way, you can offset that extra construction cost with plant cost".*

The opinion being expressed here seems to be that the project cost for residential low carbon buildings are definitely higher than those of normal buildings, but no significant difference for those of non-residential. However, the general opinion being expressed from the study result is that low carbon buildings are more expensive to build. The participants represented with 'no comments' either skipped the question in case of survey or out rightly say they cannot really tell, in the case of interviews. So they are considered to be indifferent.

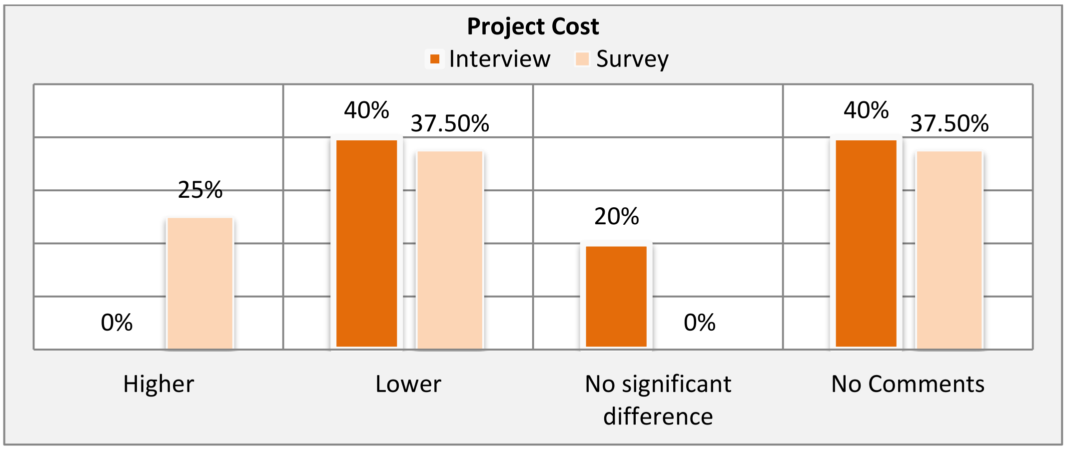


Figure 6.25: Professionals Opinions about the cost of the Project (construction & pre-construction if the building under study were to be none-low carbon

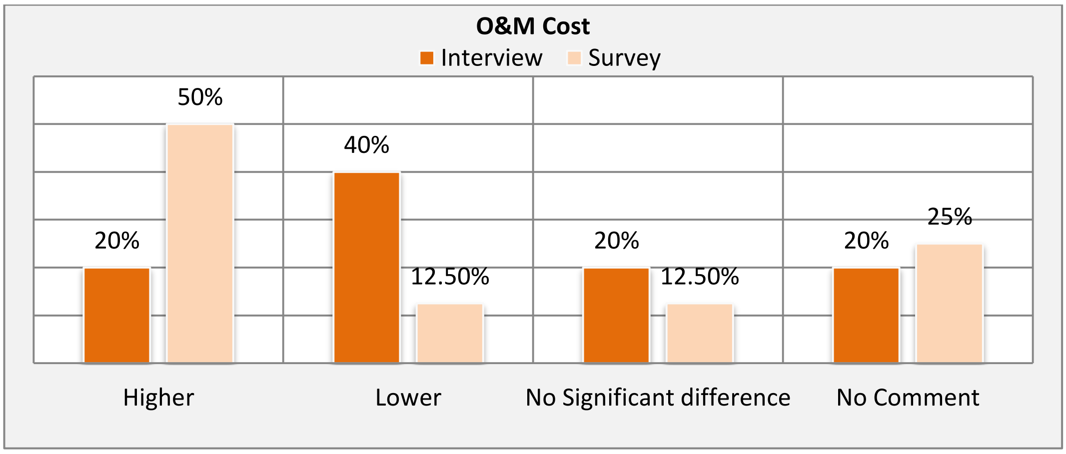


Figure 6.26: Professionals Opinions about the cost of Operation & maintenance if the building under study were to be none-low carbon

In the case of the operation and maintenance (O&M) cost, the interview results show that if the low carbon building being discussed were to be a normal building the O&M cost would have been lower, whereas the online survey result shows that it would have been higher as shown on figure 6.26. While only 20% of interviewees believed that the O&M cost for a normal building would be higher than that of low carbon buildings, 50% of the survey respondents opined that it would be costlier to operate and maintain normal building than a low carbon building. 40% of interviewees and only 12.5% of survey respondents believed that the O&M cost would be lower for non-low carbon buildings.

This discrepancy between the interview and online survey results called for further examination of the background data. It shows that nearly 70% of the online survey respondents are architects and architectural technologists. Section 6.6.1 examines designers (architects) attitudes towards maintenance issues and concluded that most architects do not give sufficient attention to issues of operation and maintenance, so it is possible to conclude that in the case of cost of operating and maintenance of low carbon buildings in comparison to normal building, their opinions may not be strongly considered. Secondly the result presented in figure 6.27 shows that 88% of the online participants do not know the cost of operating and maintenance of the building they have been involved with at one level or the other. So their judgement on this issue could be in doubt.

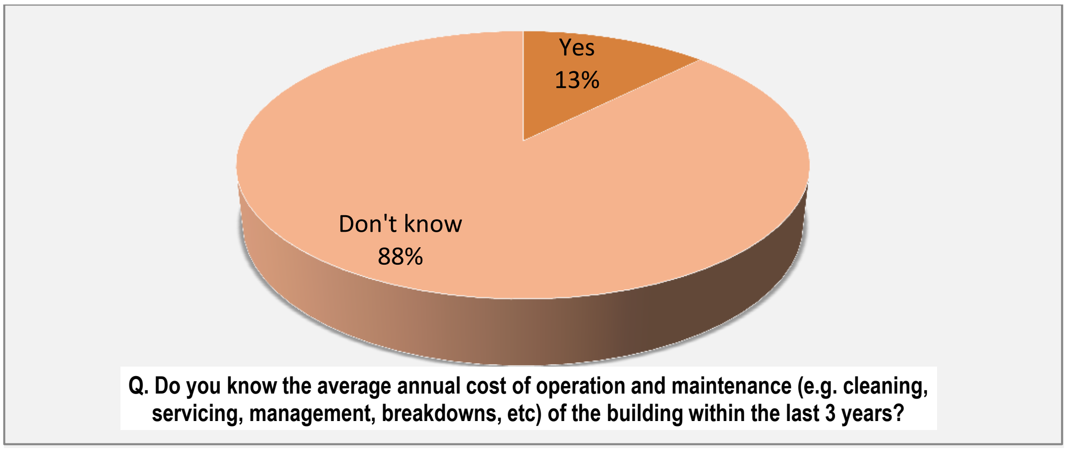


Figure 6.27: Opinion of online participants about their knowledge of the average annual cost of operation and maintenance of the buildings they have mentioned

Examining a data from the United States Energy Information Administration (EIA) which produces forecasts of energy supply and demand using the National Energy Modelling System (NEMS) (IER, 2013); it presents an average national 'levelized' cost for electricity generating technologies across the regions of the country.

'Levelized' costs is expressed as the present value of the total cost of building and operating/maintaining the technology over its financial life and duty circle, converted to equal annual payments and amortized over expected annual generation from an assumed duty cycle (Ibid). This cost includes the capital costs, fixed O&M costs, variable O&M (including fuel) costs and transmission investment costs (Cook, 2013). Table 6.6 shows the 2016 forecast published in December 2010. It presents the minimum cost of the technologies as modelled for 2016, the maximum cost and the average across the various regions of the country, measured in Dollars per megawatt hour ($/MWh).

Table 6.6: Regional Variation in 'Levelized' Cost of New Generation Resources, 2016

Plant Type		Range for Total System 'Levelized' Costs (2009 $/MWh)		
		Minimum	Average	Maximum
Conventional Coal		85.5	94.8	110.8
Advanced Coal		100.7	109.4	122.1
Advanced Coal with CCS		126.3	136.2	154.5
Natural Gas-fired	Conventional Combined Circle	60.0	66.1	74.1
	Advanced Combined Cycle	56.9	63.1	70.5
	Advanced CC with CCS	80.8	89.3	104.0
	Conventional Combustion Turbine	99.2	124.5	144.2
	Advanced Combustion Turbine	87.1	103.5	118.2
Nuclear	Advanced Nuclear	109.7	113.9	121.4
Renewable Sources	Wind	81.9	97.0	115.0
	Wind - Offshore	186.7	243.2	349.4
	Solar PV[1]	158.7	210.7	323.9
	Solar Thermal	191.7	311.8	641.6
	Geothermal	91.8	101.7	115.7
	Biomass	99.5	112.5	133.4
	Hydro	58.5	86.4	121.4

Source: DOE/EIA-0383 (2010) in Cook (2013)

The table indicates that the total amount involved in building, operating and maintaining ***Solar thermal*** that produces a megawatt hour of Solar thermal energy will cost as much as $641.6 or £408.68 (exchange rate: £1 = $1.56993), in extreme case. The maximum amount estimated for the most expensive fossil fuel energy, ***Advanced Coal*** with carbon control sequestration (CCS) is $154.5 per MWh as compared to the $641.6 for Solar thermal. Table 6.7 lists these technologies according to their average levelized costs in a descending order. Renewable energy sources are seen to be the top three expensive sources of energy to acquire and operate.

Table 6.7: Regional Variation in Levelized Cost of New Generation Resources, 2016 Arranged in Descending Order of Average Total Cost

Plant Type		Average for Total System Levelized Costs (2009 $/MWh)	Comments
Renewable Sources	Solar Thermal	311.8	Most expensive source of energy
	Wind - Offshore	243.2	2nd most expensive source of energy
	Solar PV	210.7	3rd most expensive source of energy
Fossil Fuel	Advanced Coal with CCS	136.2	Most expensive type of fossil fuel source and 4th most expensive source of energy
Nat. Gas-fired	Conventional Combustion Turbine	124.5	Most expensive type Gas-fired type and 5th most expensive energy source
Nuclear	Advanced Nuclear	113.9	Surprisingly, nuclear is not within the first 5 most expensive source
Renewable	Biomass	112.5	
Fossil Fuel	Advanced Coal	109.4	
Nat. Gas-fired	Advanced Combustion Turbine	103.5	
Renewable Sources	Geothermal	101.7	
	Wind	97.0	
Fossil Fuel	Conventional Coal	94.8	
Nat. Gas-fired	Advanced CC with CCS	89.3	
Renewable	Hydro	86.4	The cheapest renewable source of energy. But there are arguments that Hydro is not sustainable, because it inhibits the thriving of aquatic lives.
Natural Gas-fired	Conventional Combined Circle	66.1	The cheapest sources of energy
	Advanced Combined Cycle	63.1	

From these three sources of data (Interview, online survey and US energy archive), it therefore becomes necessary to conclude that the life cycle cost of low carbon buildings (buildings fitted with renewable technologies) is higher than that of ordinary (non-LCBs). However, Cook (2013) put forward a valid argument which suggests that the impacts of fossil fuel on the environment and human health greatly outweigh the difference in cost for renewable technologies. Also one of the interviewees (code no. 001) under general comments warns thus:

> *"I think there has to be a balance, if you put too much emphasis on minimizing the maintenance cost, then you will get a very average, potentially poor quality building in terms of or in a very cheap form of curtain edge technology".*

So in creating this balance between Cost vs. clean + 'cutting edge technologies' low carbon building designers need to carefully select their specified technologies in line with how they blend with the design overall in order to reduce the frequency of maintenance activities. Logically, reducing maintenance frequencies helps to reduce the overall cost-in-use. This is why the need for maintainability conscious designs.

6.5 NEED TO PROVE OPERABILITY AND MAINTAINABILITY

The concept and principles of maintainability has been presented in section 3.4 as an age-long traditional theory of architecture which requires building designers to give considerations to maintenance issues and cost from the design inception (Seeley 1976; Mills 1994; Lush 1994). Also, according to CIRIA (2009), the obligation for designers to deliver safely and economically maintained buildings is already enshrined in law. However, this is often not well done, and there is a lack of practical guidance (Ibid). Dunston and Williamson (1999) noted also that maintenance problems in facilities are heavily attributed to design limitations, among other issues. It has also been reported that maintenance considerations were ranked by designers to be among the least important design factors considered during design, and that maintenance related complains ranked much higher among the complains designers reported receiving from clients and tenants. This was the outcome of a related study carried out of 211 Architectural firms in the United States, aimed at investigating the relationship between design practices and maintenance considerations as reported in Arditi and Nawakorawit (1999a).

This indicates that designers are largely responsible for the huge cost of operation and maintenance of buildings and should consequently be liable to finding an enduring solution.

So one question this study sets out to answer is if in the recent years there have been some improvements in designers' attitudes to maintainability, and if not, what should be the appropriate method (best practice approach) that will ensure that designers adhere reasonably to this age-long requirement – maintainability?

The key findings that emerged were that building designers attitude to maintainability is still very poor, and in most cases clients were never aware of the maintenance implication of their proposed buildings before they are erected. The findings also show that if designers are made to prove the operability and maintainability of their designs before they are constructed, they will for certain be maintainability conscious and the clients will be fully abreast of the maintenance requirements of their proposed building and be able to make informed choices at their own risk.

6.5.1 Attitude of Building Designers to Maintainability

The question about designers' attitudes to maintenance consideration during design featured both in the online and manual surveys. The online respondents which consist of nearly 70% of building designers (58.3% of architects and 8.3% of architectural technologists) were asked the question; "From your experience as a professional in the building industry, how would you agree or disagree with the statement – most architects pay less attention to issues of maintenance and operation challenges in their designs?" The result is reflected in figure 6.28. This could be said to reflect architect's opinion, since architects constitutes nearly 70% of the study population.

Figure 6.29 presents the result of the manual survey which has 50% of the study population made up of facilities managers (FMs). Other professionals in this population are just 7% (1 participant) each except the quantity surveyors which are 14% (2 participants). So it may also seem proper to say that this reflects the opinion of facilities managers.

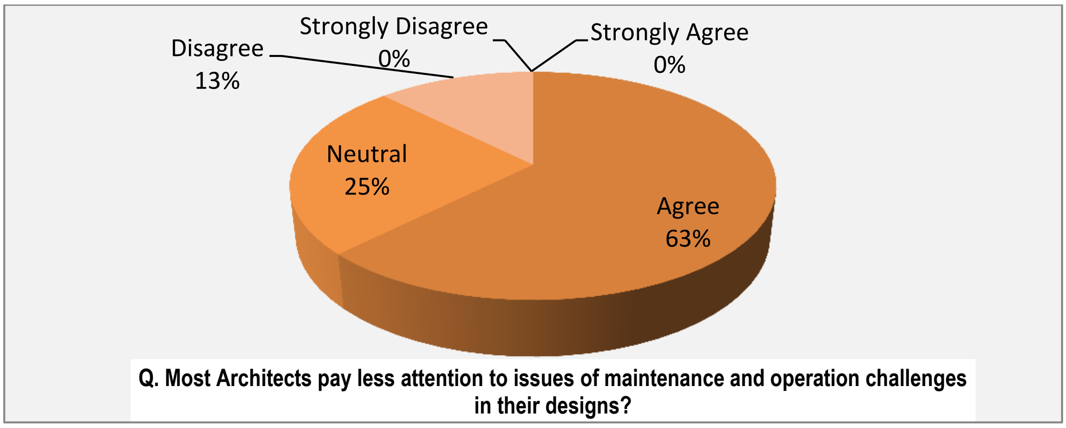


Figure 6.28: Attitudes of Architects towards Maintainability (Architects opinions)

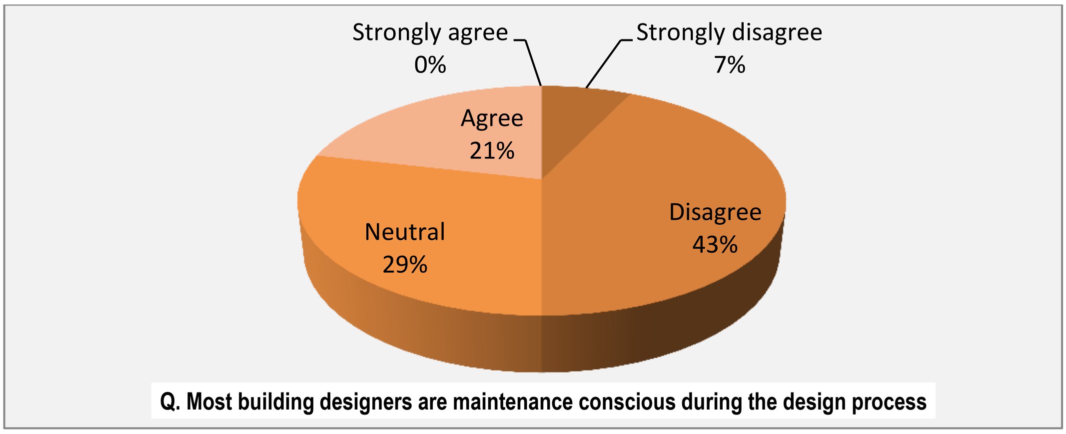


Figure 6.29: Attitudes of building designers towards Maintainability (FMs opinions)

Both results show that architects' attitude to maintainability has not improved much. While 62% of architects agree that most architects or building designers pay less attention to maintenance and operation issues during design, 50% of facilities managers corroborate this by disagreeing and strongly disagreeing that building designers are maintenance conscious during the design process. In both cases the percentage of neutrality are 25% and 29% respectively.

The interview result also returned 60% of the interviewees agreeing that most architects do not pay attention to maintenance and operation considerations during design. The question was put; 'there is an opinion that most architects are not maintenance conscious while making their designs. What do you think about that? It is interesting to quote their answers directly:

- *"Absolutely right!"* (Code no. 004). Interestingly, this participant is an architect with 30years experience in both private practice and in teaching and research in the UK.
- *"I think it is very variable, there is a school of thought that signature architects pay less attention to the issue of maintenance and operation challenges of the building in use".* (Code no. 001). This participant also has 30 years' experience and also involved in managing building procurement processes as well as managing the buildings in operation.
- *"It is not their primary concern how the building operates after construction".* (Code no. 002). Although this participant is less than 10 years in the industry, he sits on the management side of a renowned building developer company that has won several awards for the several buildings they have been involved with.

All three (3) study tools; the interviews, online and manual surveys, concluded that most architects do not give sufficient attention to issues of operation and maintenance in their designs.

6.5.2 Clients Awareness of O&M Implications

Following the strategy of inductive coding described by Marks and Yardley (2004), which involves drawing themes from the raw data itself, a comment from one of the interviewees was found to be interesting and worth further probing. Interviewee 001 represented a client body. The question about how as a client he would ensure that the building delivered to him was maintainable was put to him. His answer suggested that a skilled member of his team is usually assigned to work with the design team. This member uses his experience to identify any concern on the proposal as regards maintenance or operational challenges that are reasonable. Furthermore, a project management group, responsible for all of the individual projects will receive regular reports and presentations from the design team, and will use their collective skills also to voice out any concern regarding the proposals. This suggested that this client is usually armed with the operation and maintenance implications of his proposed buildings before they are constructed. So the online questionnaire was designed to also find out when low carbon building owners became aware of the maintenance implications of the buildings delivered to them. Participants were asked to indicate when the client for the exemplar LCB became aware of the maintenance implication of the technologies and when, by their respective experiences they think is best for the client to be aware.

The results from these two questions are reflected on figure 6.30. Although opinion was varied, however, results indicated that majority of the clients (37%) became aware of the maintenance implications during the design stage (RIBA stage C – E). This result seems to be in disagreement with section 6.6.1 which concludes that most architects do not pay attention to maintainability issues during the design process. If the client became aware of the maintenance implication of his proposed technology at the design stage, then it most likely that the information would have been passed on to the design team, or even emanating from the design team.

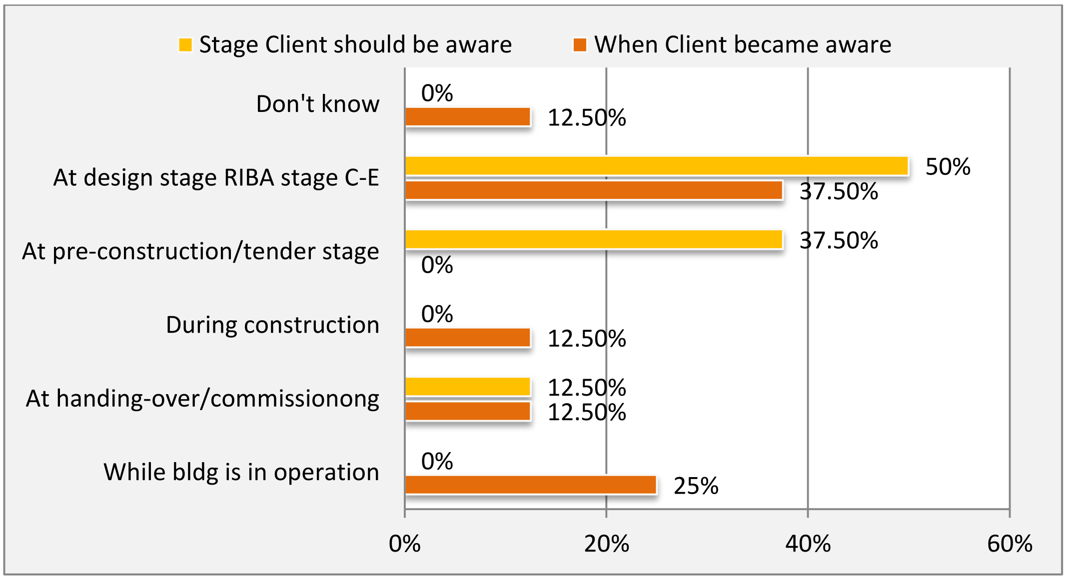


Figure 6.30: Clients' Awareness of O&M Implications of the Technologies (On-line Survey)

To validate this result, the question was reframed and included in the hard copy survey. Reframing the question became necessary because facilities managers whom the survey was targeted at are seldom involved in the design process as discussed in section 3.4.2. The reframed question reads; *"From your experience as a building professional, do you think that clients are usually aware of the operation and maintenance implications of their proposed building before construction?"* Figure 6.31 presents the results.

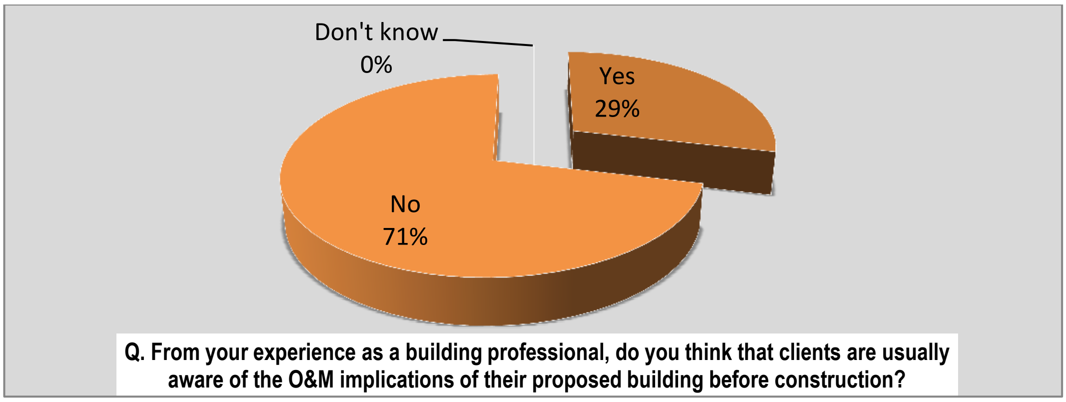


Figure 6.31: Clients' Awareness of O&M Implications before construction (Hard Copy Survey)

In this result, only 29% of the population (mainly facilities managers) agree that clients are usually aware of the maintenance implications while 71% said no. However, it is also noteworthy that the result of the first survey also shows that 25% of participants (mainly architects) indicates that clients became aware while the building is in operation. Another 25% said it was either during construction or during handing-over/commissioning and 12.5% do not know when. So the result in figure 6.30 could be interpreted as:

i) Clients are aware of O&M implications before construction – 37.5%

ii) Clients are not aware of O&M implications before construction – 50%

iii) Don't know – 12.5%

So the conclusion here would be that, in most cases clients are not aware of the maintenance implications of their proposed buildings before construction, however, in some cases they do.

Figure 6.30 also indicated that 50% of the respondents suggested that it would be best practice for clients to be aware of the maintenance implications of their proposed developments at the RIBA stage C – E of the design process. Another 37.5% opined that the pre-construction/ tender stage (RIBA stage F – H) will be the best period. Both stages are before the construction stage. That means 87.5% are of the opinion that clients should be aware of the O&M implications of the design before construction.

6.5.3 Proving Operation and Maintenance

Commenting freely on what could be done to make architects think maintenance while designing, 60% of the interviewees said it will be necessary to prove how the building will be operated and maintained, before it is constructed. Interviewee code no. 004 commented thus;

> *"The first thing that is going to happen is that as the standards for low carbon buildings gets tighter, then architects will be required*

> *to prove that their buildings are going to perform and I suspect what is going to happen is that the building regulations will start to incorporate a maintenance regime or some kind of test after a year to see how it is working. The rest is how people feel in the building and that I think is bound to change".*

Interviewee 003 suggested that the architects need to demonstrate how the building operates *"before it is up".*

The second survey, directed at facilities managers was used to validate this opinion mainly because the facilities managers are those who engage with the building longer than other built environment professionals. In most cases, they represent the client, and in economic terms, they are consumers of the designers' and contractors' products. Tunstall (2006) argued that the consumer is in the best position to judge the success or failure of a product, and that their level of expectation is crucial.

The result is shown on figure 6.32. In total about 93% of the study population agree or strongly agree that building designers need to demonstrate that the buildings they design will be maintainable (safely and economically maintained) before it is constructed.

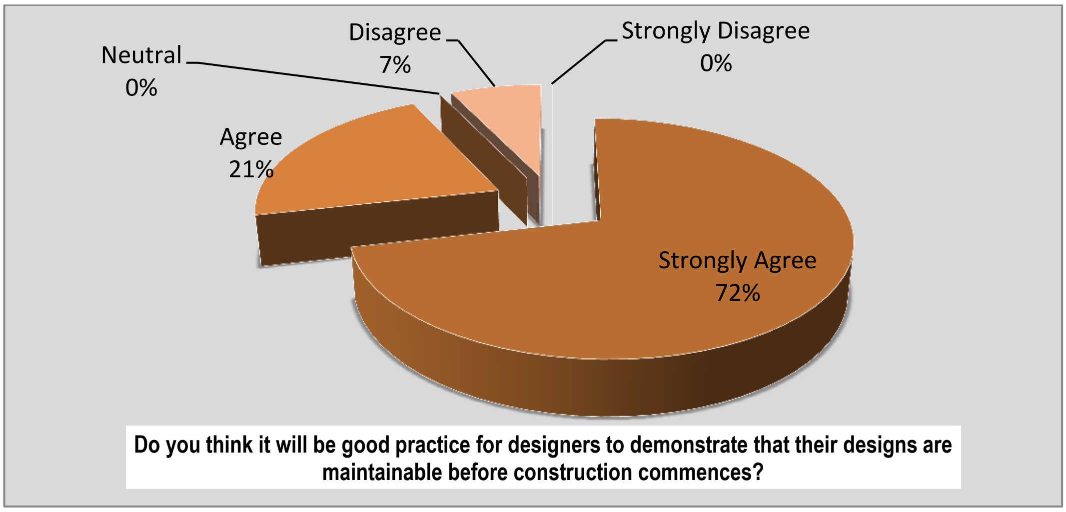


Figure 6.32: Need to Prove Maintainability

In the opinion of Interviewee 001, this is already a requirement by law; "*the CDM regulations require designers to think through these things* (operation and maintenance), *the issue is how well do they do this?"*

The question of how well they do this seems to have been answered in the previous sections. Section 6.6.1 concludes that most architects do not give sufficient attention to issues of maintenance. In section 6.6.2 it was noted that most clients are never aware of the maintenance implications of their buildings before they are built, which by extension could imply that the designers never communicated that to the clients, probably because it was neither part of the clients' brief nor the design brief.

The issue of how well the law is being obeyed suggests that the best solution to improving designers' attitude to operability and maintainability should not end in legislation, but should extend to a cultural or process change. This change is inevitable if low carbon buildings need to be delivered to clients' satisfaction and to achieve value for money.

CIRIA (2009) corroborates the stands of interviewee 001. It argued that the obligation for building designers to provide their clients with safely and economically maintained and repaired assets, as well as whole-life considerations are already enshrined in law. However, it is often not well done and there is no practical guidance to this effect (Ibid). CIRIA (2009) also suggested a *'cultural shift in work attitudes and thinking';* on the part of both clients and designers.

This suggests that there has to be a change in what clients expect from designers, and designers need to re-orientate themselves in the way they design. When clients constantly demand from their design consultants what the maintenance and operational implications would be (in terms of 'how' and 'how much'), then designers will sit up to their social responsibility of providing buildings with *'commodity, delight and firmness'* (Vitruvius in Strelitz, 2008). Tunstall, (2006) describes firmness to refer to 'Constructability and Durability'. Meaning that, designers need to design buildings and their fixtures to be both constructible and durable.

6.6 THE INDISPENSABILITY OF A GOOD O&M MANUAL IN THE OPERATION AND MAINTENANCE OF LOW CARBON BUILDINGS

Adopting maintainability or thinking maintenance at the design stage is a good first step to ensuring value for money in LCB delivery. However, these thoughts need to be communicated to the end users of the building, particularly, for low carbon buildings that are usually fitted with new and innovative technologies; mostly unfamiliar to end users. In the light of this, a good O&M manual becomes indispensable. The antecedents and need for a good O&M manual has been highlighted in chapter 3, based on findings from literature (theoretical knowledge). However, this section examines practically, what the building practitioners think about O&M manuals; whether it is fit for purpose or just to meet legal requirements as noted in literature. It also tries to examine what could be the best way forward for the O&M manual regime in the UK.

6.6.1 The O&M Manual Regime in the UK

In chapter 3, it has been established that it is a 'legislative must' for owners of buildings in the UK to be provided with information on how to safely and efficiently operate and maintain building services. Findings from literature and preliminary investigations have also revealed that the O&M manual has continued to fail in meeting its expected requirements as a tool for safe, healthy and efficient operation and maintenance of buildings. In July 2011, BSRIA asserts that construction industry has a poor reputation with regards to O&M manual quality and timeliness of delivery, based on findings from its ten year research on the key performance indicators for building services contractors (BSRIA, 2011).

At the interview stage of this study, some of the interviewees expressed the opinion that suggests that the O&M has not been able to meet the needs of users and operators of the buildings; in most cases they find it difficult to use. Quoting one of the interviewees:

> *We've done building before, when they are finished we handed over the maintenance manual and six months later we get a phone call saying; what do we do with this?"*

The question from this client suggests that the manual was not in a form they could identify with or understand. Imagine that you buy a car and you are handed the car manual and you ask, 'what do I do with this'? This typical client definitely may not have a good impression about O&M manuals.

6.6.1.1 Why the Poor Reputation of the Industry with O&M Manuals: In this study therefore, participants in the surveys were asked to identify reasons responsible for this poor reputation. As presented in figure 6.33, the results from the online survey show that the top reason for this poor reputation is that '*most O&M manuals lack enough details that could aid effective operation and maintenance'*, as identified by 50% of the participants. Other top reasons; each identified by 37.5% of the occupants are that:

1) The manuals are just compilations of manufacturers' manuals
2) They are being provided just for legal purposes and not fit for purpose
3) The time of delivery does not aid maintainability.

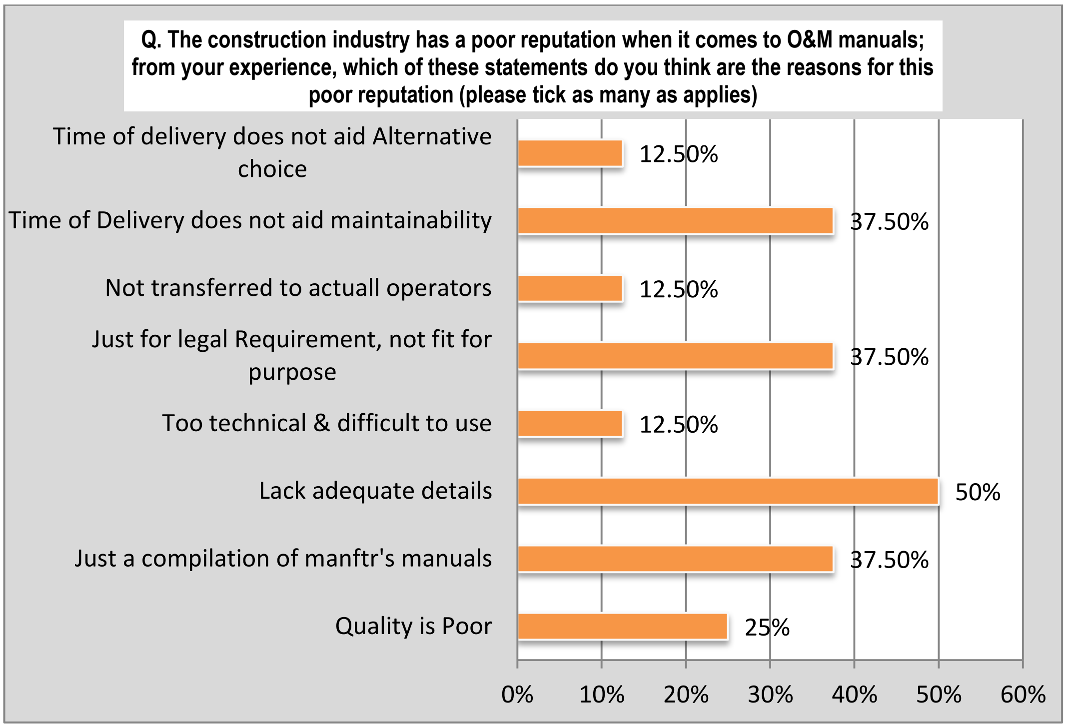


Figure 6.33: Possible Factors Responsible for the Poor Reputation of the O&M Manual in the Building Industry (online survey)

In the second survey which was specifically aimed at understanding practitioners' opinions about the O&M regime, the question was reframed in a rating scale format. Participants were asked to rate the level of their agreement or disagreement with the factors outlined on the questionnaire, as being responsible for the poor reputation O&M manuals attract to the industry. The rating was on a scale of 1 – 5 where 1 is 'strongly disagree' and 5 - 'strongly agree'. From the result, most participants who are mostly facilities managers rated '*Just a compilation of manufacturers' manuals'* to be the top reason why the O&M manuals attract poor reputation to the industry. The rating average for this option was 4.29 out of 5 as shown on figure 6.34. Closer look at how the participants rated this option shows that the minimum rating was 3 out 5 (ie., Average), and by only 7% of the participants. A total of 93% of the participants Agreed and strongly agreed that '*most O&M manuals are just compilation of manufacturers manuals'* (figure 6.35a). This is also among the top 4 factors noted from the online survey.

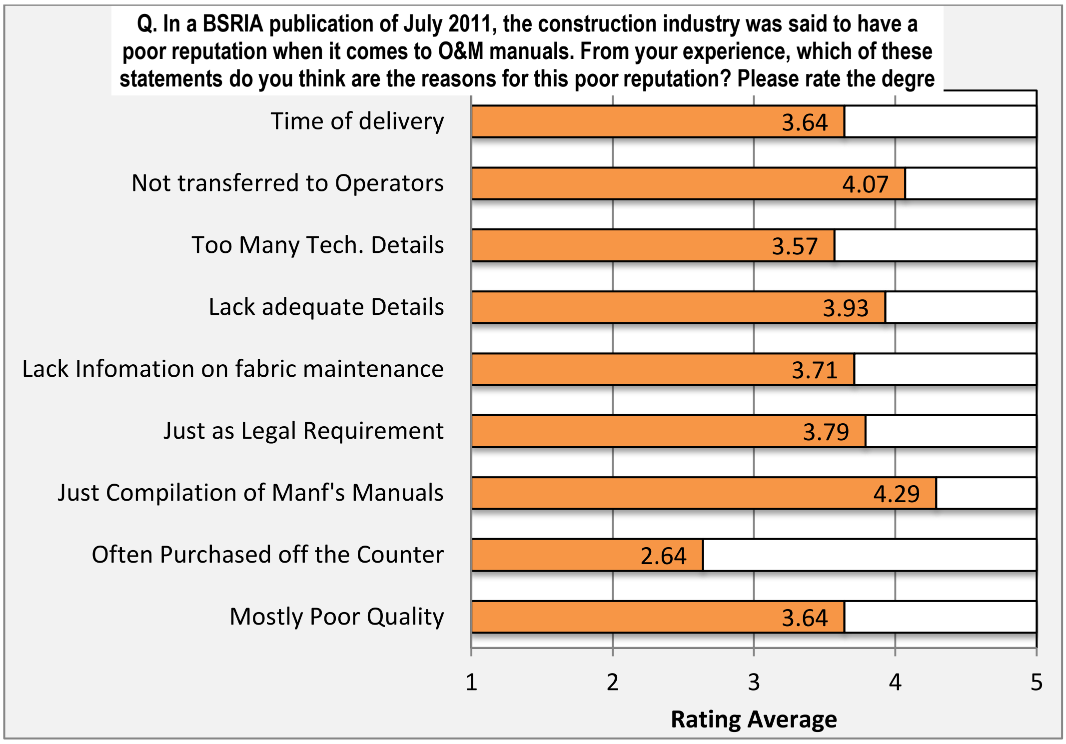


Figure 6.34 FM Professionals Perception of Possible factors Responsible for the Poor Reputation of the O&M Manual in the Building Industry (Hard Copy survey)

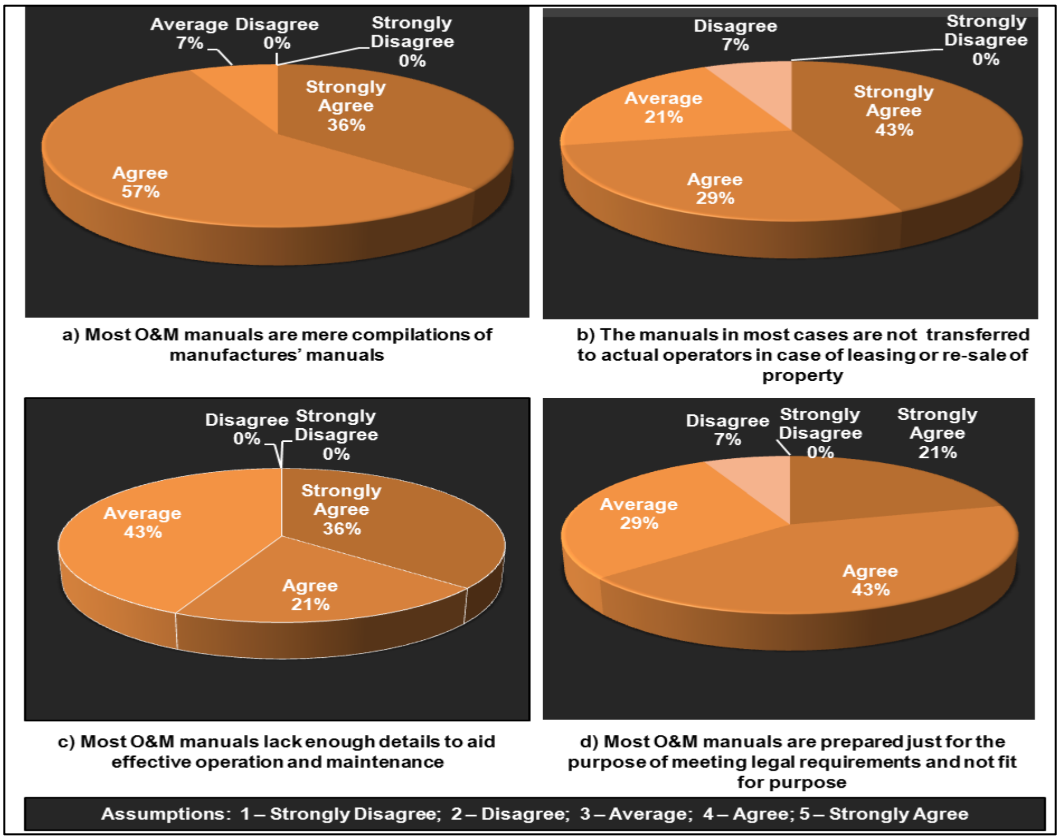


Figure 6.35 Top Four Rated Possible factors Responsible for the Poor Reputation of the O&M Manual in the Building Industry (Hard Copy survey)

Three other top-four possible factors responsible for the poor reputation include:

1. *'The manuals in most cases are not transferred to the actual operators in case of lease or re-sale of property'* (Rating Average = 4.07). Only 7% disagreed with this factor. 21% rated it average while a total of 72% of participants agree and strongly agree (figure 6.35b).
2. *'Most O&M manuals lack adequate details to aid effective operation and maintenance'* (Rating Average = 3.93). No participant disagreed with this factor. However, 43% rated it average, while a total of 57% agreed and strongly agreed (figure 6.35c). This is the highest rated factor in the online survey.
3. *'Most O&M manuals are prepared just for the purpose of meeting legal requirements and not fit for purpose'* (Rating Average = 3.79). This is also one of the highly rated 4 factors in the online survey.

However, there are other factors that were rated above average by the participants as see in figure 6.34.

Respondents were also asked to comment freely about the O&M manual regime in the UK. Some of the comments are as shown in table 6.8

Table 6.8: Respondents' Comments about the O&M Regime in the UK

S/n.	Comments by Respondents	Researcher's Comments
1	Suppliers/Manufacturers often seem to think this is a marketing document.	Seen as mere compilation of manufacturers' manuals
2	I am currently working on a large PFI - it is an O&M manual nightmare!	Perhaps too many details and technicalities that make them too difficult to use
3	Not easy to use for management of maintenance	
4	Contractors are slow at providing	Problem with time of delivery
5	The current production of O&M manuals for the O & M of buildings is inadequate to ensure efficient operation	Lack adequate details to aid effective O&M
6	Too often left to the construction team, seen as an unnecessary burden to them when they are trying to complete the build.	Seen as a burdensome legal requirement
7	Web enabled soft copies with hyper-links are much easier to use	Currently seen to be of Poor quality
8	Most O&M manuals are off-putting at first glance and making user friendly is vital	Not user friendly

A total of ten factors have been identified as being responsible for the poor repute O&M manuals have attracted to the industry, based on the finding of this study. They are summarised in table 6.9.

Table 6.9: Factor Affecting the Construction Industry's Reputation about O&M Manuals

S/n.	Factors	Sources
1	Most O&M manuals lack adequate details that could aid effective operation and maintenance	Online and Hard copy Survey
2	Most O&M manuals are just compilations of manufacturers' manuals	
3	Most O&M manuals are prepared just for the purpose of meeting legal requirements and not fit for purpose	
4	The time of delivery does not aid maintainability	Online Survey
5	The manuals in most cases are not transferred to the actual operators in case of lease or re-sale of property	Hard copy Survey
6	Most O&M manuals lack information about the building fabric	
7	The Time of delivery does not give clients opportunity of alternative choice of materials, equipment and/or technology	
8	The quality of most O&M manuals is poor	
9	Most O&M Manuals contain too many details and technicalities that make them too difficult to be useable	
10	Most O&M Manuals are not user-friendly	

6.6.1.2 Current Practices with respect to O&M Manual Delivery Process:

During the preliminary studies and the interview stages it was noted that most O&M manuals were being produced not as a necessity for the project, but as an unnecessary and painful legal requirement that must be met. So at the end of the projects, contractors grudgingly gather every document they have received from suppliers and sub-contractors into file, as an O&M manual. In the words of one of the interviewees, he said:

> *"What a contractor does at the end is that he gets a young member of staff to photocopy everything he ever received about everything in the building and he very kindly puts it in a series of ring binders folders for you. If you're lucky, you get an index, but finding things and getting that information from the O&M manual is very painful. …. So I see the industry does have a poor reputation. The contractor thinks if he hands the building over and he gives you all these files, then he think he has done his job. That is poor in my view"* (Interviewee 003).

As part of general comments about the O&M manual in the hard copy questionnaire, one of the respondents noted thus:

> *"Too often left to the construction team; seen as an unnecessary burden to them when they are trying to complete the build".*

Further findings from the study also revealed that there are 'Specialist O&M Manual Editors (Blacker, 1994; People4Business, 2010; WebFm, 2010), who are usually neither in the designers nor contractors teams. In most cases they come in towards the end of the construction stage, when all equipment and machineries may have been installed, sometimes when the building is being prepared for handing over and commissioning. Figure 6.36 shows the results from the online survey. The question sought to know at what stage of a typical building project the first and final drafts of the O&M are usually prepared. It shows that preparation of the first draft of the manual is usually commenced from the construction or during handover and commissioning stage of the project. The final draft is then handed in while the building is in operation or during handover/commissioning and in few cases, still within the construction period.

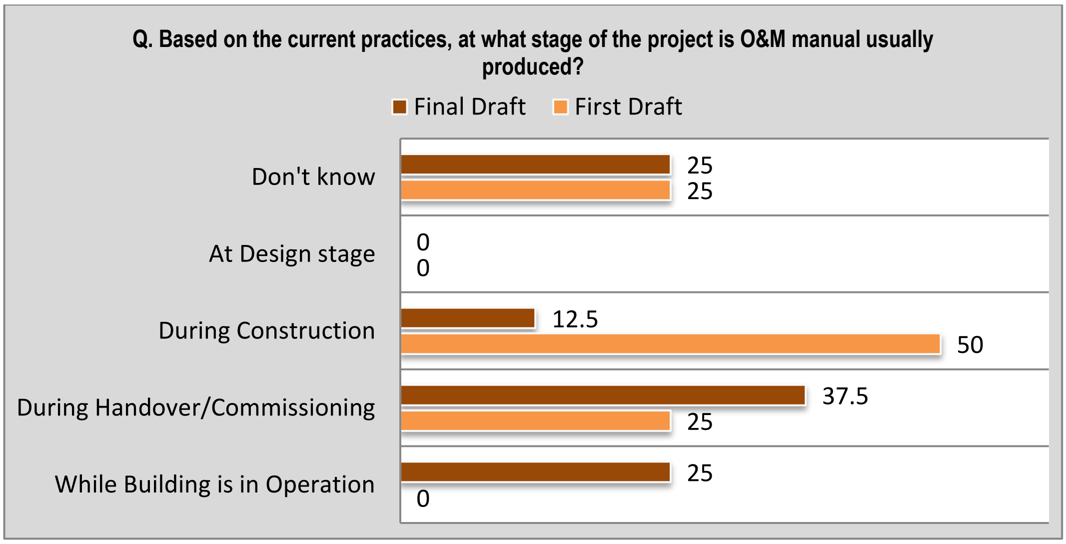


Figure 6.36: The stage of Construction when the O&M manual is usually produced, based on current practices (online survey)

6.6.1.3 The Extent to Which O&M Manual has met its Intended Purposes for Buildings in the UK: As discussed in chapter 3, the O&M manual was introduced to the UK by the report of The Committee on Building Maintenance published in the Research and Development Bulletin of Ministry of Public Building and Works of September 1970. The purpose of the O&M manual as contained in the committee's submissions included:

1) It will enable the property manager to organise the repair and maintenance of the building, its services and surrounds effectively and economically;

2) It will enable the occupier to clean and operate its services efficiently and reduce losses of time and production;

3) It will establish a link between the project design team and the client and his maintenance organisation to their mutual benefit.

A fourth purpose of the O&M manual was also highlighted in Blacker (1994) and CIRIA (1999) which requires that a good O&M manual needs to provide basis for improved future design through lessons learnt from previous projects.

The hard copy survey was used to also test how well the O&M manual has met its intended purposes for buildings in the UK. The respondents rated the extent to which the manual has met each of the four purposes of O&M manual listed above, on a scale of 1 – 5; where 1 is very unsatisfactory and 5 is very satisfactory. Figure 6.37 shows the rating average in each case. All of the cases returned a rating average below the 3.0 'Average' rating.

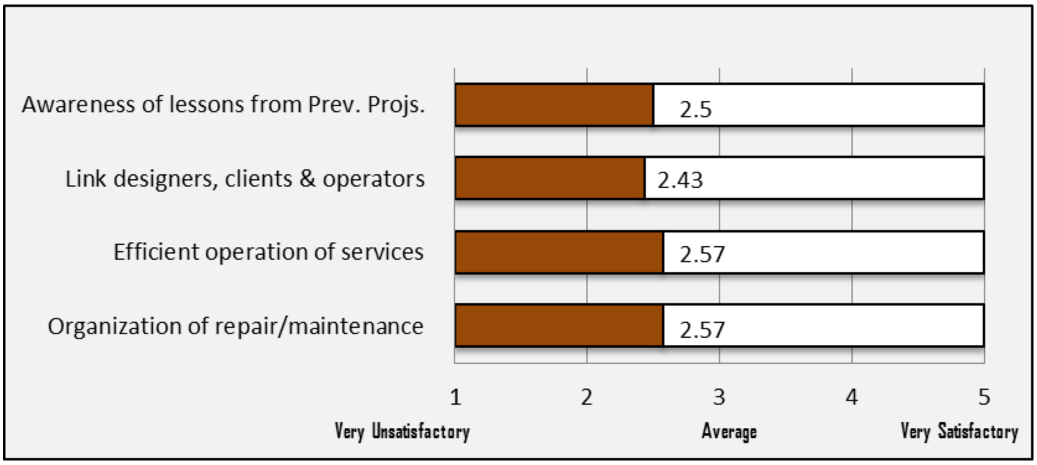


Figure 6.37: Respondents Rating Average of the Extent to which O&M Manual has met its intended purpose for Buildings in the UK

This infers that the extent to which O&M manual has met its intended purposes in the UK building industry is unsatisfactory. Figure 6.38 describes the detail percentage distribution of the participants' ratings. In terms of how O&M manuals have helped in organising repairs and maintenance, 50% of the participants think it has been unsatisfactory and very unsatisfactory (figure 6.38a). Nearly 60% think O&M manuals have not helped in the efficient operation of building services (figure 6.38b). 56.7% also think the manuals have not met its purpose of linking designers, clients and operators (figure 6.38c), while another 58% think that the O&M manual regime in the UK has not been able to serve the purpose of providing lessons previous projects (figure 6.38d)

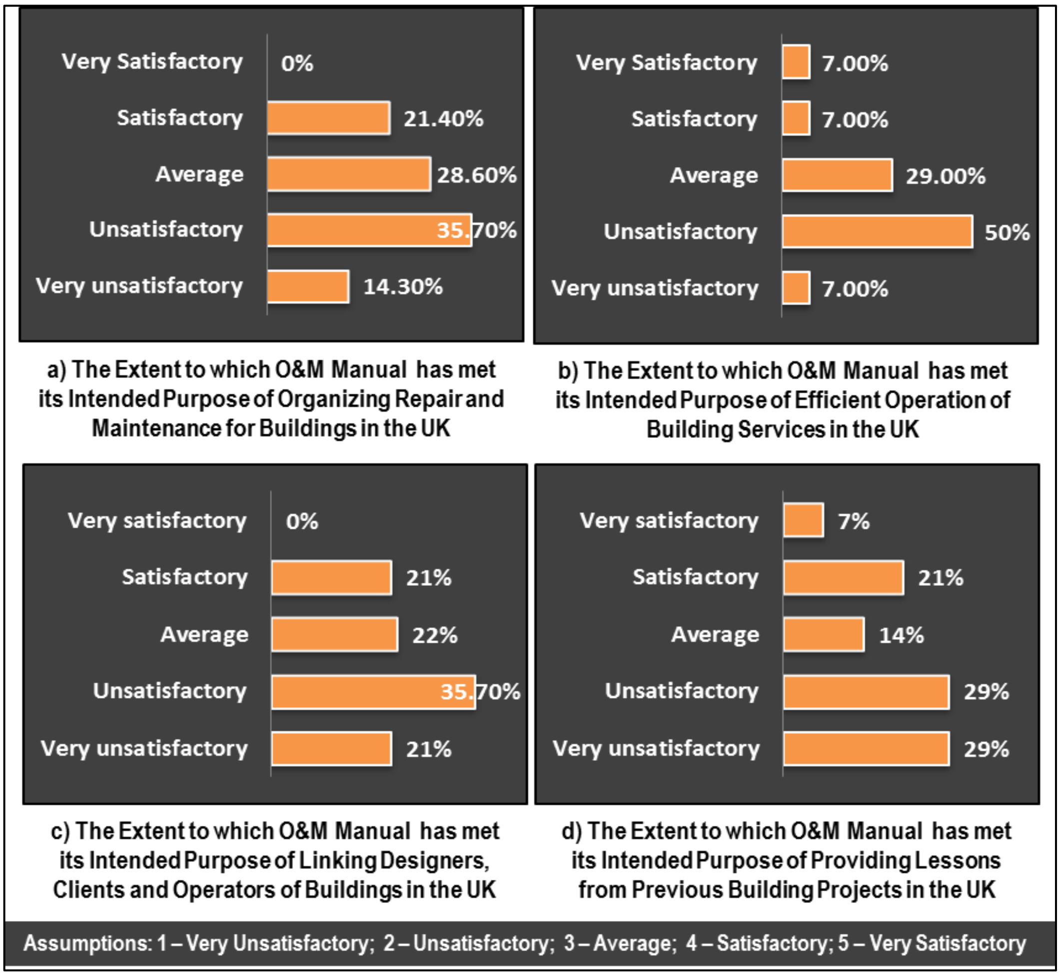


Figure 6.38: % Distribution of Respondents Rating of the Extent to which O&M Manual has met its intended purpose for Buildings in the UK

6.6.2 Why a Good O&M Manual is Indispensable for Low Carbon Buildings

The indispensability of the benefits of a good O&M in the operation and maintenance of buildings generally has been discussed in chapter 3. References were made to Blacker (1994), CIRIA (1999) and Silva et al (2004). However, there was no evidence found that their assertions have been subjected to empirical testing. The benefits of a properly prepared O&M manual discussed in section 3.5.3 of this thesis could be summarised to mean that 'if properly prepared, the O&M manual can act as a bridge to the existing gap between designers and operators of buildings. So participants in the online survey were asked to rate the extent of their agreement/disagreement to this statement. The result returned 100% of the respondents agreeing or strongly agreeing to the statement as shown in figure 6.39.

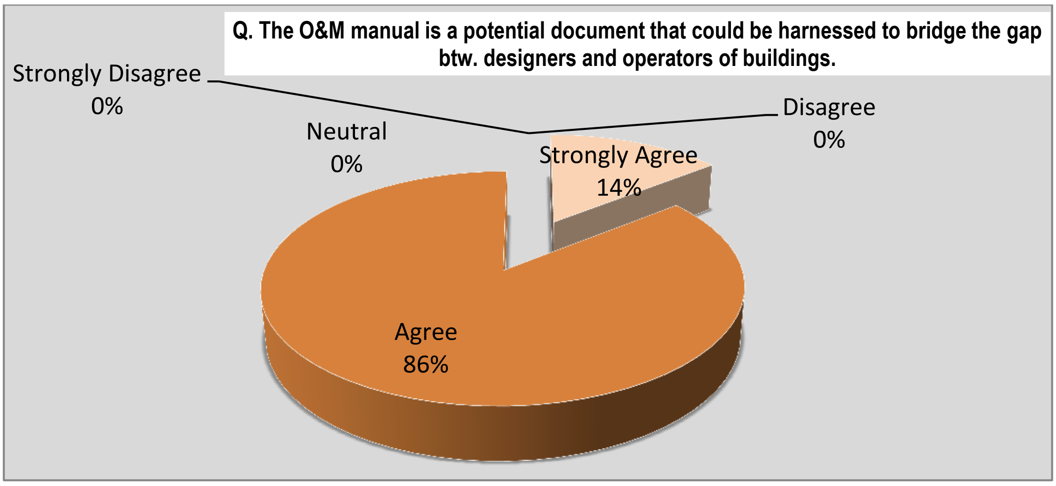


Figure 6.39: Practitioners' Opinion about O&M Manual as a Potential Document that could be harnessed to bridge the gap btw. Designers and Operators of LCBs

This indicates that if the gap between designers and operators of buildings needs to be bridged, then a properly prepared O&M manual is indispensable, and more so for buildings with unconventional, new and innovative technologies. Corroborating this statement, the hard copy survey respondents who are mostly facilities managers were asked to rate how well they agree/ disagree with the statement that *'a well prepared O&M manual is* *indispensable for the operation and maintenance of low carbon buildings*. Figure 6.40 highlights the results.

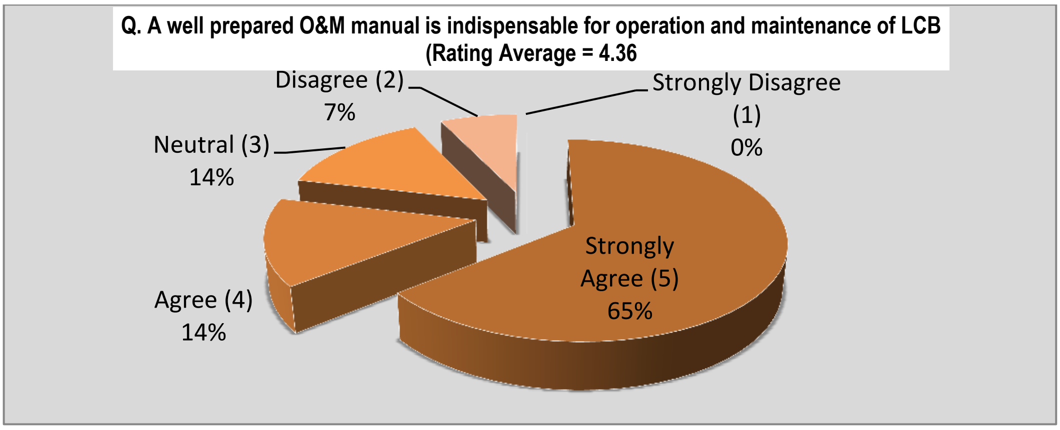


Figure 6.40: Facilities Manager's Opinion about the Indispensability of O&M Manuals in the Operation and Maintenance of Low Carbon Buildings

The rating was done on a scale of 1 – 5, where 1 is 'strongly disagree' and 5 is 'strongly agree'. A rating average of 4.36 was returned. A total of 79% of the respondents agreed that the O&M manual is an indispensable document for LCBs, while only 7% disagreed and 14% were neutral.

The interviewees were also asked; *'Considering the disappointing outcomes of O&M manuals, do you think it is still a necessary document for low carbon buildings'?* 100% of them believed the O&M manual remains a needful document for the effective and efficient operations of buildings with new technologies. Comments from some of the interviewees are:

- *"Very necessary!"* (Interviewee 002).
- *"I think it is definitely a useful thing to have, whether it helps you do the maintenance, it will definitely help you to find spare parts and that kind of stuff"* (Interviewee 004).

6.6.3 Repairing the Industry Reputation with respect to O&M Manual

This section examines the way forward for the O&M manual; how the dented reputation which O&M manual has attracted to the industry can be repaired;

how O&M manual can be made an effective tool that is capable of ensuring maintainability and efficient operation and maintenance. Results gathered through interviews, online and manually circulated hard copy surveys returned eight (8) recommendations from the respondents on the way-forward for O&M manual regime in the UK.

6.6.3.1 Integrating the O&M Manual Process into the Design Process:

Interview results indicated that 60% of the interviewees were of the opinion that if O&M manual process is brought in to the design process, it could enhance the quality of the manual. This question was however not part of the original intended interview questions, but emanating from the comments of one of the interviewees;

> *"I think you need someone who understands management and facilities management to come in at design phase and oversee that kind of knowledge transfer process and for them to assemble a manual"* (Interviewee 002).

Following the strategy of inductive coding described by Marks and Yardley (2004), which involves drawing themes from the raw data itself, it became necessary to make further probe with subsequent interviewees and the surveys. So the other 40% of interviewees who were interviewed earlier were not asked this question. In essence, 100% of the interviewees who were confronted with the question agreed that it will be good practice to bring the O&M manual process into the design process.

The online survey also returned 100% of respondents agreeing and strongly agreeing to the opinion that bringing the O&M manual drafting process into the design process is capable of enhancing the quality of O&M manuals in the UK. The result is summarised in figure 6.41.

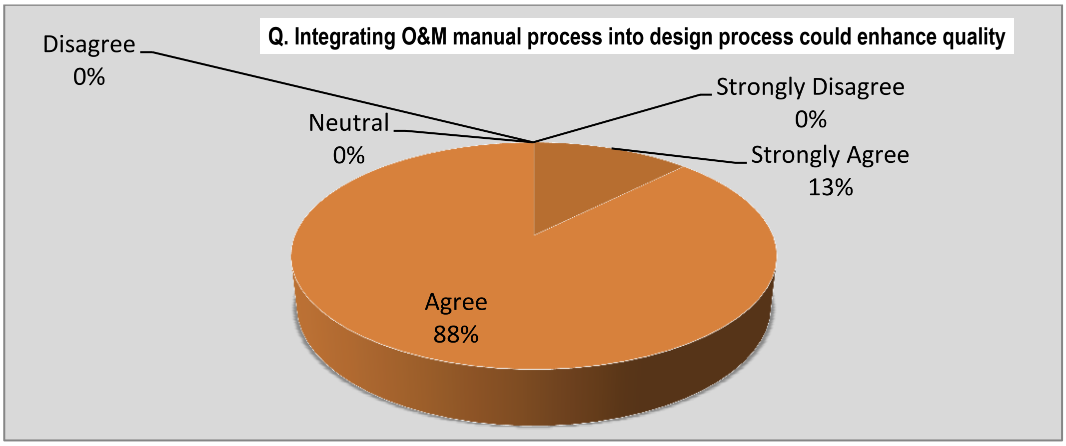


Figure 6.41: Integrating O&M Manual Process into Design Process (Online Survey)

Figure 6.42 shows the result from the hard copy survey which returned 93% affirmation that bringing O&M manual process into the design process is capable of ensuring that designers think through maintenance when designing. Only 7% of the respondents were neutral and none disagreed with the postulation.

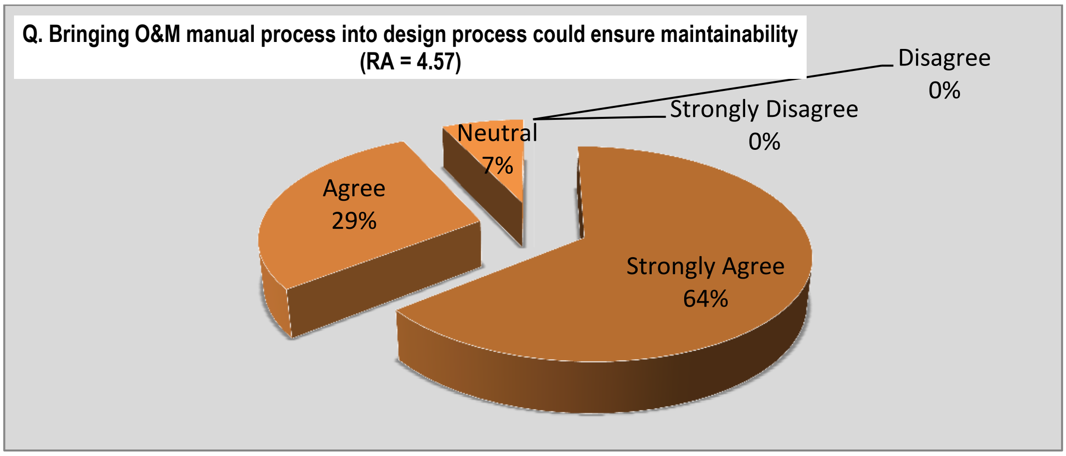


Figure 6.42: Integrating O&M Manual Process into Design Process (Hard Copy Survey)

Also a web advert by Denaploy, a specialist O&M manual authoring company, with the caption; 'Making Manuals that Work', corroborated these results. It noted that O&M manuals preparation should start at the beginning of the project, and that if you leave it to the last minute just as the handover looms, then it will always be a second best. Interestingly, this is coming from people who are experienced in the preparation of O&M manuals (Denaploy, 2013).

6.6.3.2 Involving O&M Manual Specialists from the Design Stage:

> *"…I don't ask my cleaners for example to impute on the design or my engineers and direct labour staff who are dealing with repairs and maintenance because they will just ask for everything to be the same as they have been used to and so you will stifle innovation and technological advancement in building design by always being conservative and always wanting everything to be the same as you've been used to in the past. I think this has to be a balance …"* (Interviewee 001).

The above statement is a direct quote from one of the interviewees. His opinion is that involving maintenance staff in making imputes to design may result in stifle in innovation and technological advancements in design. However, other interviewees (60%) believed that involving personnel who are involved and/or are experienced in building operation and maintenance management will improve the design output. Another interviewee comments:

> *"I don't think the design team necessarily understands. They do care but it is not their primary concern how the building operates after construction. So you need some with a good understanding of facilities management I would say"* (Interviewee 002).

So both statements were tested with the online survey as well. Results show that 63% of respondents expressed neutrality to the statement that Involving O&M specialist will stifle innovations (see figure 6.43). Only 12% agreed and 25% says involving O&M specialists will not cause stifle in innovations.

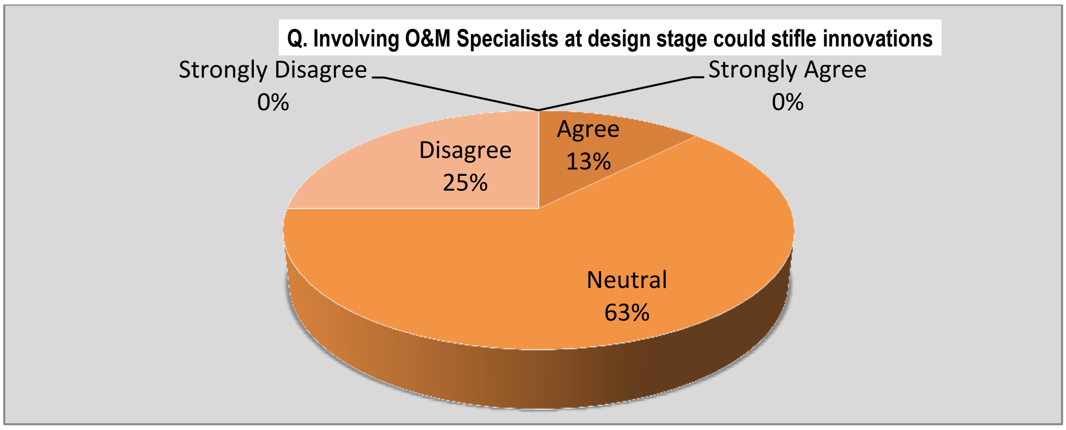


Figure 6.43: Involving O&M Specialist Could Stifle Innovations (Online Survey)

Whereas, twisting the question to read; '*If the O&M manual specialists become part of the design team, this could contribute to architects giving more attention to operation and maintenance challenges'* was put to respondents and 87% agreed, the remaining 13% were neutral, with none disagreeing (figure 6.44). So it can be concluded that rather than causing stifle in innovation and technological advancement, involving O&M manual specialists in the design process will help to improve design maintainability.

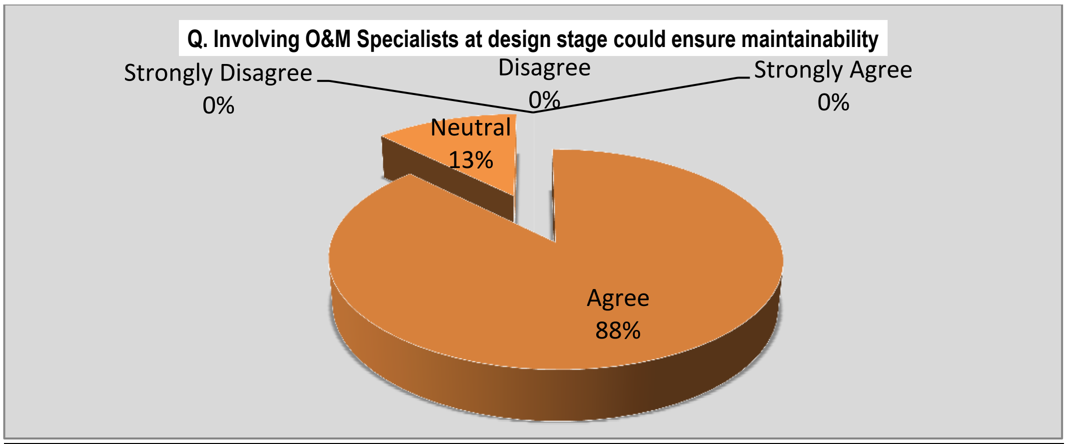


Figure 6.44: Involving O&M Manual Specialist Could Ensure Maintainability (Online Survey)

6.6.3.3 Transferring Responsibility of Collating/Authoring to the lead designer: It seems to be that the original intention of the Committee on Building Maintenance of the Ministry of Public Building and Works of August 1965 was that the O&M manual was to be produced by designers. MPBWR&D (1970) noted in its preface that one way of ensuring that clients and maintenance managers possess good knowledge of the buildings they occupy and for which they are responsible is '*for designers to produce O&M manuals as part of their commission'*. However, as noted in previous sections and from comment by interviewees and survey respondents, the current practice is that the responsibility appears to be that of the contractors. Also the CDM Regulations 2007 places responsibility on the CDM Coordinator to collate and compile the Health & Safety File, which normally incorporates the O&M manuals (CDM Reg. 2007 Approved Code of Practice, Regulations 17).

In this study therefore, respondents in the online survey were required to rate the extent of their agreement/disagreement with the statement; 'If responsibility of collating the O&M manual is transferred to the lead designer, it will help to strengthen the link between designers and operators of buildings'. Here also majority (87%) of the respondents were indifferent and 13% strongly agreed. Although none disagreed, but 13% is a very small percentage and cannot be used as a basis for affirming that designers be responsible for collating and compiling O&M manuals..

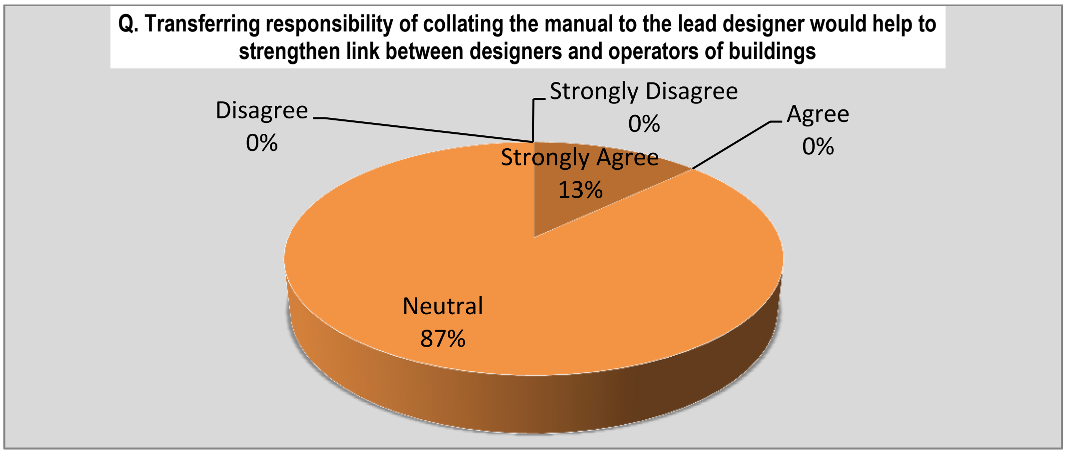


Figure 6.45: Transferring Responsibility of Collating O&M Manuals to the Lead Designer (Online Survey)

The interviewees were equally sceptical about transferring responsibility for collating the manual to the lead designer. A comment from an interviewee refers:

> *"I think you have a fair point about making him responsible, but I'm concerned about doing it through legislation or statutory control, that's quite a big step. …, <u>irrespective of who handles it, my preference is that it is not done as an after-thought</u>. …. I think as the process goes on, it's a good idea that the O&M manuals grow with the building, so that people understand what they are getting"* (Interviewee 003).

Conclusion here is that whoever collates the manual is irrelevant, what is relevant is that it should be started from inception of the design stage. CIRIA (1999) corroborates this position. It noted that various professionals involved in the design and construction process are well placed to lead the preparation of an O&M manual; either a senior member of the design team or the main contractor or a specialist author.

6.6.3.4 Develop a first Draft of the O&M Manual at the Design Stage: As discussed in section 6.8.1.2, current practices of O&M manual delivery indicates that preparation of the first draft of the manual is usually commenced from the construction or during handover and commissioning stage of the project. The final draft is then handed in while the building is in operation or during handover/commissioning and in few cases, still within the construction period. Respondents were also asked to indicate the extent of their agreement or disagreement with the statement that 'It will be good practice to make first of the O&M manual at the design stage. The result as shown in figure 6.46 indicates that 75% of the respondents accented to the affirmative, while the remaining 25% were neutral. None disagreed.

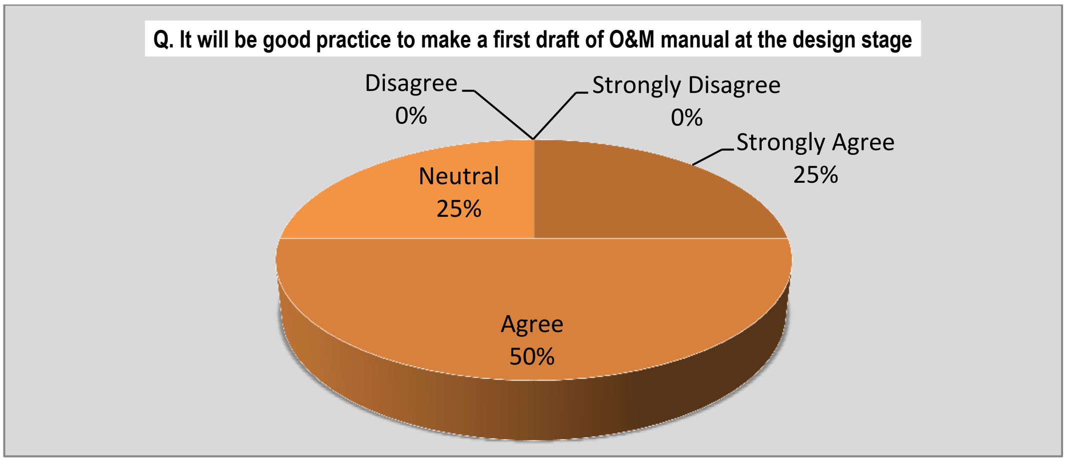


Figure 6.46: It will be Good Practice to Make a First Draft of O&M Manual during Design (Online Survey)

<u>6.6.3.5 Providing Information in User-Friendly Formats:</u> Analysing the general comments on the manual survey using the thematic content analysis approach indicates that over 50% of respondents proposed that the information in the O&M manual be provided in alternative user-friendly format. A few of the comments include:

- *"Provide information in other user-friendly formats"*
- *"Too much detailed high level specific specs; this cannot easily be read by non-technical staff. Should be simple".*
- *"Web enabled soft copies with hyper-links are much easier to use".*
- *etc.*

Another comment by an interviewee reads thus:

> *"… people's answer to digital form I find frustrating, because what they tend to do is to give you a PDF, you can't search a PDF. That's not clever technology. My view is that you need to put it on a CD. If you go to a garage with your car and you say you want to change a broken light bulb and you type in broken light bulb and it reads the CD, and says where is it? You type in break light and it gives you the number, that's what you want for your car. If I try to find what that broken light bulb is in the O&M manual, it will take me twenty minutes or more and I might not find it. …. That is poor in my view"* (Interviewee 003).

All these comments are clear indications that facilities managers are desirous of O&M manual, not only in a web format, but also in an easy to comprehend form by a non-technical building owner or building user. Majority of the respondents to the manual survey are facilities manager, Interviewee 003 is also a facilities manager with a background in Architecture.

<u>6.6.3.6 Separate Technical Details from Users' Operation and Maintenance Guide:</u> Similarly, in the manual survey, under general comments about any improvements desired for the O&M manual regime in the UK, about 70% of the respondents opined that there should be a separation between the actual

operation and maintenance guide and the technical cum manufacturers' literature. Some of the comments include:

- *"Separate actual operator manual and maintenance regimes, etc. Hazard/emergency procedure, etc."*
- *"Remove manufacturers' promotional literature"*
- *"I think O&M manuals should have 2 sections. First of all there is a requirement for all the technical data that is essential. However, there should also be the 'easy to use layman's guide' which is easier for maintenance staff to understand".*

6.6.3.7 Physical Examples of where Products have been Used: Analysis of comments on the surveys and interviews also revealed an interesting but lone opinion. In a bid to respond to general comments desired to improve the O&M manual regime, the respondent indicated thus;

> *"Examples of where the products have been used in place before; to see work in progress".*

The intention of what is meant to achieve, may be to show proof that the proposed technology is a tested technology, and from where operation and maintenance lessons could be learnt. It is possible that this respondent may have been influenced by the experience of the Paradise Park Children Centre at Islington, where the vertical garden or living wall was said to have not survived the test of time, because it was an untested technology.

6.7 CONCLUSION

The results of this study as outlined in this chapter reinforce the principle of duty of care, discussed in chapter 3. The principle places duty on designers to take reasonable care to ensure that their clients do not suffer the burden of high cost of maintenance and general under-performance in terms of energy savings and indoor air quality; thereby achieving good value for money. Meeting this requirement entails ensuring maintainability in design as deduced from the findings of this study. By applying the principles of maintainability, the problems of product support and maintenance of complex systems can be reduced, if not eliminated as opined by Blanchard and Lowery (1969).

Also, by the concept of 'right first time' discussed also in chapter 3, it is imperative for designers and their clients to take steps early enough to get the building right at the outset, to avoid the extra cost that will be involved in early replacement of components and unnecessary repairs. Therefore putting in place a system or process that can facilitate compliance to maintainability considerations will no doubt enhance a re-orientation in designers' attitudes towards maintainability as discovered from the results of this study. Some activities necessary for the system to thrive effectively that were identified in this chapter include:

- ❖ Attitudinal change on the part of designers towards maintainability
- ❖ Clients to be made aware of the Operation and maintenance implications of their proposed buildings before they are erected
- ❖ Designers to prove the operability and maintainability of the buildings they have designed, before construction
- ❖ Acknowledge the indispensability of a properly prepared O&M manual as a maintainability tool by
    - Integrating the O&M manual process into the design process
    - Involving O&M manual specialists in the design process
    - Developing a first draft of the manual at the design stage
    - Providing information in a user-friendly and web format
    - Separating technical details from users' operation and maintenance guide
    - Provide reference to physical examples where specific technologies included in the design may have been used.

Chapter 7:

CASE STUDY

7.0 INTRODUCTION

A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within a real life context (Yin, 2009). Thomas (2011) noted that "the case that is the *subject* of the inquiry will be an instance of a class of phenomena that provides an analytical frame — an *object* — within which the study is conducted and which the case illuminates and explicates". Also as noted in section 6.1.2.1, the selection of subjects for a case study is better based on information-oriented sampling than based on random sampling (Flyvbjerg, 2006).

So, from the results of the preliminary studies, interview, survey and secondary data a few cases were noted and analysed as reported in chapter 6. However, in order to make an in-depth study and considering the limitation of time and funds for the research it became necessary to select one case that illuminates and explicates the research objectives, for this in-depth study.

The objective of this case study is to support the interviews and questionnaires with a real life example; thus validating the study. The findings examined in this chapter include how the operation and maintenance challenges impact on the building performance. It also examined how the building documents impacted on the building operation and maintenance.

7.0.1 Executive Summary of Data

1. Data sources are mainly from a case study conducted using a post occupancy evaluation (POE) methodology, of the No.1 Nottingham Science Park (No.1). The POE methodology involved:

- Walk-through physical evaluation
- Building User Survey (BUS) standard occupants satisfaction survey format
- Bespoke questionnaire and
- Interviews involving 3 participants who are involved in direct oversight of the building in one form or the other.

2. The choice of No.1 for an in-depth case study was based on information-oriented sampling technique. Sources in literature required that the case to be selected be an *Outlier case* (revealing more information than the other cases) and/or a *Key case* (possessing inherent interest or peculiar surrounding circumstances than the others) and/or a *Local knowledge based case* (where the researcher possesses in-depth knowledge of the case).

3. Selection Criteria used were based on the objectives of the case study, time and resource limitations for the study. Five criteria were used, including: Age of Building, buildings identified with O&M Challenges, buildings identified with one form of Building Documents or the other, Proximity and Accessibility and Other Criteria that sets the building apart from the others.

4. The No.1 stood out as an outlier and key case, being a building owned by a private body, managed by a separate body and used (occupied) by separate bodies as well. It has also won several awards since its completion in 2008, making it a widely accepted good example of low carbon building.

5. The Walk-through Physical Evaluation exercise involved a guided tour of the building and note taking; physically assessing the low carbon technologies in the building, how they interact with other elements and their general state of repair. The various types of building documents available to users were also identified.

6. Two sets of questionnaires were used; the BUS occupant survey, a standard POE survey questionnaire developed over the years by Usable Building Trust and a bespoke questionnaire which dealt with key areas of the research objectives that were not covered by the BUS survey.

7. A number of low carbon technologies were identified in the Building. However, the HVAC systems; biomass boiler and the adiabatic cooling systems appear to be the most challenging systems in this building. Literature sources confirmed that comfort, health and well-being as well as employee productivity are to a large extent dependent on the effectiveness of the HVAC system.

8. In the No.1, the sources of energy include the Photo-Voltaic Systems, the Biomass system and the National Grid. At the time of the research, the biomass system was out of use, generating 0% of energy, the PV – 15% and the rest 85% from the National grid.

9. The study shows that the No.1 was supplied with a set of 21 folders of Health and Safety (H&S) file, incorporating an Operation and Maintenance (O&M) Appendices, and 3 versions of building manual (BM). There were separate maintenance log books for different aspects of the building systems.

The building is also managed through a digital Building Management System (BMS).

10. Due to the difficulties encountered with the use of the of the H&S file for operating and maintaining the building, a third party consultant was engaged to prepare a user friendly building manual for the building. The manual was prepared in 3 versions (Virtual tenants', Tenants' and Building manager's versions). They were supplied in both hard copy and pdf soft copy format.

11. Over 70% of the occupants do not have access to any of the building documents mentioned in 9 & 10 above. About a quarter attests to having access to only one document, and 5% representing 1 occupant attested to having access to all the building documents available.

12. The result of the bespoke questionnaire shows that the occupants found none of the building documents helpful at all, including the later prepared building manuals.

13. 86% of the occupants claimed not to have encountered any difficulty in trying to operate any of the systems, particularly during their first few days in the building. On how they got used to the system, about 60% of them adopted a *'trial and error'* method; a method described as *"an unsystematic method which does not employ insight, theory or organised methodology", also* time consuming, wastes materials and dangerous.

14. Occupants prefer to resort to the building manager for any difficulty rather than consult the tenant version of the building manual, which they claimed not to have access to, but the building manager confirmed that all tenant companies are handed a copy of the manual through a point man in each company.

15. The occupants' satisfaction indices were measured along 3 factors namely; satisfaction with the design, ability of the building to meet occupants' needs and the image the building presents to visitors. Occupants' level of satisfaction with these three aspects shows that they are highly satisfied. When compared to other similar buildings in the UK dataset it falls above 90 percentile for both its design and ability to meet needs and above 70 percentile for its image.

16. In terms of temperature stability, 'hotness and coldness' during summer and winter, when compared with other similar buildings in the UK dataset for both seasons, it reveals that the hotness and coldness is just like any other typical building. However, occupants' comments highlighted also that the building was slightly cold in winter and slightly hot in summer indicating that occupants' may be exposed to a degree of discomfort at extreme weather conditions. A further probe with the bespoke questionnaire and interview corroborates this, as most faults/breakdown cases reported borders on heating and cooling systems.

17. Comments on both the BUS questionnaire and the bespoke questionnaire as well as the building manager's comment, revealed that the operators of the building had some difficulties operating the heating and cooling systems. This of course is likely to have a negative impact on energy efficiency. It also suggests that the operators were not adequately guided on how to efficiently operate the building. Despite the numerous awards this building has bagged, its operators were still confused on how to manage the systems.

18. In terms of the Indoor Air Quality, about 80% of respondents were satisfied with the air freshness while about 60% were satisfied with the relative dryness of the indoor air. About 90% of them were also satisfied with the indoor air odour. Overall indoor air quality was reported to be better in winter than in summer. However, there were issues with control of air quality; only 27% satisfaction was recorded for control of ventilation. When compared to other buildings in the BUS dataset, it fell below normal; below 40 percentile mark. This again shows that the users have not been well tutored on how to control the adiabatic cooling system and/or the windows.

19. Occupants' satisfaction with lighting was rated at 80%. Other lighting variables like artificial lighting, glare lights, daylight and sun glare rates between 65 – 85%. General lighting condition in the building was perceived to be satisfactory and falls above 75th percentile in comparison with lighting conditions of other similar buildings in the UK dataset. However, there were also comments that the light bulbs were being changed more frequently within the office.

20. Although 34% of occupants rated the building as having positive impact on their productivity, 15% rated it as having negative impact, while another 52% believed that the building had no impact on their productivity. When compared to other similar buildings in the UK BUS dataset, the No.1 stands within the top 25%. However, occupants' comments on productivity show that some occupants feel agitated and stressed due to occasional overheating experienced. This no doubt may negatively affect their concentration and eventually, their productivity.

21. Over 80% of occupants were dissatisfied about the control of noise level in the building.

22. The occupants were not also satisfied with the healthiness of the building. There were complains about electric shocks in some parts of the building. The pollution from the toilets affects the indoor air quality (IAQ) and in turn, occupants' healthiness.

23. On perception of impacts of maintenance activities, the occupants attest to the fact that the No.1 is well maintained. However, there were few indications that Maintenance works in this building are being carried out too frequently than in other traditional buildings, unexpected breakdowns and mal-functioning of systems have not been frequent, but had occurred a couple of times. Also, maintenance activities have disrupted occupants' business activities a few times as well.

7.1 SELECTING A CASE STUDY

Following Flyvbjerg's postulation as noted in sections 7.0 of this thesis, it became necessary to analyse the preliminary information gathered about these cases to determine a suitable case to be studied. Kumar (2011) also corroborates Flyvbjerg's position by stating that selecting a case should usually be based on purposive, judgemental or information-oriented sampling techniques". Flyvbjerg also argued that the choice may be based on any one of the following rationale:

1. ***Outlier cases*** – those which are extreme, deviant or typical, i.e., they reveal more information than the assumed representative case.
2. Selected as a ***key case*;** chosen because of the inherent interest of the case or the circumstances surrounding it.
3. It may also be chosen based on the researchers' in-depth ***local knowledge*;** where the researchers stand in a good position to *"soak and poke"* as Fenno (1986) puts it.

By this understanding therefore, certain criteria were set out for the selection of a suitable case for in-depth study. The criteria set were informed by the objectives, time and resource limitations for the research, as well as information gathered from the preliminary survey, interviews and questionnaire. It is also to ensure that the case selected is an *Outlier case* (revealing more information than the other cases) and/or a *Key case* (possessing inherent interest or peculiar surrounding circumstances than the others) and/or a *Local knowledge based case* (where the researcher possesses in-depth knowledge of the case). Figure 7.1 partly describes the exemplar LCBs identified in this study. It consists of 20 buildings arranged according to their typology and indicating the respective sources of data. It also provides a 'base plate' for deselecting cases that did not meet the set criteria.

Table 7.1: Exemplar LCBs Identified in the Study (Arranged According to Typology)

S/N.	Building	Type	Height	Total Flr. Area (sq.m)	Age (yrs.)	Data Source
1	No.1 Notts Sc. Centre	**Commercial**	Low-rise	5109.67	2 - 5yrs	**Interview**
2	Romero House	**Commercial**	Mid-rise	33000	2 - 5yrs	**Questionnaire**
3	David Wilson Millennium Eco House	**Residential**	Low-rise	137	>10yrs	**Preliminary Interview**
4	BASF House	**Residential**	Low-rise	112	5 - 10yrs	**Preliminary Interview**
5	Termac Masonry Home 1 (Code 6)	**Residential**	Low-rise	99	2 - 5yrs	**Preliminary Interview**
6	Termac Masonry Home 2 (Code 4)	**Residential**	Low-rise	86	2 - 5yrs	**Preliminary Interview**
7	E.ON 2016 Research House	**Residential**	Low-rise	106	2 - 5yrs	**Preliminary Interview**
8	Private Residential - High Wycombe	**Residential**	Low-rise	No Information	>10yrs	**Questionnaire**
9	Green Street Development	**Residential**	Low-rise	No Information	< 2yrs	**Interview**
10	Arc. Julian Marsh's Private Residence	**Residential**	Low-rise	No Information	2 - 5 yrs	**Interview**
11	Peveril House	**Residential**	Low-rise	No information	2 - 5yrs	**Interview**
12	ZedFactory	**Mixed Use**	Low-rise	No Information	5 - 10yrs	**Site Visit/ Website**
13	Jubilee Wharf	**Mixed Use**	Mid-rise	3000	5 - 10yrs	**Questionnaire**
14	Phoenix Square	**Mixed Use**	Mid-rise	No Information	2 - 5yrs	**Interview**
15	Sustainable Research Building	**Educational**	Low-rise	1762	5 -10yrs	**Questionnaire**
16	Bio-Energy Building	**Educational**	Low-rise	3493	< 2yrs	**Questionnaire**
17	Sir Colin Campbell Building	**Educational**	Low-rise	4534	2 - 5yrs	**Questionnaire**
18	CSET Building	**Educational**	Mid-rise	1300	2 - 5yrs	**Interview/ email**
19	The Gateway Building	**Educational**	Low-rise	3253	< 2yrs	**Interview**
20	The living Wall - Islington Children Centre	**Recreational**	Low-rise	No Information	5 - 10yrs	**Email/Website**

7.1.1 Selection Criteria 1 - Age of Building

The study is designed to adopt a Post Occupancy Evaluation (POE) method as discussed in section 7.3. In conducting POE, it is advisable for the building for which POE is to be carried out not to be less than 12 – 18 months of occupancy, so that users must have adequately experienced and adjusted to their new environment and also experienced the building through the seasons (SGV, 2010). However, since this study is looking a little beyond POE to operation and maintenance challenges, it was necessary to look at buildings that have been operated for at least 2 years as the first selection criteria. In chapter 6 (figure 6.24) it was noted that 80% of the 20 buildings identified are more than 2 years old, so eliminating those that are less than 2 years still allows for wide choice.

In table 7.2, the buildings that are less than 2 years old are highlighted to be deselected.

Table 7.2: Exemplar LCBs Identified in the Study (Deselect Cases with less than 2yrs Post-Occupancy)

s/no.	Building	Age Range (yrs.)	O&M Challenges with:	Building Docs.
1	No.1 Notts Sc. Centre	2 - 5yrs	Biomass Boiler	Health & Safety Files
2	Romero House	2 - 5yrs	Service Personnel for GSHP	O&M manual
3	David Wilson Millennium Eco House	> 10yrs	Vacuum Tube Collectors	CHP manufacturer's manual
4	BASF House	5 - 10yrs	Biomass failed	WS tank manufacturer's manual
5	Termac Masonry Home 1 (Code 6)	2 - 5yrs	Biomass Boiler	None
6	Termac Masonry Home 2 (Code 4)	2 - 5yrs	Biomass Boiler	None
7	E.ON 2016 Research House	2 - 5yrs	Not inhabited yet	None
8	Private Residential - High Wycombe	> 10yrs	No Information	As-built Drawings
9	Green Street Development	< 2yrs	No Information	No Information
10	Arc. Julian Marsh's Private Residence	2 - 5 yrs	Maintenance Personnel for GSHP	No Information
11	Peveril House	2 - 5yrs	No Information	User Manual
12	ZedFactory	5 - 10yrs	Biomass Boiler	No Information
13	Jubilee Wharf	5 - 10yrs	Biomass Boiler	O&M manual
14	Phoenix Square	2 - 5yrs	No Information	O&M manual
15	Sustainable Research Building	5 -10yrs	Wind turbine	Health & Safety Files
16	Bio-Energy Building	<2yrs	Biomass Boiler	O&M manual
17	Sir Colin Campbell Building	2 - 5yrs	Lake Source Heat Pump	O&M manual
18	CSET Building	2 - 5yrs	No Information	BMS
19	The Gateway Building	< 2 years	No Information	No Information
20	The living Wall - Islington Children Centre	5 - 10yrs	Watering System	No Information

Cases with less than 2 years Post Occupancy

Cases with no information about Operation & Maintenance Challenges

Cases without evidence of at least one building document or building management system (BMS)

7.1.2 Selection Criteria 2 – O&M Challenges

As the objective of the case study is centred on operation and maintenance challenges, a key case or an outlier case for this study should be one that illuminates and explicates operation and maintenance challenges. It therefore becomes necessary to eliminate cases where the operation and maintenance challenges were not highlighted during the initial surveys. It does not follow that these buildings without record of O&M challenges does not indeed have challenges with O&M, because in one of the interviews conducted, the participant who is an academic and sits as a principal partner to an architectural practice in Nottingham for an upwards of 30 years noted that every LCB has issues with maintenance. In his words; *"They've all got challenges with maintenance. …"* (Interviewee 004). It is also a common parlance that maintenance starts the day the contractor hands over the keys (CIRIA, 2009). So it will not be entirely correct to infer that these buildings that may have been in operation for an upwards of 2 years. However, what is being implied here is that the source from which information about the building(s) is being gathered could not give any information about the O&M challenges. It is also not impossible (though doubtable) that the buildings were being well managed, so that there were no issues with O&M. However, the risks of random sampling need to be avoided. In table 7.2, cases with no information about O&M challenges have also been highlighted to be deselected.

7.1.3 Selection Criteria 3 – Building Documents/Building Management System (BMS)

One of the objectives of this research which the case study also tries to focus on is to explore the potential of the O&M manual and/or other building documents as maintainability tool(s). So if the case to be studied need to be outlier or key case it should be able to provide basis for testing of the set objectives. In line with the argument for criteria 2, the case needs to be sensitive to the context in which the research occurs. So this criteria looks out for cases for which no information about the existence of any building document or specific equipment manual was recorded in the initial surveys. They are also highlighted on table 7.2 to be deselected. As also argued in criteria 2, the inquiry at this stage is not exhaustive, but trying to avoid the risk of random sampling.

7.1.4 Selection Criteria 4 – Proximity and Accessibility

Having eliminated buildings less than 2 years post-occupancy, buildings with no record of O&M challenges and buildings without any building documents, it was still necessary to trim down the number of cases further to pick out a key case for the in-depth study. So considering the risks, time and resources involved in travelling, vis-à-vis the time and resources available for the study, it becomes necessary to examine the proximity of the cases to the research base, which is the Sustainable Research Building (SRB), University of Nottingham. On table 7.3, the highlighted buildings are over a hundred mile from the research base and the possibility of travelling several times before one can really gain access to the buildings, users, managers and owners of the buildings for further in-depth study was brought on board. After deselecting these ones, 5 buildings still remain; the farthest being 1.1 mile driving distance through the Wortley Hall Close exit.

Table 7.3: Exemplar LCBs Identified in the Study (Deselect distant cases)

s/no.	Building	Location/Address	Distance from Research Base (NG7 2QB)/ Driving Time
1	No.1 Notts Sc. Centre	Jesse Boot Avenue, Nottingham. NG7 2RU	**1.1 mile (4mins.)**
2	Romero House	55 Westminster Bridge Road, London. SE1 7JB	**128 miles (2hrs. 23mins.)**
3	David Wilson Millennium Eco House	Green Close, University of Nottingham. NG7 2RX	**0.08 mile (3sec.)**
4	BASF House	Green Close, University of Nottingham. NG7 2RX	**0.05 mile (2sec.)**
13	Jubilee Wharf	Commercial Road, Penryn, Cornwall. TR10 8FG	**308 miles (5hrs. 17mins.)**
15	Sustainable Research Building	Dept. of Architecture & Built Environment, University of Nottingham **(Actual Research Base)**	**0.0 miles**
17	Sir Colin Campbell Building	Jubilee Campus, University of Nottingham. NG7 2TU	**0.9 miles (3mins.)**

Cases not within close proximity (over 100 miles from research base)

Table 7.4: Exemplar LCBs Identified in the Study (5 Cases selected from within Nottingham)

S/N.	Building	Type	Total Flr. Area (sq.m)	Age (yrs.)	Distance from Research Base (NG7 2QB)/ Driving Time
1	**No.1 Notts Sc. Centre**	Commercial	5109.67	2 - 5yrs	**1.1 mile (4mins.)**
3	**David Wilson Millennium Eco House**	Residential	137	>10yrs	**0.08 mile (3sec.)**
4	**BASF House**	Residential	112	5 - 10yrs	**0.05 mile (2sec.)**
15	**Sustainable Research Building**	Educational	1762	5 -10yrs	**0.0 miles**
17	**Sir Colin Campbell Building**	Educational	4534	2 - 5yrs	**0.9 miles (3mins.)**

7.1.5 Selection Criteria 5 – Other Criteria

Having reduced the number of cases to 5 using the 4 criteria discussed above, it was still necessary to further select one for in-depth exploration. As shown in Table 7.4, the final 5 cases comprise of 1 no. commercial, 2 nos. residential and 2 nos. educational buildings. The residential and educational buildings are owned by the University of Nottingham which can be referred to as an "Informed Client", some had been studied to some extent during the preliminary studies and reported in chapter 6.

The only commercial building; No.1 Nottingham Science Park seem to stand out of them all as a typical case for the study, being a building owned by a private body, managed by a separate body and used (occupied) by separate bodies as well. Other reasons supporting the choice of No.1 Nottingham Science Park (No.1) are as follows:

- As a building owned by a small private body, the likelihood of bureaucratic bottlenecks in gaining access to building and users will be minimized as this was evident during the preliminary studies.
- Also, at the time when this studies were being carried out, it was coincidental that some other researchers from the university had also concluded arrangement with the developer to carry out some studies related to in-door environment quality assessment of the building, it therefore will be reasonable to collaborate with them.
- The No.1 has won several awards since its completion in 2008, including (Blue Print, 2012):
    - DESIGN EXCELLENCE - No.1 Nottingham Science Park (Nottingham Evening Post Commercial Property Awards)
    - PROJECT OF THE YEAR - Nottingham Science Park (Constructing Excellence, East Midlands 2008)
    - SUSTAINABLE DEVELOPMENT OF THE YEAR - No.1 Nottingham Science Park (Insider East Midlands Property Dinner Awards 2008)
    - DESIGN COMMENDATION - Nottingham Science Park (Nottingham Civic Society, 2008)
    - DEVELOPER OF THE YEAR - Blueprint (Property Week, Midlands Property Awards 2008)
    - DESIGN-LED PROJECT OF THE YEAR - No.1 Nottingham Science Park (Property Week, Midlands Property Awards 2008)

These awards testifies that the building is accepted widely to be an exemplar low carbon building and could be said to be an 'Outlier Case' defined by Flyvbjerg, 2006 as an extreme deviant or typical case, or a 'Key Case', chosen because of the inherent interest of case or circumstances surrounding it.

- Being a building managed by a renowned building management company like Innes England which is noted for her repute in commercial property management in the East Midlands provides an opportunity for best practice in operation and maintenance, thereby presenting itself as a key case for study

- Igloo (2012) and Ncube and Rodrigues (n.d.) noted that the contiguity of the No.1 to the University stimulates opportunity for a two way flow of research and innovation. This statement implies, though indirectly, that the building has attracted a couple of built environment researchers in the past, so there is a likelihood of accessing some secondary data here to boost and fast-track the study.
- The No.1 is also said to be generally perceived as providing higher satisfaction ratings than other similar buildings in the UK Building Use Studies (BUS) dataset (Ncube and Rodrigues, n.d).

7.2 NO.1 NOTTINGHAM SCIENCE PARK: Description of the building

Figure 7.1: The Main Entrance View of the No.1 Nottingham Science Park

The building is a two storey exemplar and award-winning low carbon building, located south-east of the University of Nottingham, on the opposite side of the University Boulevard (A6005), Nottingham, United Kingdom. It is located on Jesse Boot Avenue, NG7 2RU which lies 2 miles (about 3.2km) west of

Nottingham City Centre, on a major transport corridor and just 5 miles (about 8km) from M1 J25 (UKSPA, n.d.). Its adjacent land-uses include: the University Park and boating lake with its restaurant and art gallery to the North, the Dunkirk Pond fishing lake and the Beeston Siding's Nature Reserve to the South, while the West and East are bordered by the Nottingham Tennis Centre and the existing Science Park respectively.

The building covers a total floor area of about 55,000ft^2 (5,109.67m^2), consists of about 3,902m^2 of flexible let-able office spaces, capable of providing up to 32 separate offices; each with its own services consumer units and water supply. It also consists of under-croft car parking and a brown roof. The façade is a rainscreen trespa arrangement on an insulated metzec frame walling structure with plasterboard scim finish interior. Structurally, it stands on post tensioned concrete framed structural system and constructed with recycled and sustainable building materials as much as possible (Gleeds, 2012). It was designed by award-winning architects Studio Egret West and Hawkins Brown, for an East-Midlands property Development firm – Blueprint.

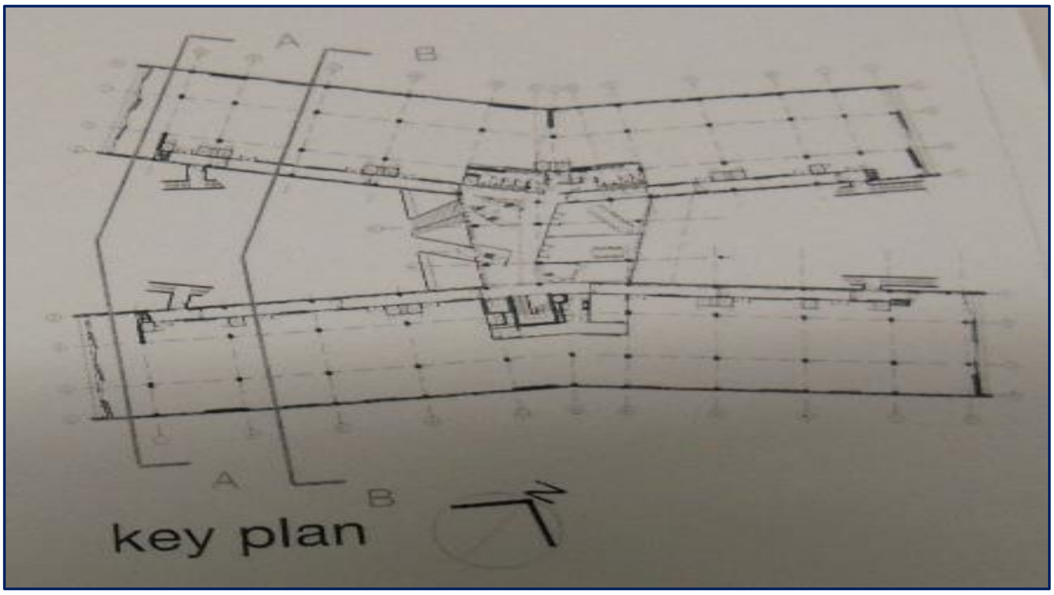


Figure 7.1: No.1 Nottingham Science park Building - Typical Floor Plan (Source: H&S manual for the building)

The building also benefits from a number of low carbon technologies, including:

- Biomass heating system
- Mixed mode adiabatic mechanical cooling/natural ventilation system
- Solar Photovoltaic panels
- Brown roof
- Thermal mass construction
- Re-cycled materials
- Timber/Aluminium composite materials
- Curtain walling
- Motion activated lighting

  Etc.

The building also benefits from a set of hard copy *Health and Safety file,* which were also referred to as O&M manual, locked up in a small storage room. There is also a 'pdf' version of the H&S file/. Interview with a representative of the developer organization revealed that neither version of the O&M manual was capable of sustaining effective management of the building and so a 'User-friendly Building Manual was developed years later.

7.3 METHOD ADOPTED FOR THE CASE STUDY

A post occupancy evaluation approach was adopted in the study. Post occupancy evaluation (POE), also known as Building performance evaluation (BPE) (BSRIA, n.d.) and involves a systematic evaluation of opinions about buildings in use, from the perspective of the people who use them (postoccupancyevaluation.com). It evaluates how well the building matches users' needs, and identifies ways to improve building design, performance and fitness for purpose (Ibid). POE is used to evaluate new and old buildings when they are fully operational; preferably, not less than 12 – 18 months of occupancy, in which period users must have adequately experienced and adjusted to their new environment and also allows for a full circle of the seasons (SGV, 2010).

A study carried out by GAIA Research (2003) revealed that there are over 150 POE methods developed by researchers within the last 3 decades to suite their desired POE concerns, information expected and outcomes. So selecting an appropriate technique for a specific study becomes very difficult, and trying to develop a personalized approach stands the risk of re-inventing an existing method (Malekzadeh, Bouchlaghem and Wheeler, 2010). However, Preiser (1995) summarises the POE methodology in three broad categories as discussed in section 3.4.3, to include: *Indicative POE, Investigative POE and Diagnostic POE*

The focus of most POE studies available in literature has been on occupants comfort and productivity as influenced by environmental factors like air quality, temperature, humidity, noise, day-lighting, etc. In this study, additional objectives include:

- ❖ To investigate the operational situation of low carbon technologies in the building
- ❖ To review maintenance and operation challenges associated with these technologies. This of course includes the general comfort of users, including their productivity, health and well-being while in the building. It also includes the nature of maintenance works and how they affect other activities within the building, etc.
- ❖ To explore the role of the O&M manual in ensuring effective and efficient operation and maintenance of the building.

In essence, we are evaluating users' response about the operation and maintenance, as to identify ways of improving maintainability. It therefore becomes necessary to adopt the Indicative POE technique, being the most appropriate of the 3 methods described by Preiser (1995).

The method involved a walk-through physical evaluation of the building and its surrounds, 2 sets of questionnaires to users and one on one semi structured interviews with the developer and also with the representatives of the building management team. The study was also documented photographically and on notepads.

7.3.1 Walk-through Physical Evaluation

This physical evaluation exercise involved a guided tour of the building and note taking, firstly with a representative of the developer company – Blueprint and later with a representative of the management team. This part of the study was basically to physically assess the low carbon technologies in the building, how they interact with other elements and their general operational state. The type of building documents available to users and the management/maintenance staff was also investigated. This formed a background for the development of the questionnaire both for the quantitative survey of occupants' opinion and the qualitative semi-structured interviews. The following were noted about The No.1 Science Park building:

- ❖ The building fabric is generally in a very good state of repair (exterior and interior)
- ❖ The immediate surround is paved and in good state of repair, however, the western end close to the biomass boiler looked a bit over-grown with bulrushes. Operators of the building said it was part of the planning; to enhance biodiversity
- ❖ Code activated main entrance door

- Natural day lighting was enhanced by large pane of double glazed fenestration, framed in aluminium and timber composite frames (aluminium to the exterior and timber interior).
- Motion activated artificial lighting at communal spaces like corridors, toilets, etc.
- Dual fuel biomass boilers unit located in a separate rotund building clad in an Etha rubberised membrane.
- Roof mounted Solar PV panels
- Mixed mode adiabatic mechanical cooling/ natural ventilation system
- Brown roof
- Sustainable Urban Drainage System (SUDS) which recycles storm water into the wetlands area on which the tall bulrushes feed with a timber lily pad shaped walkway.
- The building also benefits from a set of 21 folders of *Health and Safety file,* locked up in a small storage room.

7.3.2 Questionnaire

At the time this study was going on, it was coincidental that other researchers and staff of the university of Nottingham were also carrying out a post occupancy indoor environment quality assessment of the same building on behalf of Blueprint (developer) and Usable Building Trust; a UK educational charity, dedicated to improving the performance of buildings in use (UBT, 2012). The methodology used was centred on the use of a standard **Building User Survey (BUS)** Occupants Questionnaire developed over the years by Usable Building Trust. It became necessary to collaborate with them in the distribution of questionnaires and sharing of relevant data.

The standard BUS Occupants Questionnaire covers a wide range of variables related to indoor environment quality (IEQ) and the building design, facilities, fit-outs and furnishings. The questions were framed based on quantitative satisfaction rating scales and few open-ended comments on key issues. However it did not cover issues relating to maintenance and functional state of the facilities as well as the role played by the available building documents in operation and maintenance. So in order to broaden the scope of the questionnaire and still retain the standard structure of the BUS occupant survey format, a new bespoke questionnaire was developed; adopting the quantitative rating scale style as well. It seemed inappropriate to modify the BUS survey because it is expected to provide consistent measure that enables comparison and benchmarking of productivity effects within and between buildings in the UK (Ncube and Rodrigues, n.d.). Also, to avoid a situation where participants will be bored of answering the same question twice on two separate questionnaires, it became necessary to avoid some questions that were dealt with in the BUS survey.

Leaman (2009) noted on the Usable Building Trust website that the BUS occupant survey may be used by itself or with other techniques as part of a post-occupancy evaluation. So adopted the use of additional questionnaire for this POE study is not out of decorum.

7.3.3 Interviews

The Interviews were taken in two stages; the first stage came before this in-depth study, with the primary aim of identifying low carbon buildings in the UK and to determine which will fit for case study. A senior member of the developer team who has direct oversight of the No.1 was also interviewed at this stage. The second stage was designed to dig deeper to areas not covered by the quantitative survey and to understand the views of the persons who manage the building. Persons interviewed include a shareholding partner of

Inness-England; the managing company for the building. The building manager who is also a staff of Inness England who works on-site in the building to see to the day–to–day running of the building was also interviewed. Outline questions were drawn up based on feedback from the earlier quantitative survey. The questions were open-ended, allowing the participants to express themselves in their own words. Although there was an outlined set of questions in each case, but not restrictive as questions also emanated from their responses. The interviews created better insight to some of the issues that were not clear during the walk-through evaluation and the survey collected. Table 7.5 shows a summarised description of the interviewees, indicating their identification code and their roles in the building.

Table 7.5: Summary of Interviewee Data

s/no.	Identification Code	Responsibility
1	DV01	Member of the Developer Team
2	BM02	A director in the Building managing firm
3	BM03	Building Manager

7.4 FINDINGS AND DISCUSSION

It is important to note that the walk-through physical evaluation provided basis for drafting an appropriate survey questions and the interviews were also aimed at corroborating and/or clarifying grey areas from the findings of the survey as well as seek to provide answers to questions that can ordinarily not be known to tenants. So this discussion shall encompass the findings from the three sources of information.

While the first phase of this study (walk-through physical evaluation) was based on the perception of the researcher, the second part was based on the perspective of users; those who work in the building. Five different companies with a total of about 80 people work in the building at the time of the study, and only 21 persons representing about 25% of occupants completed the survey. The reason for this low response rate was that only 3 of the 5 companies who work in this building accepted to take part in the survey, since it was optional for them to do so. Of the 21 participants, 86% had worked for over one year in the building and as such are capable of providing reliable information about the building having used the building long enough to be familiar with the setup and performance of the building at different times of the year. The interview phase provided information from the perspective of the developer (building owner), being represented by a staff that has direct oversight function of the No.1 Nottingham Science Park. It also provided information from the perspective of the building manager who is directly responsible for the day-to-day operation and maintenance of the building on the behalf of the developer. So this chapter reports findings from across the actors in the operation and maintenance stage of the building.

7.4.1 Low Carbon Technologies in the Building

The building was designed to benefits from a range low carbon/low energy technologies and strategies which make it environmentally sustainable and also reducing the amount of energy spent in operation and maintenance.

7.4.1.1 HVAC Systems: Heating for the building was being provided by a **dual fuel biomass boiler** located in a separate rotund building clad in an Etha rubberised membrane. The boiler was designed to use either bark chippings or pellets. However, at the time of this study the biomass system was not in use. The three interviewees confirmed that the grid-gas fired system which was provided as a back-up has been the sole source of heating for the building, besides occupants generated heat from IT systems used within the building. Interview with the building manager (Interviewee BM03) in particular revealed that the biomass was used for approximately $2^{1}/_{2}$ years before it was abandoned. Further probing revealed that the system is not broken, but was set aside due the operational and maintenance challenges associated with it. Figure 7.3 shows the external view of the isolated rotund structure (figure A), that houses both the biomass boiler unit and the 'stand-by grid-gas boiler unit (figure B) and the pellet (fuel) storage compartment at a lower level – the top level being less than 150mm above the ground surface (figure C).

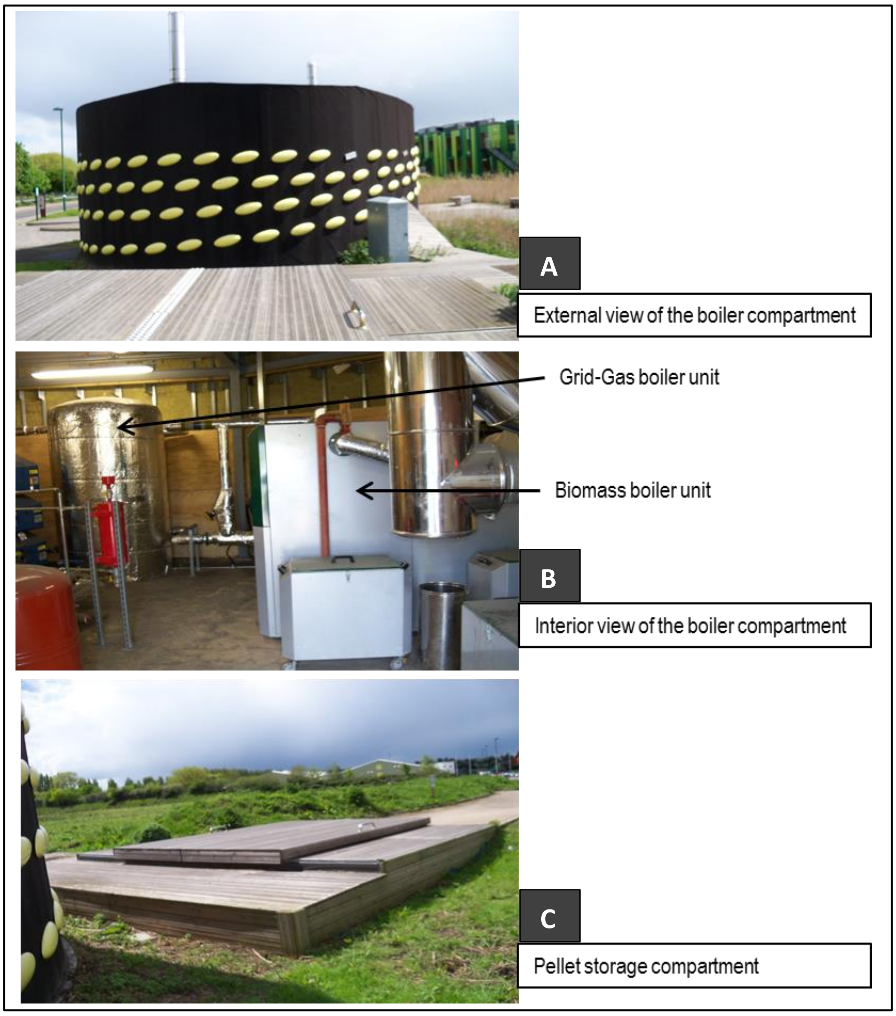


Figure 7.3: The Boiler Plant at No.1 Nottingham Science Park

The challenges identified through the interviews include:

- ❖ The pellet storage compartment gets occasionally flooded with water, because of its height from the ground, thus requiring regular and frequent checks, cleaning and drying of the pellets.
- ❖ The ash pan needs to be cleared up on a daily basis, and the Archimedes screw which pulls the pellets in get blocked and needs to be unblocked when it happens.
- ❖ There is need for additional personnel to be on site for the management of the boiler. Although it does not require a technical or professional personnel as opined by interviewee (BM02), but this will definitely impact on the cost of running the building.
- ❖ The heating up time of the system is too slow compared with the conventional gas boiler.
- ❖ The running cost of the biomass boiler was deemed higher than the grid-gas system by at least 11% (detail analysis in section 7.4.1.7).

Summarily, *"The management regime of the biomass boiler is higher than we expected"* (Interviewee BM02).

The **Mixed mode adiabatic mechanical cooling/natural ventilation system** becomes very beneficial to the building at that period of the year when the ambient temperature goes higher. It uses water vapour and pressure to enhance heat exchange in addition to naturally ventilating the spaces with top-hung transom windows. However, this system proved to be another problem area for the building operators for a while. One of the interviewees noted that it took them a while to get the balancing of the cooling system sorted (Interviewee BM02). Another interviewee expressed the fact that they were still confused whether on hotter days, if it was better to have the windows closed and just the adiabatic going or whether it was better to have the windows open and the adiabatic as well. *"I have had conflicting advice on that"* (Interviewee DV01).

7.4.1.2 Micro-generation Systems: The interviews also revealed that the **roof mounted Solar PV** was retrofitted 3 years after practical completion. It provides only about 15% of the energy required for the building. This retrofitted element was confirmed to have been updated in the O&M manual. However, no detail of its maintenance requirements were included in the manual as noted during the walk-through evaluation study when a detailed study of the manual's content was made by the researcher. At the time of the Survey, the PV was about 2 years old and so no known O&M issue was reported. However, particular notice was made about how the PV panels were mount at almost 90^{o} to the roof top, thus enhancing easy self-cleaning. See figure 7.4.

Figure 7.4: Showing the inclination of the Roof Mounted PV Panels

7.4.1.3 Day-lighting Enhancement Systems: Natural day lighting was optimized by the use of **large pane of double glazed windows**, which reduces the need for electric energy for lighting during work hours. **Motion activated artificial lighting** at communal spaces was also adopted to cut down on electric energy usage. However, it is arguable that motion activated lighting are better energy savers in the night than in the day. The light comes on by mere sensing of movements, even when the room is bright and thereby constituting a waste of energy that could have been saved by switching on only when it is dark.

7.4.1.4 Energy Efficiency and Conservation: The interview sessions also revealed that the **building envelope was highly insulated**. This, in addition to the double glazed windows helped to keep the building interior at a comfortable temperature even through the winter. However, survey results discussed in subsequent sections shows that occupants still complain at winter that the spaces are too cold and too hot in the summer.

7.4.1.5 The Use of Renewable Materials: The use of Aluminum and timber as **composites framing** for the building fenestration is noteworthy. The aluminum acts as a protective member to the renewable timber frames against weathering effects and to keep the façade in its brilliant colours. Although Aluminum is not renewable, it is 100% recyclable without any loss in its natural qualities, and requires just about 5% of the energy required to produce the original stock (EAA, 2002). Aluminum is also more durable than timber; possess high corrosion resistant quality, ductile, light weight, impermeable and odourless (ibid).

7.4.1.6 Biodiversity: The building also benefits from a **Brown roof** that was created to encourage biodiversity in addition to achieving some of the traditional aims of brown roofs (Evergreen Roof Gardens Ltd.):

- Reduced rainwater runoff
- Enhanced roof insulation properties
- Attractive visual appearance
- Reduction in urban heat island effect
- Enhances roof lifespan by protecting underlying waterproofing system

- Provide green space in urban areas

The **Sustainable Urban Drainage System (SUDS)** is another innovative aspect of the design that is worth noting. Apart from allowing rainwater run-offs to be effectively managed within the site, the system ensures a cool exterior environment as the run-off water is being collected within tall bulrushes and under some aesthetically laid out wooden **lilypads,** and both providing habitat for aquatic and amphibious wildlife within the urban environment. The lilypads also provides a good sit-out and interaction area among staff as well as a pedestrian link to the building.

7.4.1.7 General Conclusions about Low Carbon Technologies: Conclusively, the HVAC systems (biomass and adiabatic cooling systems) in the No.1 appear to be the most challenging systems in this building. Comfort, health and well-being as well as employee productivity are to a large extent dependent on the effectiveness of the HVAC system (Reidmiller, 2012). Graham (2009) also argued that HVAC systems account for about 39% of the energy used in commercial buildings in the United States. The situation is not likely to be much different in the UK. Graham (2009) added that the use of efficient (high performance) HVAC system could result in considerable energy, emissions, and cost savings. Conversely, inefficient HVAC system could result in increased energy, emissions and cost in building operation.

In the No.1, the sources of energy include the Photo-Voltaic Systems, the Biomass system and the National Grid. At the time of the research, the biomass system was generating 0% of energy, the PV – 15% and the rest 85% from the National grid. This probably accounts for why no considerable savings is made in running the No.1 as deduced from the interview results. According to Interviewee BM02, when asked if the cost of operating and maintaining this building would have been any different if it were a non-low carbon building;

> *"I don't think there is a huge saving in this building, I think there may be some savings, but I don't think it's huge. ………. I don't know what the utility bills are, but I can't tell you that they are significantly lower than any other places, no I don't see a big benefit, I can't sell that benefit to people".*

He added;

> *"My experience is that it is not hugely different from everywhere else, I don't get the impression that the biomass is any cheaper, and I think the biomass may be, pushes it slightly higher…"*

Response from interviewee BM03 revealed that in 2012, the biomass was never operational and about £17,000 was the target-spend on gas for that year. As at 21 Dec. 2012 the sum of £15,136 has already been spent on gas (the bills for December were probably not included yet). In 2011 the biomass was operational and was often supported with the grid-gas, yet about £18,958 was spent on biomass pellets deliveries alone for that year; a difference of £1,958 which is about 11.5% higher than the cost of grid-gas in 2012. This does not include the cost of daily clearing of the ash pan, unblocking the pellets inlet and dewatering the pellets storage compartment. It also does not include the cost of occasional back-ups with the grid-gas. In essence it is more expensive to heat up the building with biomass than with the grid gas. This corroborates findings stated in section 6.5.

7.4.2 Building Documents

The study shows that the No.1 was supplied with a set of 21 folders Health and Safety (H&S) file, incorporating an Operation and Maintenance (O&M) Appendices, and 3 versions of building manual (BM). The 3 versions of the manual consist of:

- 17 page Building Manual for virtual tenants
- 55 page Building Manual for tenants
- 71 page Building Manual for the building manager

The building is also managed through a digital Building Management System (BMS). Interview with the building manager also revealed that the building has separate maintenance log books for different aspects of the building.

7.4.2.1 Health & Safety File: The 21 folder H&S file contains detailed technical information about the project; address, project description, ownership (client), consultants, principal contractor, sub-contractors and suppliers. It also contains information on:

- Fire safety within the building
- Constructional details like structural calculations and other details; including piling and brown roof details, external cladding craftwork
- Sub-contractors advert information
- Architectural and structural As-built drawings, including finishes schedule
- External lily pad walkway details
- Biomass system details
- Mechanical & Electrical information; including schedule of equipment and their technical information, commissioning and handover documents.
- Emergency procedures and maintenance requirements, Planned maintenance instructions, detailed maintenance schedule, etc.
- Operating procedure for some systems
- Manufacturers directory and advert information
- Spares
- Commissioning results and test certificates
- Etc.

Figure 7.5 shows the array of the folders on a shelf in the storage room. Figure 7.6 is a typical cover page of the folders.

Figure 7.5: A set of the Health and Safety file for No.1 Nottingham Sc. Park

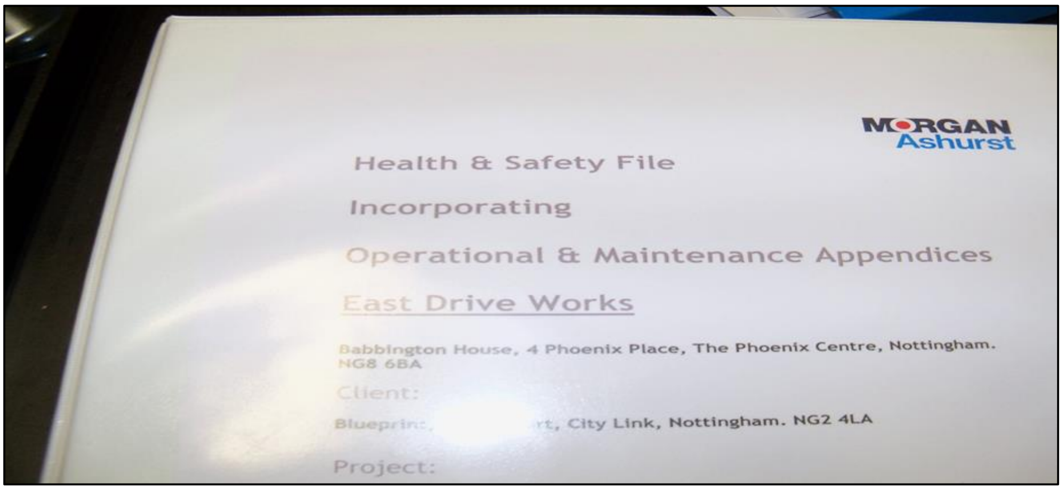


Figure 7.6: Cover page of a typical Health & Safety file

From the researcher's point of view, the contents of the H&S file of the No.1 appears to be so detailed; with relevant information for a technical minded user only. It was put together to serve also as an O&M manual as evident on the cover page (figure 7.6). It also contained information that are neither relevant for the H&S file nor for the O&M manual, while also lacking in some relevant information. For instance the sub-contractors and manufactures advert information are not of any benefit to future work, what is required is their contact information.

From the point of view of the building operators, the size of the file itself is intimidating and 'putting-off'. They find it difficult to search out information. As discussed in chapter 6, the H&S file is supposed to be distinct from the O&M manual as they serve different purposes. This combination of H&S file and O&M manual may have been responsible for why the O&M information appears buried and difficult to be reached by the building operators.

7.4.2.2 Building Manual: Due to the difficulties encountered with the use of the of the H&S file, a third party consultant was engaged to prepare a user friendly building manual the building. As discussed earlier, the manual was prepared in 3 versions. They were supplied in both hard copy and pdf soft copy format.

- ❖ The virtual tenants building manual consists of a 17 page document. It serves individuals or starters who require office and/or meeting spaces not on a permanent basis
- ❖ The 55 page Tenants Building Manual was designed for the long-term tenants who use the building as their permanent work base, they required a more detailed manual because they have day by day interaction with the building and other users.
- ❖ The building manager's copy was a little more detailed, as it contained more information not required for tenants; for instance, information about the operation of the BMS system.

Generally, the building manual details out responsibilities of the tenants and that of the building manager as regards:

- ❖ Fit-outs design and construction by tenants
- ❖ Emergencies and repairs
- ❖ Access and security

- Fire protection
- Etc.

It abstracted relevant information from the H&S file and conveyed in an easy to read manner.

7.4.2.3 Building Management System (BMS): The BMS facility in the No.1 was designed to facilitate monitoring and control of communally delivered services; heating and ventilation. The technical details of BMS equipment were logged in folder 13 of the H&S file. The information here require only an expert of BMS or software engineers to comprehend. Operational procedure of the BMS was also lacking in the file. However, the building manager's version of the building manual was able to describe the operational process of the BMS which the manager confirmed to be easy to comprehend.

7.4.3 Impacts of the Building Documents on the Operation and Maintenance of the Building.

The H&S file is intended by law to provide information that will alert those responsible for operating and maintaining the building about the key health and safety risks that may need to be addressed during subsequent maintenance, repair and other construction and/or deconstruction works (Construction Design and Management (CDM) 2007, Regulation 17). The O&M manual enables operators to organise repairs and maintenance of the building, its services and surrounds effectively and efficiently; and also enables buildings and its services to be operated efficiently.

Building Regulations Part L requires that owners of buildings be provided with sufficient information about the building, the fixed services and their maintenance requirements to enable buildings to be operated in the most efficient way possible (Building Regs. L2A; parag. 82). The regulation also recommends CIBSE TM31 Building Log Book Toolkit template, the O&M manuals and The H&S file as ways of complying to the regulation.

The BSRIA, after series of research identified that the O&M manual seem not to be meeting its intended purposes as discussed in chapter 6 recommends the adoption of the Building manual and the Building User Guide, not as replacing the O&M manual but to complement it by outlining the salient points that an operator would need to operate their building effectively. So this study also examined how these documents have helped in the effective operation of the No.1.

The result shows that whereas a user friendly building manual exists, occupants will not want to use them, they rather resort to the building manager or adopt a trial and error method to be operate systems they were not familiar with. Also the H&S/O&M files were found to lacking in assisting the client and managing team to effectively operate the building.

7.4.3.1 Accessibility to Building Documents: The bespoke survey results in figure 7.7 show that over 50% of the occupants do not have access to any of the building documents and about a quarter attests to having access to only one document, and 5% representing 1 occupant attests to having access to all the building documents available. 19% skipped the question. Reasons for skipping this question are not known, but it could be assumed that these 19% of the occupants do not know what these documents are and may not have seen one. So they also do not have access to any of the building documents; bringing the total percentage of those who do not have access to 71.

Further probe at the interview with Interviewee (BM02) on why over 70% of the occupants do not have access to any of the building documents revealed that:

> *"All the tenants have a key person when they move in who signs the lease or the tenancy agreement with Blueprint or with Inness England, they are all issued with all that when they move in, but they don't seem to pass it down to their colleagues".*

Further probe on what the occupants do when they have emergency revealed that they come to the building manager.

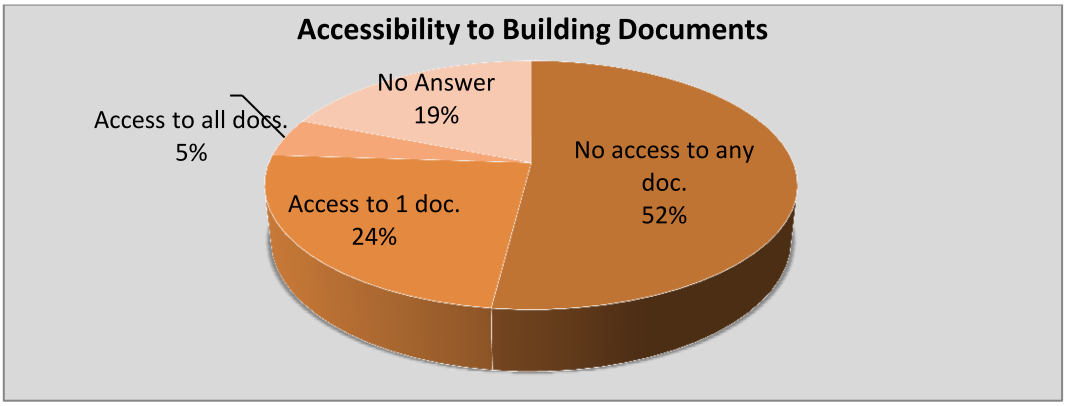


Figure 7.7: % Distribution of Occupants Accessibility to Building Documents

7.4.3.2 How Helpful the Building Documents have been: The occupants were also asked to rate how helpful the various building documents have been to them, particularly during their first few days in the building, using a scale of 1 – 7 where 1 = 'not helpful' and 7 = 'very helpful'. The result as illustrated in figure 7.8 shows that they found none of the building documents helpful at all, except the H&S file which received an average rating of 2.4 out of 7 (or 34%), which can be interpreted to mean fairly helpful.

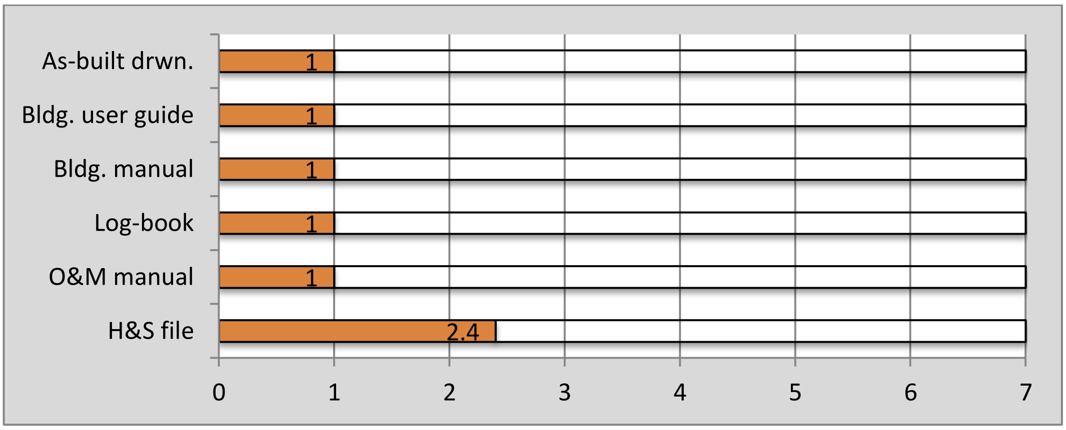


Figure 7.8: Occupants Rating Average of How Helpful Specific Building Documents have been to them

However, the H&S file, O&M manual, Log-books and As-built drawings in the No.1 were not intended for the general occupants (tenants), but for the building owner, manager and maintenance personnel. The building occupants were supplied with hard copy building manuals which also incorporates the building user guide. They were intended for use by the building client, building managers and maintenance personnel.

100% of the Interviewees which comprises people involved with the direct oversight of the No.1 both from the client side and the managing company decried the difficulty in comprehending and searching out the H&S/O&M file. Some of their comments in this regard are:

> *"when I first came in it was a process of trying to understanding the systems within the building, understanding both from a kind of operations perspective, so how the centre manager could operate the systems through the BMS and also from an occupier perspective, how they can gain comfort control and actually use this space, that sort of thing. To be frank, I found the O&M manual lacking in that regard"* (Interviewee DV01).

> *"… finding things and getting that information from the O&M manual is very painful. …. If I try to find what that broken light bulb is in the O&M manual, it will take me twenty minutes or more ad I might not find it. So I see the industry does have a poor reputation. The contractor thinks if he hands the building over and he gives you all these files, then he has done his job. That is poor in my view"* (Interviewee BM02).

> *"To me, I personally find them difficult to understand from somebody who is not used to technical details, as the building manager, it's not been an easy manual, they are not as simple as I think they could be. For an electrician to look at, for a plumber to look at, they probably will be a lot easier …"* (Interviewee BM03).

A comment from Interviewee (BM03) suggests that it is possible for maintenance personnel to find the manual useful. This possibility is also inferred from the added comments by Interviewee (DV01) below:

> *"… I mean it has information regarding, if you want to change you light bulb or replace a floor tile, something like that, but in terms*

of a concise kind of user manual, if you like, it wasn't there" (Interviewee DV01).

7.4.3.3 Getting Conversant with Operating the Systems: The study also tried to find out if the occupants had any difficulty in trying to operate any of the systems during the first few days in the building. 86% of the occupants claimed not to have encountered any difficulty, while only 5% had some difficulties (see figure 7.9). Figure 7.10 shows how these 86% got used to the systems or why they had no difficulty.

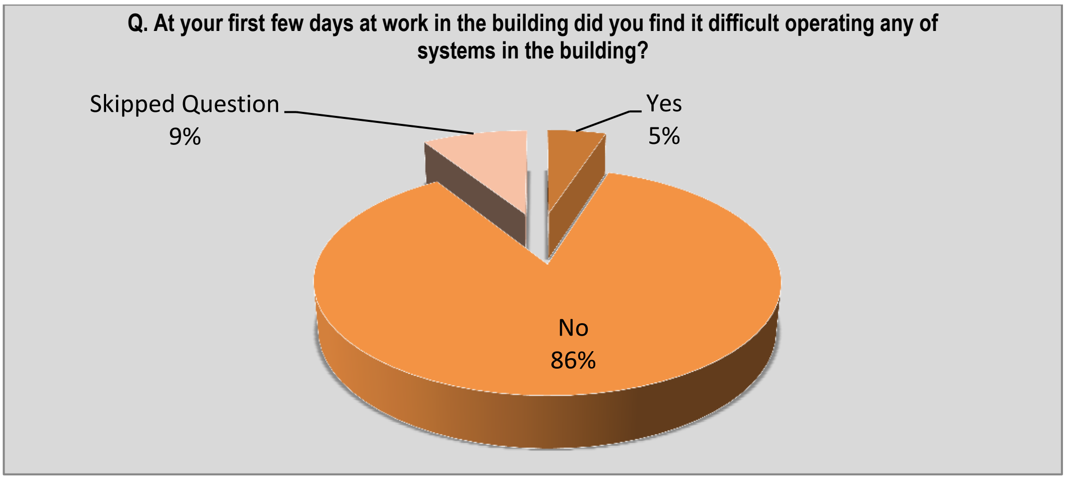


Figure 7.9: Any Operational Challenges Encountered by Occupants?

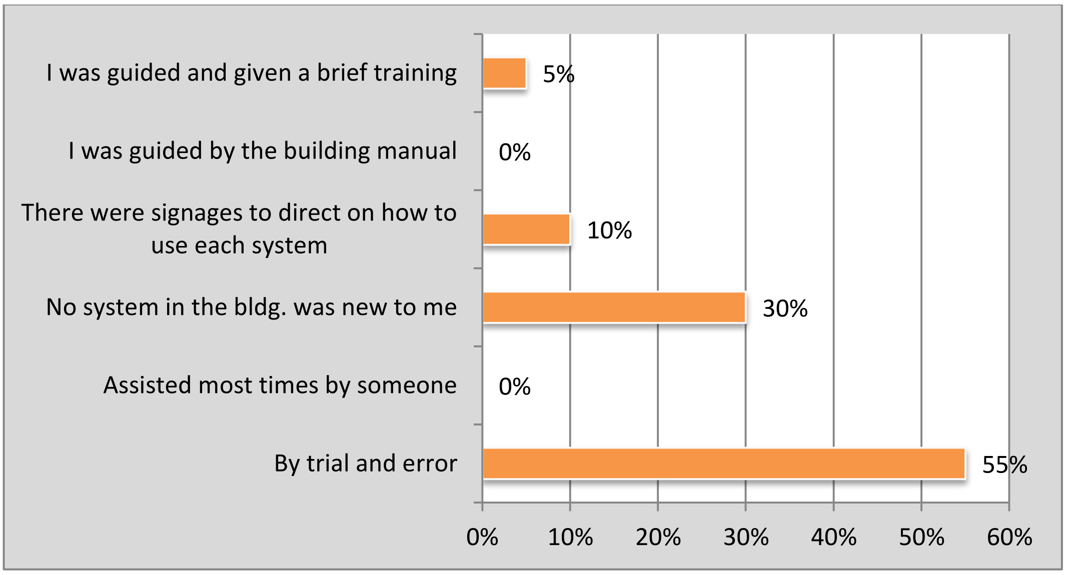


Figure 7.10: % Distribution of How Occupants Got Used to Operating the Systems in the Building

Occupants were asked to identify from the list of options, which best describe how they got used to operating the systems in the building. Nearly 60% of them adopted a *'trial and error'* method (see figure 6.10). This method has been described as *"an unsystematic method which does not employ insight, theory or organised methodology"* (Hornby, 2012).

The trial and error method has also been known to be time consuming, wastes materials and dangerous (Hazelton, 2013). This means that what should ordinarily take 20 seconds to operate, could take up to 20 or more minutes, finding a way round it, thereby wasting man-hour and reducing productivity. Hazelton cited the example of clinicians who work on their patients by trial error; this sometimes results in ground-breaking medical product and some other time could be as dangerous as causing serious harm or death to the patients. Similarly, in buildings fitted with new technologies, trial and error may not only be time consuming, but could cause harm to the operator or damage to the system, in some cases, particularly when health and safety requirement for that operation is unknown to the operator. A case in point is that one of the occupants noted on his/her comments that either s/he or his/her colleague broke one of the window levers in the course of opening the window. S/He may probably be turning it the wrong way, whereas the right procedure is clearly explained in the Tenants version of the building manual.

7.4.4 Impacts of Operation and maintenance challenges on the Building Performance

As evident from the numerous awards bagged by the No1, it stands as a good exemplary sustainable and low carbon building in the UK. According to Ncube and Rodrigues (n.d.), the building is generally perceived as providing higher satisfaction ratings than other similar buildings in the UK BUS dataset, even though there were still room for improvements. This section examines the general performance of the building as rated by the occupants and how the operation and maintenance challenges may have affected the performance; in terms of its indoor environment quality (IEQ) and the impact on the comfort and wellbeing of the occupants. Results from the surveys and interviews form the basis for analysing the operation and maintenance challenges vis-à-vis the building performance. As stated earlier, the surveys involved the use of a BUS standard questionnaire and a bespoke one developed by the researcher to address other questions not addressed in the BUS standard questionnaire.

The results show that about 95% of the occupants were satisfied with the design, image and the building's ability to meet their needs. Their perception of comfort within the building, health and wellbeing, facilities, furnishings and fit-outs were rated high. They also believed that the building impacts positively on their productivity, although there were a few negative feedbacks. Also about 95% of the participants believed that the building is well maintained. However, a small percentage of about 14% says maintenance works are carried out in this building more frequently than other traditional buildings they have experienced. Although about 85% of occupants never had problems in operating any of the systems at their early days in the building, but 60% of this 85% claimed to have employed a trial by error approach.

7.4.4.1 Occupants Satisfaction – the occupants' satisfaction indices was measured along 3 factors namely; satisfaction with the design, ability of the building to meet occupants' needs and the image the building presents to visitors. Figure 7.11 shows occupants' level of satisfaction with these three aspects; design, needs and building image, it shows that they were highly satisfied. Ncube and Rodrigues (n.d.) argued that the No.1 reinforces its good performance when compared to other similar buildings in the UK dataset as it falls above 90 percentile for both its design and ability to meet needs and above 70 percentile for its image. Figure 7.12 shows the BUS summary index, derived from the variables, comfort and satisfaction indices. The graph shows that the occupants of this building find their building highly acceptable. The index also shows that the building is rated in the upper percentiles (94th) in comparison with other buildings in the UK BUS dataset. Figures 7.13, 7.14 and 7.15 are BUS Methodology graphs showing the level of the occupants' satisfaction with design, image of building to visitors and the building's ability to meet their needs respectively, in comparison with other similar buildings in the UK.

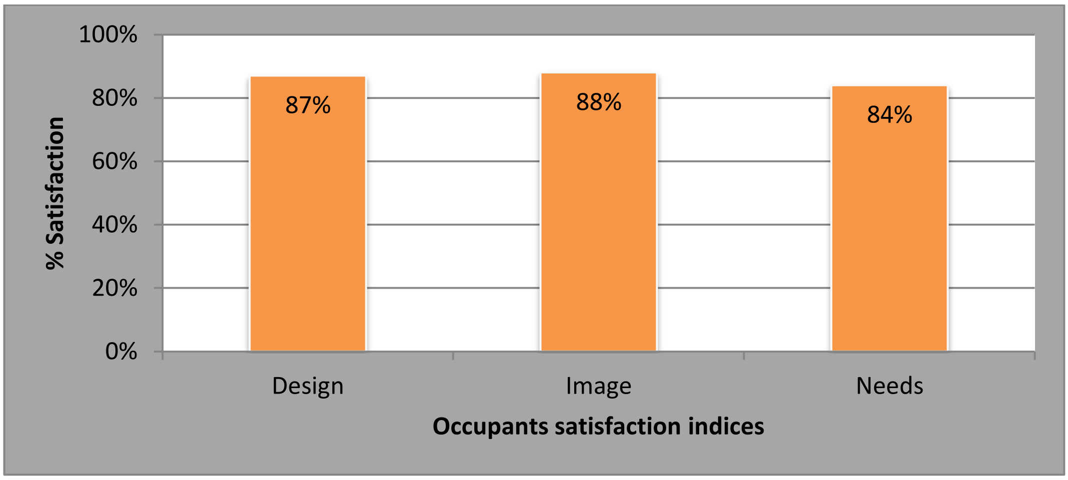


Figure 7.11: The level of satisfaction with regards to design, image and needs of occupants

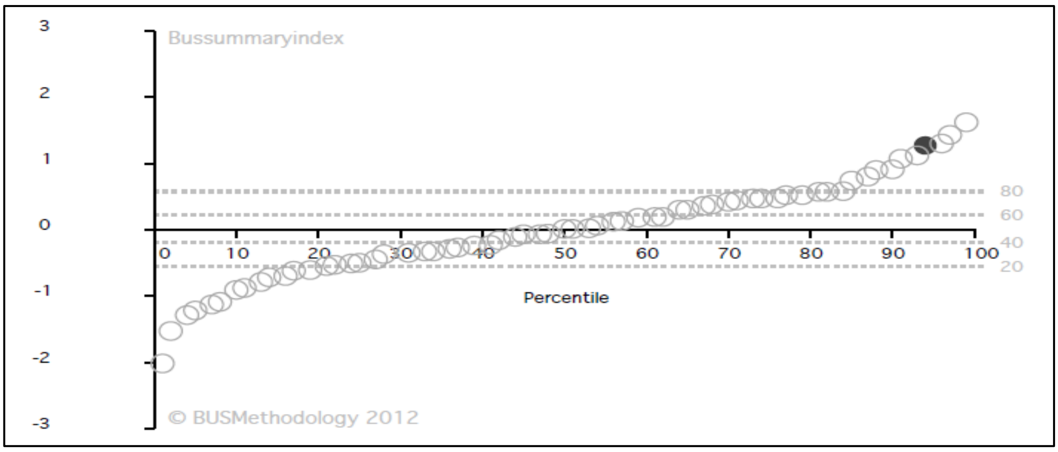


Figure 7.12: BUS summary index showing the position of No.1 Nottingham Science Park when compared to other buildings in the UK BUS database

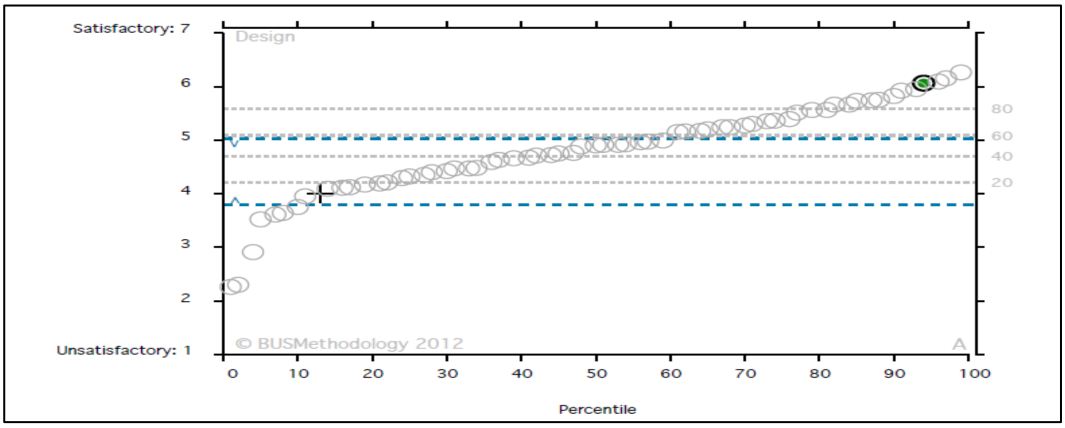


Figure 7.13: Level of occupants' satisfaction with design when compared to other buildings in the UK BUS dataset

They show good performance indices as the occupants' ratings placed the building above the 90th percentile for both its design (figure 7.13) and the ability to meet needs (figure 7.14), and above 70th percentile for its image (figure 7.15).

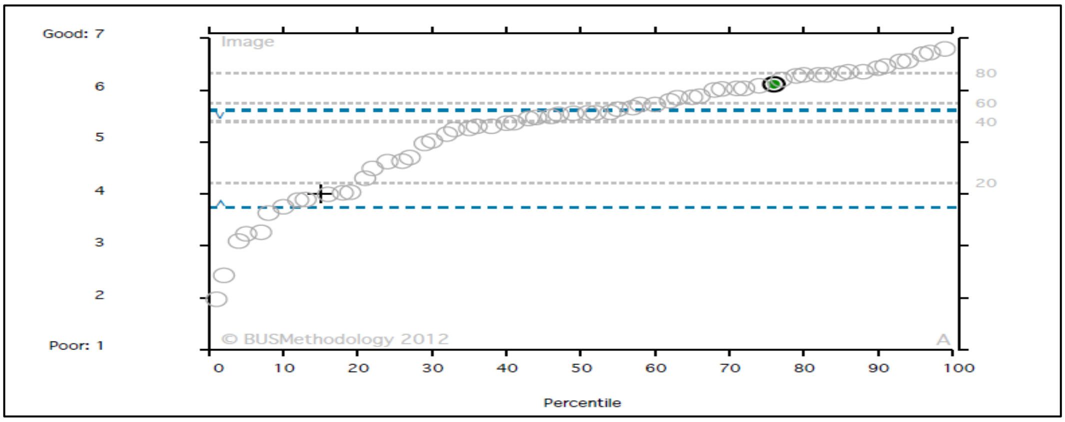


Figure 7.14: Levels of Satisfaction with the image of the No.1 Nottingham Science Park to visitors when compared to other buildings in the UK BUS dataset

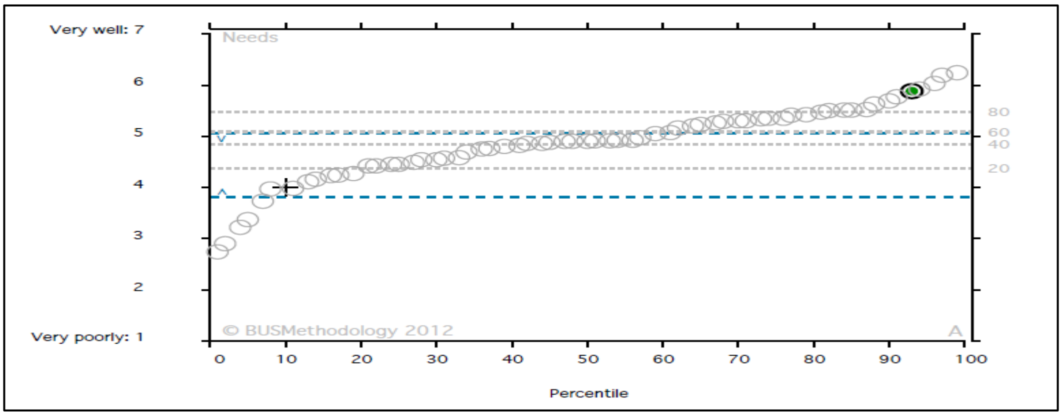


Figure 7.15: Levels of Satisfaction with the ability of the No.1 Nottingham Science Park to meet occupant needs when compared to other buildings in the UK BUS dataset

7.4.4.2 Thermal Comfort – Factors assessed for thermal comfort include; Temperature stability at summer and winter respectively, comfort level at summer and winter indoor temperature as shown in figure 7.16. The result shows that they were highly satisfactory. The rating for temperature stability during summer and winter were each above 75% satisfactory. Temperature 'hotness and coldness' exceeded 90% satisfaction during both seasons. However, in comparison with other similar buildings in the UK Dataset for both seasons, it reveals that the hotness and coldness is just like any other typical building. Perceived overall temperature satisfaction were above 80% also at both seasons; falling above the 90 percentile when compared to similar buildings in BUS dataset for the UK.

Occupants' comments on the BUS questionnaire highlighted also that the building was slightly cold in winter and slightly hot in summer indicating that occupants' expectation may have played an important role in the outcome of the thermal comfort rating. A further probe with the bespoke questionnaire and interview corroborates this, as most faults/breakdown cases reported borders on heating and cooling system. Table 7.6 shows the type of complaints the occupants had reported to the managers of the building.

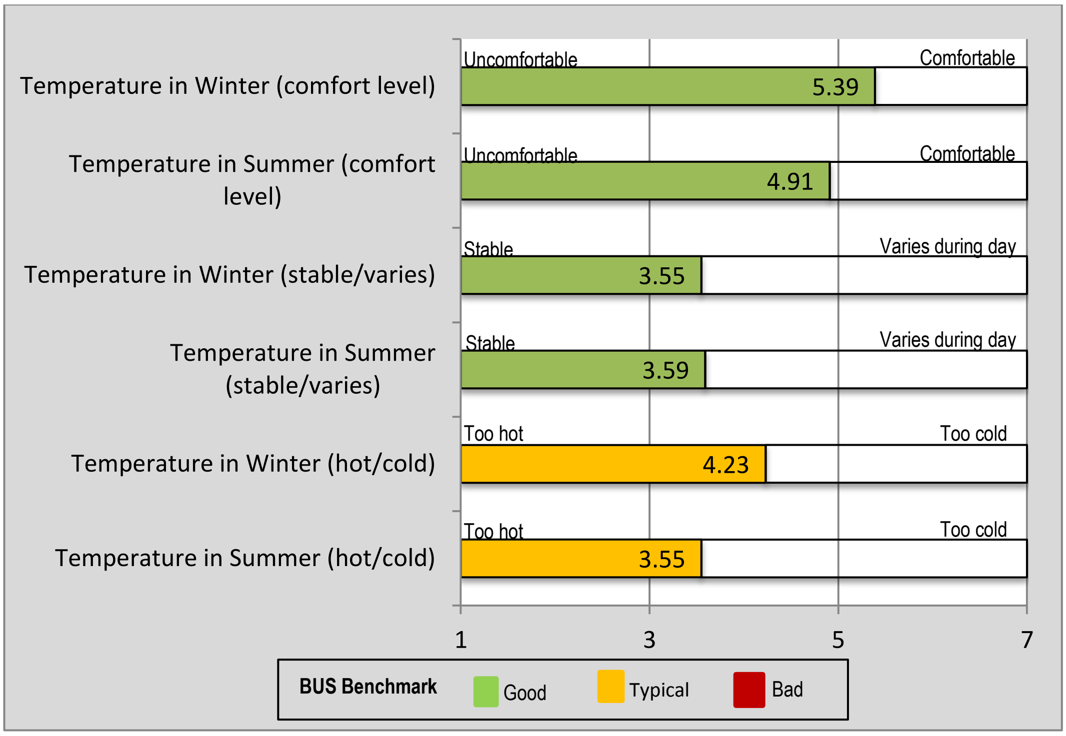


Figure 7.16: Rating Average of occupants' satisfaction with temperature at No.1 Nottingham Sc. Park

Table 7.6: Faults/Breakdown Cases Reported from when the building was occupied (2008 – 2012)

s/n.	Nature of faults/breakdowns reported	Number of times reported	Nature of work done to remedy it	How long it took to fix from time of reporting (days)
1	Heating too hot or too cold	> 20	System adjusted	Same week (≤5)
2	Heating and cooling system	≥10	System adjusted	No comment
3	Automatic doors not working	2	Replaced door stop	≥30
4	Lift not working	1	Repaired	≥7
5	car park door broken	3	Replaced control	1
6	Window openers broken	1	Repaired by tenant	No comment
7	Window opening	1	repaired	<1
8	Ventilation system	1	Replaced vent	<1

The table captures the exact phrases used by the respondents in their comment bands. Items 1 and 2 are about the same complaints; 'Heating too hot or too cold' and 'Heating and cooling system', while the first respondent claimed to have reported this more than 20 times, the second in his own words says, “at least 10 times”. It is evident from their comments that they were not keeping records of the number of times they raised a complaint, but one could conclude that they meant to portray the fact that it was a recurring complaint within the period they’ve worked in the building. Also in his words the managing consultant, interviewee BM02 says;

> *“………. the principal challenge has been, initially, the balancing of system in terms of cooling and that took us a while to get it sorted out. One of the problems in buildings like this, we always use PCs, printers, laptops and all these cause a lot of heat and I think the building was challenged to try to manage that level of heat gain from within. I think it is better now…”*

It is evident therefore from the comments of occupants in both the BUS questionnaire and the bespoke questionnaire as well as the building manager’s comment, that the operators of the building had initial difficulties operating the heating and cooling systems. This of course is likely to have a negative impact on energy efficiency at that initial stage of occupation of the building. It also suggests that the operators were not fully guided on how to efficiently operate the building. Despite the numerous awards this building has bagged, its operators were still confused on how to manage the systems. An earlier interview with the developer (client) drives home this inference better. In his words;

> *“……… the cooling system which is kind of the complex area ………….. it is a mixed- mode cooling system so it’s got natural ventilation and it is also mechanically ventilated with adiabatic cooling, ………… It is still not 100% whether on the hottest days, if it is better to have the windows closed and just the adiabatic going or whether it is better to have the windows open and the adiabatic. I have had conflicting advice on that”.*

The question here is why this confusion and waste of energy in trial and error syndrome when the building was properly commissioned as evident in the Health and Safety files? This could imply that the design team was not able to appropriately convey to the operators, how the heating and cooling systems should be efficiently operated.

7.4.4.3 Indoor Air Quality – The indoor air quality was assessed under three major parameters that affect air quality; 'freshness of the air', 'odour intensity' and 'relative dryness (humidity)'. Figure 7.17 shows the level of occupants' satisfaction with these parameters. Occupants were asked to rate their satisfaction with these parameters on a scale of 1 – 7. The figure shows that occupants reported average (typical) to air freshness during summer and good at winter, in comparison with similar buildings in the UK.

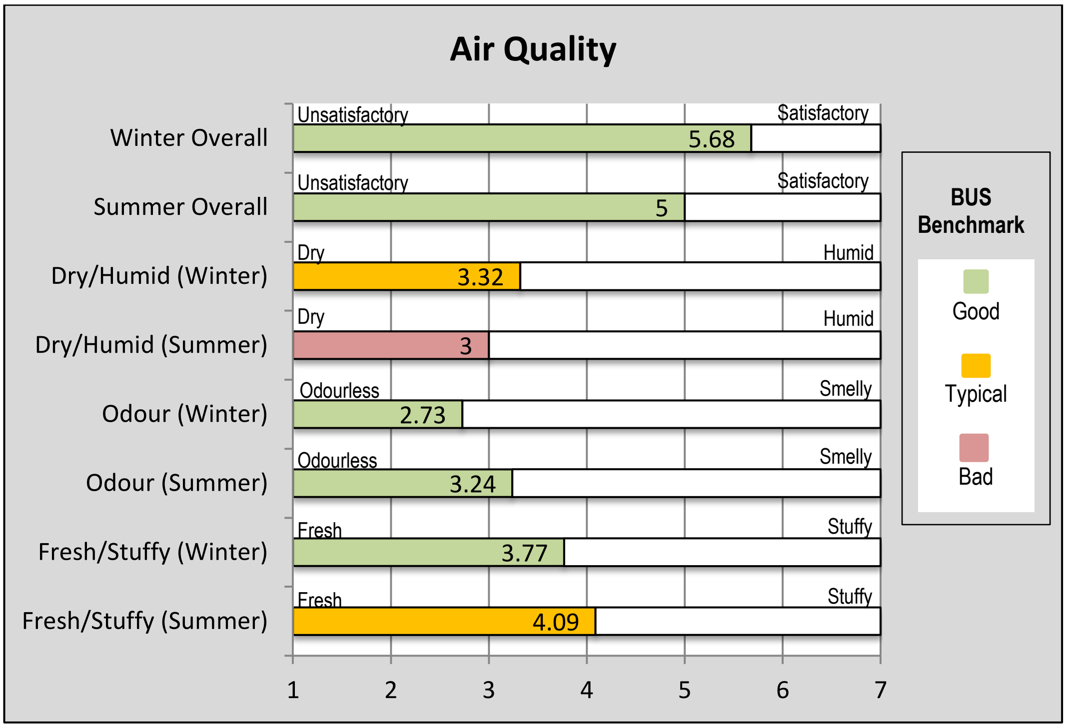


Figure 7.17: Rating Average of Occupants Satisfaction with Air Quality Parameters at the No.1

Odour perception was also good but bad air dryness in summer and average in winter when compared with the BUS dataset. About 80% of respondents were satisfied with the air freshness while about 60% were satisfied with the relative dryness of the indoor air. About 90% of them were also satisfied with the indoor air odour. Overall indoor air quality was reported to be better in winter than in summer. However, there were issues with control of air quality; only 27% satisfaction was recorded for control of ventilation (see figure 7.18).

When compared to other buildings in the BUS dataset, it fell below normal; below 40 percentile mark as shown in figure 7.19.

This again drives hove the fact that the users have not been well tutored on how to control adiabatic cooling system and/or the windows as this is evident from item 6 on table 7.6; one of the occupants reported to have broken the window lever in a bid to open it. These operational difficulties are most likely responsible for the unsatisfactory air quality in the summer.

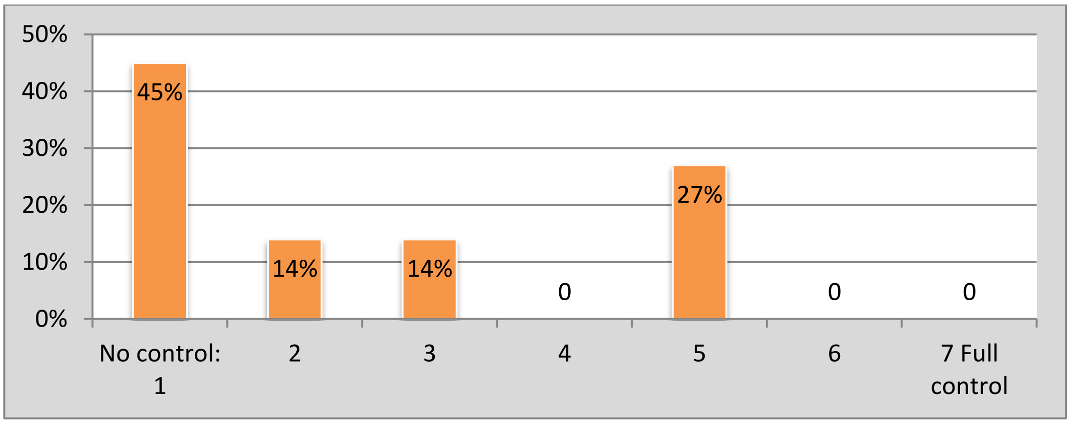


Figure 7.18: % Count of occupants' response to their ability to control ventilation in No.1 Nottingham Sc. Park

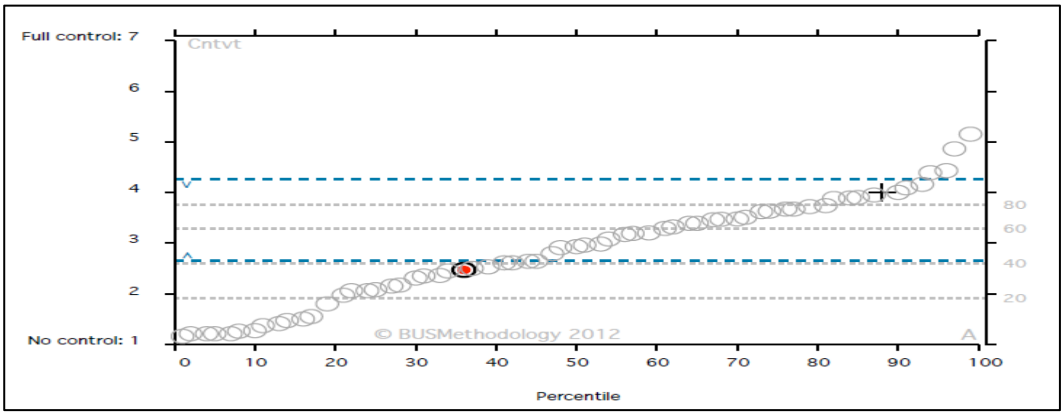


Figure 7.19: Occupants response to ventilation control in No.1 Nottingham Sc. Park when compared to other buildings in UK BUS dataset

7.4.4.4 Lighting Quality & Control – Occupants' satisfaction with lighting was rated at 80%. Other lighting variables like artificial lighting, glare lights, daylight and sun glare rates between 65 – 85% satisfaction as shown on figure 7.20. General lighting condition in the building was perceived to be satisfactory and falls above 75 percentile in comparison with lighting conditions of other similar buildings in the UK dataset, as shown on figure 7.21. There were a few comments by occupants, suggesting that artificial lighting was inadequate; particularly in the meeting rooms. There were also comments that the light bulbs are being changed more frequently within the office. However, occupants are satisfied with the level of control of lighting in the offices. Inadequate lighting could be a design oversight but the frequent change of bulbs could be linked to the fact that the lights switches on and off too frequently, since they are motion controlled.

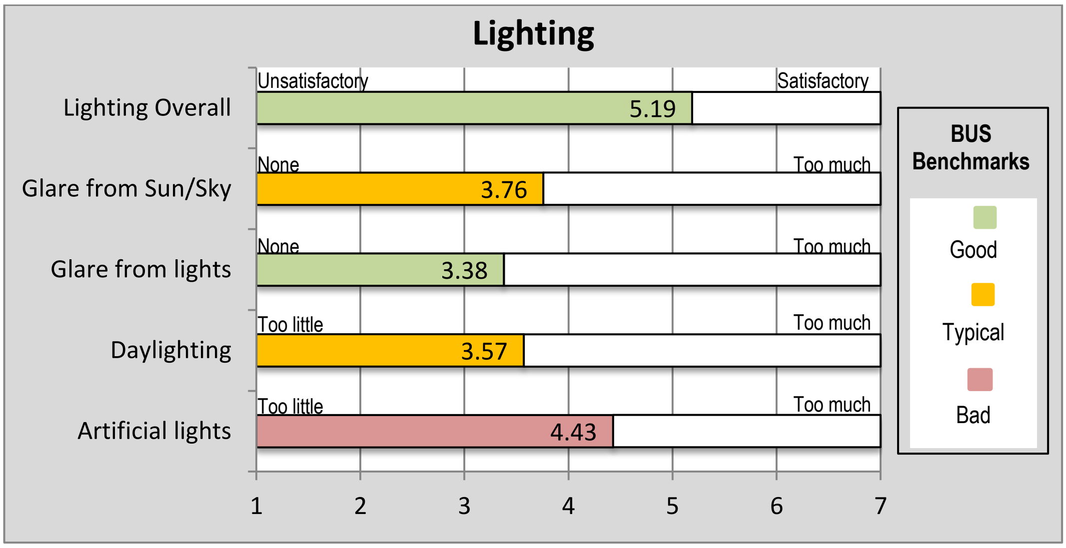


Figure 7.20: Rating Average of Occupants Satisfaction with Lighting in No.1 Nottingham Science Park

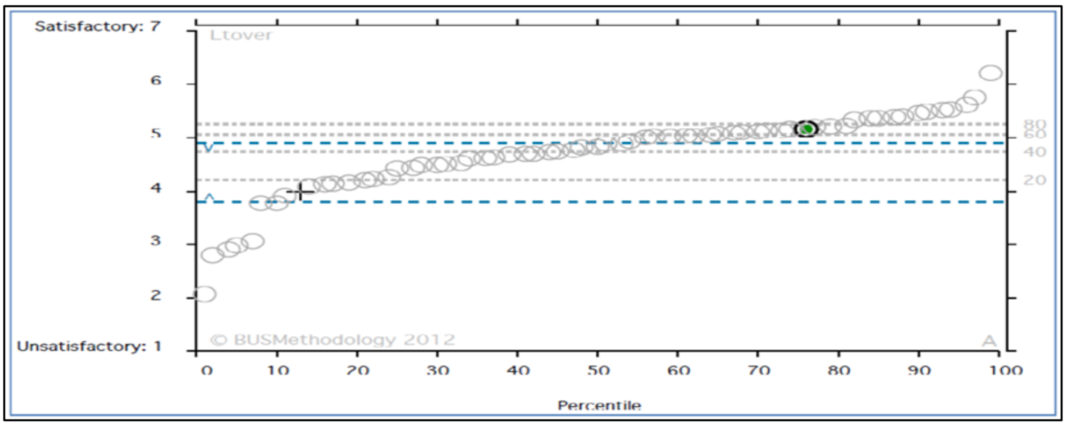


Figure 7.21: Perceived Lighting Overall in No.1 Nottingham Sc. Park when compared to other buildings in UK BUS dataset

7.4.4.5 Assessment of Productivity: Although 34% of occupants rated the building as having positive impact on their productivity, 15% rated it as having negative impact, while another 52% believed that the building had no impact on their productivity, as evident on figure 7.22. When compared to other similar buildings in the UK BUS dataset, the No.1 stands within the top 25%, as shown on figure 7.23. However, occupants' comments on productivity show that some occupants feel agitated and stressed due to occasional overheating experienced. This no doubt may have negatively affected their concentration and eventually, their productivity.

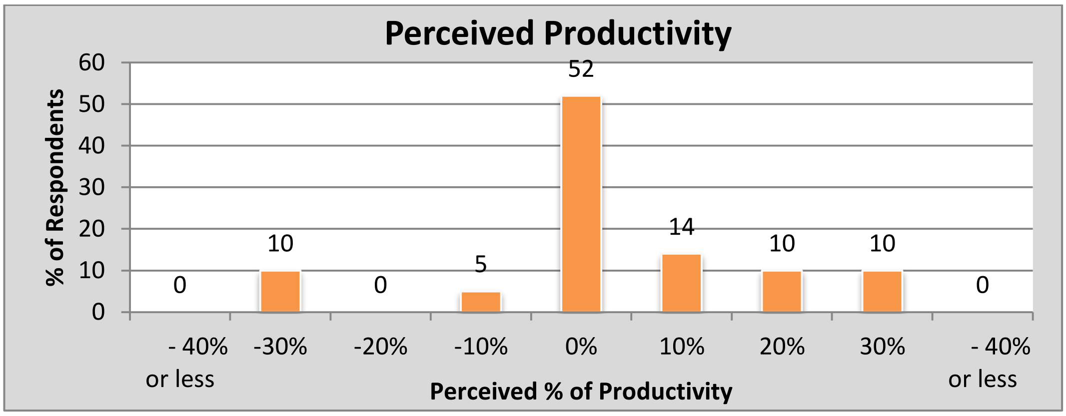


Figure 7.22: Occupants rating of their Perceived Productivity level in %

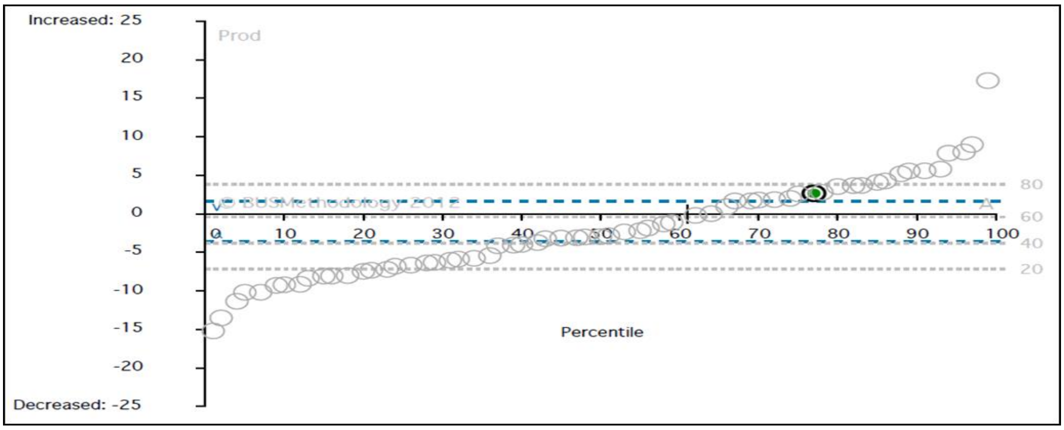


Figure 7.23: Comparison of perceived Productivity for the No.1 when compared to other buildings in UK BUS dataset

There were also issues about noise, which is a common problem in open-plan offices. Over 80% of occupants were dissatisfied about the control of noise level in the building; noise from colleagues, occasional fire testing equipment and traffic noise from the adjoining busy bus route. Errett, et al. (2006) acknowledges that noise could cause annoyance and concentration problems for workers and impact performance. Jones and Broadbent (1998) also posit that high level of noise affects productivity. In the No.1, the window vents are adjustable to allow in trickles of air to assist the adiabatic system in ensuring good ventilated interior, and this could be one of the possible sources of external noise.

So one would ask, is the adiabatic system a good choice for a commercial building by a busy traffic route? Was the operational system considered, vis-à-vis the surrounding environmental factors before the choice of the adiabatic system? The fear exists that sooner than later the adiabatic system may be replaced by another system, like the biomass that has been replaced with the gas fired system.

Other issues such as stench from toilets, draughts, glare, temperature (too hot or too cold) and the electronic access system being too slow were also noted from the comments. These are also some issues that are capable of affecting productivity.

7.4.4.6 Health and Wellbeing: The results of the BUS Occupant survey show that on the average occupants spend 8 hours or more in the building on a work day. Therefore the influence of the indoor environment quality (IEQ) on their health and wellbeing is likely to be far reaching. WBDG Sustainable Committee (2012) posits that IEQ influences the healthiness and comfort of employees in a building. Fisk (2000) also reached a conclusion that "there is relatively strong evidence that the quality of buildings and their indoor environments have significant influence on the occurrence of communicable respiratory illness, allergy and asthma symptoms, sick building syndromes and worker productivity.

In the No.1, over 70% of occupants rated the building as not negatively impacting on their health. However, of this percentage, 65% rated it at mid-scale as shown on figure 7.24. This could imply that this group of occupants were not really sure of how the building impacts their healthiness. Interestingly, nearly 25% of the occupants were not satisfied with the healthiness of the building. Comments indicated that occupants were also concerned with the level of pollution from the toilets. IEQ has been described as encompassing indoor air quality (IAQ). BRE (2013) also posits that the IAQ bears greatly on the health, comfort and wellbeing of building occupants and that poor air quality has been linked to Sick Building Syndrome (SBS), reduced productivity in workplaces and impaired learning in schools.

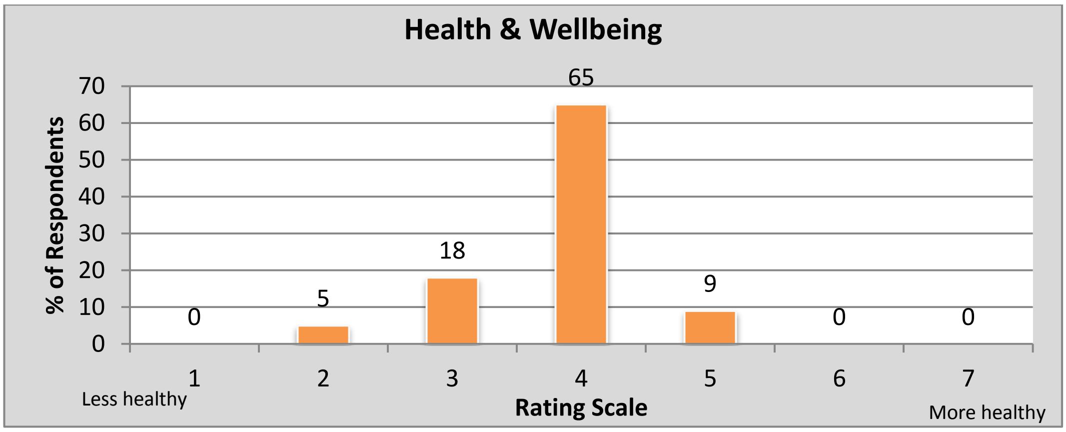


Figure 7.24: Occupants Rating of their Level of Satisfaction with the Perceived Healthiness and Wellbeing of the No.1

Other comments by occupants, which are likely to impact on their health and wellbeing include: electric shocks in some areas of the building, temperature at summer being too hot and too cold at winter; this is likely to cause discomfort and ill-health. However, in comparison with other buildings in the UK BUS database as seen in figure 7.25 shows that the way occupants of the No.1 perceived their workplace is typical of similar buildings in the UK.

WBDG Sustainable Committee (2012) recommends that acceptable IEQ is best achieved through 'source control' at all stages of the building project;

good design, construction and O&M practices. This thesis hypothesises that good O&M practice is a product of good design, and that a good design is that which takes good O&M practice into consideration. So at No.1, it would have been possible to eliminate the stench from the toilets, electric shocks in the affected parts of the building and ensure better indoor temperature, if these were envisaged at the design stage.

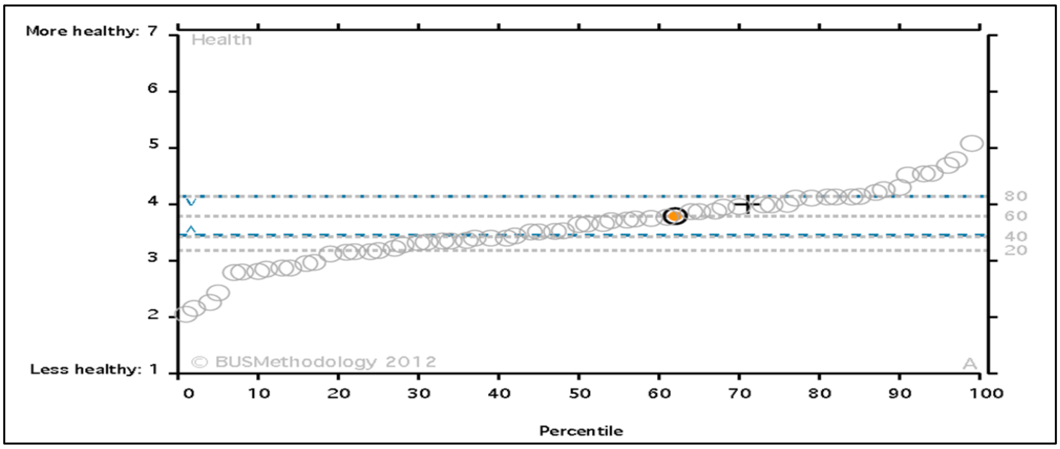


Figure 7.25: Comparison of perceived Healthiness and Wellbeing of the No.1 when compared to other buildings in UK BUS dataset

<u>*7.4.4.7 Perception of Impacts of Maintenance Activities:*</u> The bespoke survey was particularly designed to address maintenance issue, also from the occupants' perspectives. The occupants attest to the fact that the No.1 is well maintained, less than 5% were indifferent as shown on figure 7.26. The study also tries to find out if the maintenance state of the building was as a result of too frequent maintenance activities by posing the next question; '*Maintenance works in this building are carried out too frequently than in other traditional buildings I have experienced'*. 14.3% of the occupants agreed to that, while about 42.9% disagreed and another 42.9% were indifferent. Could it be that those who chose to be indifferent have not worked in another building previously so do not have basis for comparison, or they just do not have interest in what goes on in the building except for their jobs? At the interview stage, interviewee BM03 commented thus:

> *"… There are a lot of things in the building and a lot of the people who come to work in the building don't really know much about the building because they choose not to know".*

This statement seems to support the assumption that they just don't have interest in what goes on in the building except for their jobs. So if this 42.9% occupants 'on-the-fence' are set aside from the statistics, it can be concluded that majority of the occupants perceived that the building is being maintained like any other traditional (non-low carbon) building in the UK.

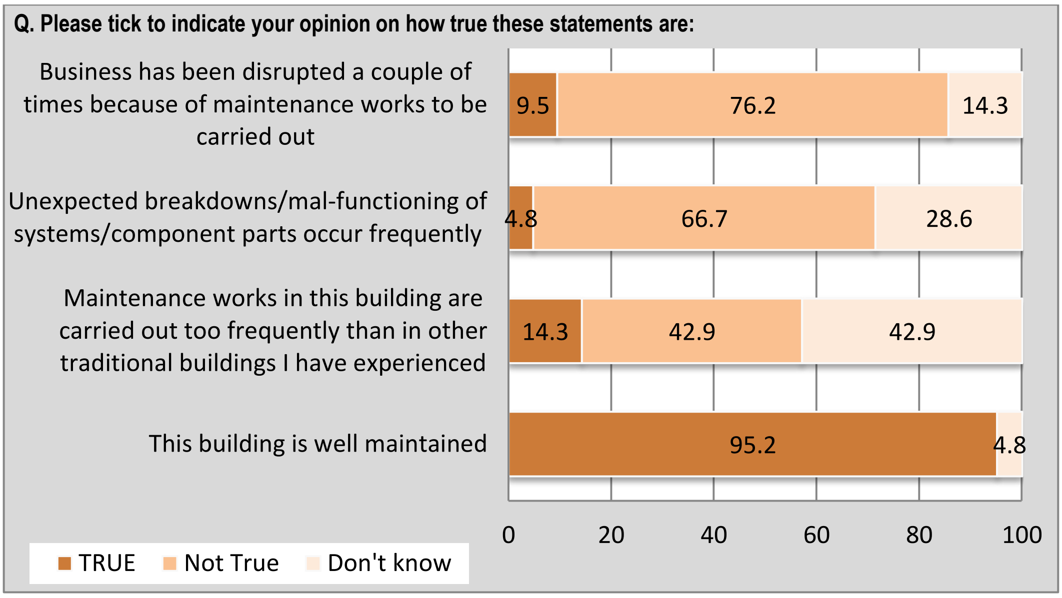


Figure 7.26: Occupants Perception of the Impacts of Maintenance Activities on the building Performance

The result also shows that unexpected breakdowns and mal-functioning of systems have not been frequent and neither has maintenance activities disrupted occupants' business activities. However a small percentage of about 10% agreed that business had been disrupted a couple of times due to maintenance works and about 5% also think that there has been frequent breakdown and mal-functioning of systems/components in the building. Less than 15% also feels that maintenance works are carried out more frequently in this building than any other traditional building. These views; though in the minority shows that some parts of the building may have suffered frequent breakdowns and maintenance, thereby disrupting business occasionally.

The question is what could have been responsible for these experiences? Interviewee DV01 explains this with an example:

> *"But because of the cooling strategy and the cross ventilation that is required to keep the building cool, we have to provide them with a lot of guidance on their fit-outs, so they have to include ventilation gaps at the top of their meeting room walls, for example, so they don't inhibit the cross ventilation. Now some of this advice was ignored by this tenant and now they are suffering from overheating".*

Secondly, Interviewee (BM03) has also explained this as recounted earlier; that a lot of the occupants don't really know much about the building because they choose not to know". User friendly manuals have been provided, yet occupants don't seem to consult it for guidance because they are not being passed down by the point-man in each of the companies.

It may therefore seem proper to conclude that Maintenance works are being carried out too frequently in some parts of the building than in other traditional buildings, unexpected breakdowns and mal-functioning of systems have not been frequent, but had occurred a couple of times. Also, maintenance activities have disrupted occupants' business activities a few times as well.

7.5 CONCLUSION

The study of No.1 Nottingham Science Park indicates that there are myriads of operation and maintenance difficulties associated with low carbon or renewable technologies, and that these difficulties in turn impact on the building performance. The case in point as examined in this study involved the HVAC systems; the biomass system and the adiabatic cooling and ventilation systems.

At the time of this study the biomass system has been put out of use, not because it was broken, but because of the associated operational and maintenance difficulties. The operators of the building, even with the BMS in operation, found it difficult to get around with the best way the adiabatic system could be used to ensure the right indoor air quality and external noise infiltration.

The study also corroborates the conclusion from the earlier surveys and interviews that O&M manuals in the UK lack adequate details that could aid effective operation and maintenance and that they contain too many details and technicalities that make them too difficult to use. Even with the introduction of the building manuals, users still resort to the building manager instead of consulting the manuals for their trouble shooting, possibly because the manuals were not in an easy-to-use form.

These therefore underscore the need for designers to ensure that the LCBs delivered to clients are easy and cost effective to operate and to maintain. One way of ensuring this, according to the 2006 Building Regulations, Part L is to *"provide suitable set of operating and maintenance instructions aimed at achieving economy in the use of fuel and power in a way that householders* (Operators) *can understand …".*

This imply that there needs to be a cultural or process change in the way building manuals are procured and the way LCBs on the whole are procured, because the current system has failed to meet up its target. It therefore may seem proper to propose a design and construction model that integrates Operability and maintainability into its delivery process.

Chapter 8:

OPERABILITY AND MAINTAINABILITY INTEGRATED (OMI) DESIGN & CONSTRUCTION PROCESS MODEL

8.0 INTRODUCTION

Results of investigation presented in chapters 6 and 7 have shown that there is need to introduce some elements that could enhance the operation and maintenance of low carbon buildings, early in the building delivery process. A novel design and construction process model that will integrate operability and maintainability into the delivery process is therefore proposed. This process model is to support the desired cultural shift in work attitudes and thinking on the parts of both clients and designers; so that clients will make a demand on designers for proof of operability and maintainability from inception of brief.

The construction industry has been using process models to manage, organise and provide framework for realising construction projects (Kagioglol et al, 2000; Tunstall, 2006). The RIBA Outline plan of work is one of such models; widely used by all building practitioners in the in the UK (Fulcher and Mark, 2012). RIBA has initiated a review of her 2007 Outline Plan of work; to come to effect from mid-2013 (RIBA, 2012c). However, issues of operability and maintainability were not addressed also in the proposed RIBA Plan of Work.

This chapter describes the process adopted in designing a process model that integrates operability and maintainability into the design and construction process, referred to as Operability and Maintainability Integrated (OMI) Design and Construction Process Model. It also discusses the steps taken to validate and evaluate the proposed process model and how the feedback from the validation exercise impacted on the final outcome.

8.1 DESIGN PROCESS FOR THE OMI PROCESS MODEL DEVELOPMENT

The concept of 'process' is regarded as a scientific framework of managing activities that are transformable from inputs to outputs (Taylor, 1911). This therefore implies that managing a process will involve managing a set of activities and tasks. Tzortopoulos (2004) argues that a process can be divided into sub-processes, activities and tasks that can be managed at different hierarchical levels as explained in figure 8.1

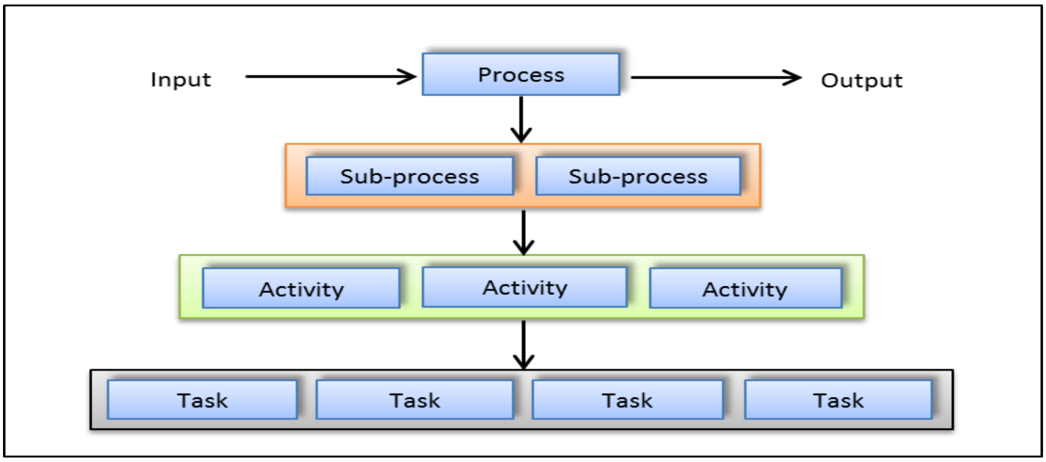


Figure 8.1: Typical Process Levels (Source: Tzortopoulos, 2004)

There are myriads of definitions for 'model' available in literature. They vary based on the purpose, objectives and application of the model devised (Isiadinso, 2010). However, in relation to process, a model is used to represent the reality of a process and how it is required to function (Friedman, 2003). Winch and Carr (2001) viewed process modelling approaches in two broad perspectives:

- IT based – this is associated with system engineering. Its focus is specifically on the flow of information and the process being modelled. Typically, it does not bring the organisational context into consideration
- Business Process Management – also referred to as Business Process Reengineering (BPR). It focuses on the actual flow of information

within an organisation and between the different actors in the process. Typically structured as a two-dimensional model, involving sequence or time along the horizontal axis, and the actors or functions involved in each activity on the vertical axis. The information and materials are then represented in the body of the model.

In terms of types, there are two broad types also identified by Winch and Carr (2001), namely 'True Maps' and 'Protocols'. While the true maps address the processes that actually happens in the organisation, the protocols deal with what ought to happen.

The OMI Process Model is based on the Business Process Reengineering protocol for the delivery of efficient low carbon buildings in the UK. It is aimed at delivering low carbon buildings that are efficient to operate and to maintain. Results and conclusions reached in this research have shown that designers need to prove the efficiency of operating and maintaining LCBs before they are constructed. So the high point of this OMI Process Model is the introduction of an activity phase that will ensure Life-Cycle (operability and Maintainability) Proving. The model also ensures that facilities management skills are brought in early enough, and continue through the design process to and after practical completion of the project. The need to improve on how building information are communicated to the building end users was also addressed by the model by scheduling the commencement of drafting of O&M documents at Design Development stage of RIBA Plan of Work 2013.

8.1.1 The OMI Process Model Development Methodology

The results so analysed from the data, including recent development in the industry; like the Government Construction Strategy, Proposed RIBA Outline Plan of Work 2013, Building Information Modelling (BIM) and other secondary data provided the foundation for proposing the ' OMI Design and Construction

Process Model' which could be adaptable to any procurement route for the design and construction of low carbon buildings. A critical and systematic review of other construction industry process models like the Generic Design & Construction Process Protocol (GDCPP), Design for Deconstruction (DFD) Process Model, etc., also provided learning platform for the development of this model. The methodology adopted for the development of the model was based on the principles of '*Applied Construction Research'* as detailed in Holt (1998). See Figure 8.2. Applied Research is described as a research that tries to resolve practical problems or improve on traditional thinking (Ibid).

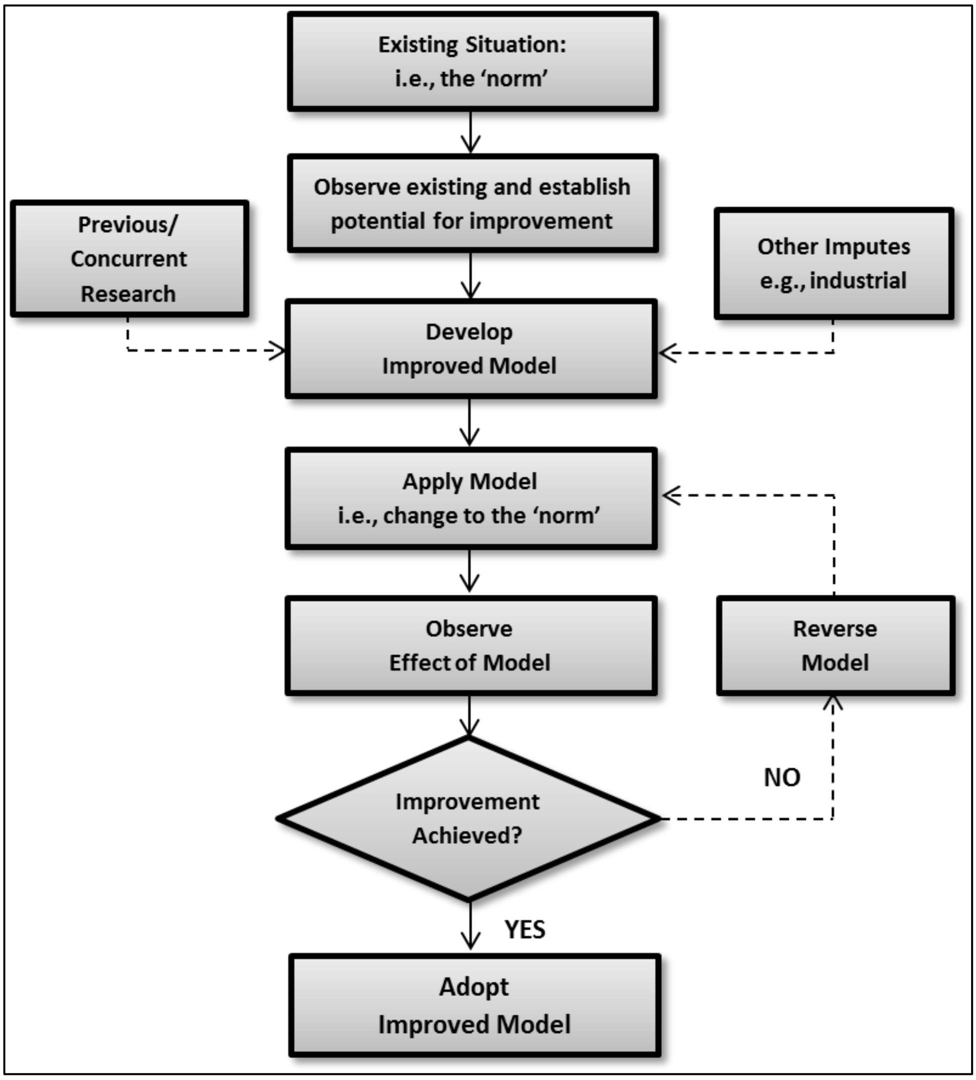


Figure 8.2: Process in Applied Construction Research (Source: Holt, 1998)

8.1.2 The Process Mind-Map

In designing the OMI Process Model, the applied construction research process discussed in section 8.1.1 was adopted as a basis for building up the model. The mind map in figure 8.3 reflects the thoughts on how the proposed model would be built up; attempting to interpret the applied construction research process in the context of the proposed process model.

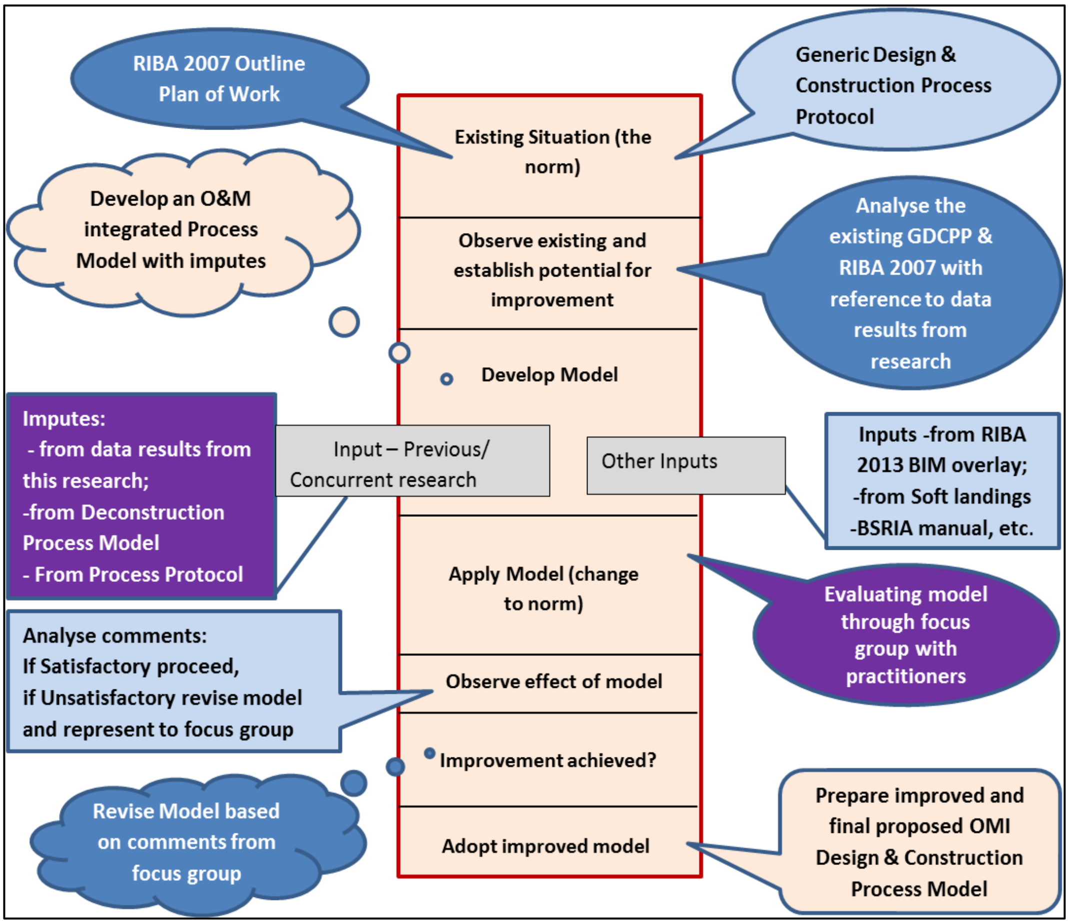


Figure 8.3: Mind-map reflecting the thinking process involved in developing the Process Model

The RIBA Outline Plan of Work 2007 and the Generic Design & Construction Process Protocol (GDCPP) were considered as the existing situation – the norm; what is currently operational. The GDCPP model is a product of an EPSRC (Engineering and Physical Sciences Research Council) research, hosted at the University of Salford in association with a host of industrial partners

(University of Salford, 2000). So this was worth considering as an existing situation.

The existing situations were analysed based on the results of this research, as a way of observing the existing and establishing potential for improvement. The model development was planned to be developed based on inputs from current research, which included results of this research, the proposed RIBA 2013 Outline Plan of work which was at its consultation stage at the time of this research. Other inputs include: developments in soft landings, BSRIA manuals, CSNP model (discussed in section 4.2.4.3), Deconstruction Process Model and the University of Nottingham Estates' procurement framework. The New Government Construction Strategy 2011 and the on-going revision in the Building Regulations were also sources of inputs.

Applying the model or testing the model; was carried out by means of evaluation. This was a way of applying the model, since it was not going to be possible within the time frame of the research to apply model to a life project and be able to observe the effects. It serves as a validation process. If the evaluation results become unsatisfactory, the model would be revised and represented to the focus group on a later date.

8.1.3 Validating of the Model

Validity in social science research has been described to mean "the extent to which an account accurately represents the social phenomena to which it refers (Hammersley, 1990 in Silverman, 2006). Smith (1991) defines validity as the degree to which the researcher has measured what he has set out to measure. According to Silverman (2006), there are two forms of validation that are particularly appropriate to qualitative research:

1. Triangulation – comparing different kinds of data to see if they corroborate one another.

2. Respondent validation – Taking one's findings back to respondents or subjects being studied, so that one's findings are verified.

Miser (1993) argues that there are no universal criteria for validation and that any validity judgement depends on the situation in which a model is used and the phenomena being modelled.

However, in this study, the two methods identified by Silverman (2006) have been adopted. The use of triangulation has been adopted in the data collection process and the validation process is evident through data analysis and discussions in chapters 6 and 7. The OMI Design and Construction Process Model was validated using the Respondent Validation approach. A focus group consisting of 9 high ranking officials of the University of Nottingham (UoN) Estates Office were chosen to provide platform for the Process Model validation exercise. The university Estates Office was chosen based on the following criteria:

- ❖ A few of the senior officials participated in the interview and questionnaire survey at the data gathering stage, so they form a cross section of the subjects being studied.
- ❖ The department doubles as an 'informed client' body and facilities managers, having in their portfolio myriads of exemplar low carbon facilities spread over the seven campuses of the University in UK and overseas. That means they are directly involved with the procurement and management of low carbon buildings.
- ❖ Between 2010 and 2012, over twelve low carbon developments have been started and commissioned by the department (UoN, 2013a) and a lot more are currently on-going (UoN, 2013b; UoN, 2013c). These show that the department is not just directly involved, but actively involved in the delivery of low carbon buildings.

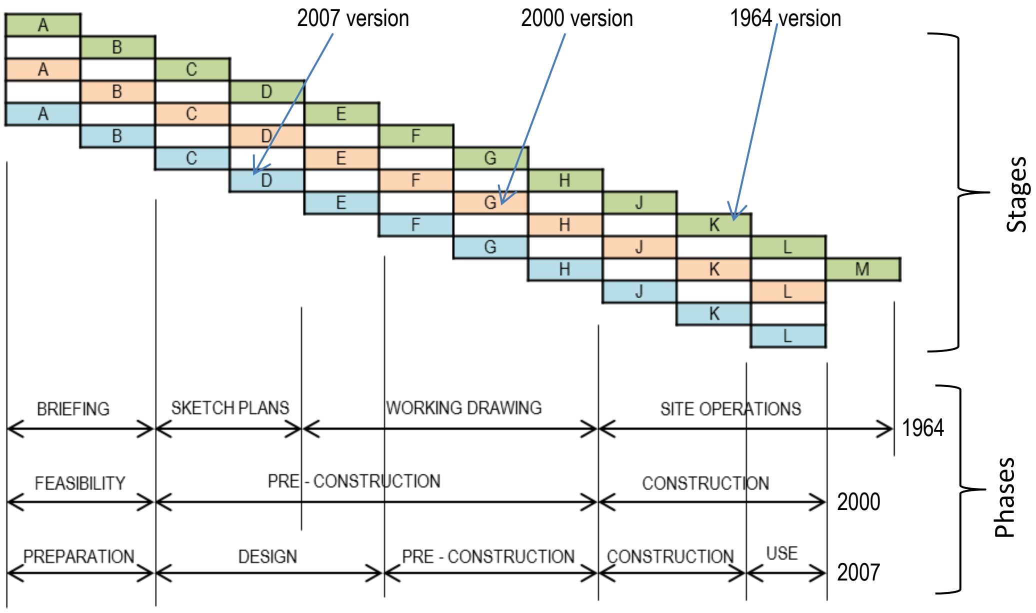
8.2 REVIEW OF EXISTING PROCESS MODELS IN CONSTRUCTION

8.2.1 RIBA Outline Plan of Work

The RIBA Outline Plan of Work was first developed in 1963 (RIBA, 2012c) and published in 1964 as a typical procedure for the design team work, and has become widely accepted as the definitive model for design and construction process in the UK building industry (Kagioglou et al, 1998b; Ibid). Since then, it has gone through several reviews, the notable ones had been in 2000 and 2007 (Isiadinso, 2000). At the time of this study, another review was on-going, billed to come into effect by mid-2013. The RIBA Plan of Work has been described as representing a logical sequence of events that should ensure sound and timely decisions on project delivery (Kagioglou et al, 1998b). The model divides construction works into phases and work stages as illustrated in figure 8.4.

The 2007 version is broken into eleven (11) stages A – L, and five (5) phases; Preparation, Design, Pre-Construction, Construction and Use. Interestingly, the Use phase which covers only stage L consists of three (3) main tasks as evident on figure 8.5:

- Stage L1 – Administration of building contract after practical completion and making final inspections;
- Stage L2 – Assisting building user during initial occupation period; and
- Stage L3 – Review of project performance in use.



STAGES	STAGE ACTIVITIES		
	1964	2000	2007
A	Inception	Appraisal	Appraisal
B	Feasibility	Strategic Briefing	Design Brief
C	Outline Proposals	Outline Proposals	Concept
D	Scheme Design	Detailed Proposals	Design Development
E	Detail Design	Final Proposals	Technical Design
F	Production Information	Production Information	Production Information
G	Bills of Quantity	Tender Documentation	Tender Document
H	Tender Action	Tender Action	Tender Action
J	Project Planning	Mobilisation	Mobilisation
K	Operations on Site	Construction to practical completion	Construction to practical completion
L	Completion	Feedback	Post Practical Completion
M	Feedback		

Figure 8.4: The Phases and Stages of RIBA Outline Plan of Work
(Adapted from Isiadinso, 2010)

RIBA Outline Plan of Work 2007 (As Amended November 2008)

	RIBA Work Stages			Description of Key Tasks	OGC Gateways
Preparation	A	Appraisal		Identification of client's needs and objectives, business case and possible constraints on development. Preparation of feasibility studies and assessment of options to enable the client to decide whether to proceed.	**1** Business justification
	B	Design Brief		Development of initial statement of requirements into the Design Brief by or on behalf of the client confirming key requirements and constraints. Identification of procurement method, procedures, organizational structure and range of consultants and others to be engaged for the project.	**2** Procurement strategy
Design	C	Concept		Implementation of Design Brief and preparation of additional data. Preparation of Concept Design including outline proposals for structural and building services systems, outline specifications and preliminary cost plan. Review of procurement route.	**3A** Design Brief and Concept Approval
	D	Design Development		Development of Concept Design to include structural and building services systems, update outline specifications and preliminary cost plan. Completion of Project Brief. *Application for Detailed planning permission.*	
	E	Technical Design		Preparation of technical design(s) and specifications, sufficient to co-ordinate components and elements of the project and *information for statutory standards and construction safety.*	**3B** Detailed Design Approval
Pre – Construction	F	Production Information	F1	Preparation of production information in sufficient detail to enable a tender or tenders to be obtained. *Application for statutory approvals.*	
			F2	*Preparation of further information for construction required under the building contract.*	
	G	Tender Documentation		*Preparation and/or collation of tender documentation in sufficient detail to enable a tender or tenders to be obtained for the project.*	
	H	Tender Action		*Identification and evaluation of potential contractors and/or specialists for the project.* *Obtaining and appraising tenders; submission of recommendations to the client.*	**3C** Investment decision
Construction	J	Mobilisation		Letting the building contract, appointing the contractor. Issuing of information to the contractor. Arranging site hand over to contractor.	
	K	Construction to Practical Completion		Administration of the building contract to Practical Completion. Provision to the contractor of further Information as and when reasonably required. Review of information provided by contractors and specialists.	**4** Readiness for Service
Use	L	Post Practical Completion	L1	Administration of the building contract after practical completion and making final inspections.	
			L2	Assisting building user during initial occupation period.	
			L3	Review of project performance in use.	**5** Benefits evaluation

Activities in italics may be moved to suit project requirements, ie:
D – Application for detailed planning approval; E – Statutory standards and construction safety; F1 – Application for statutory approval; F2 – Further information for construction; G+H – Tender & tender actions

Figure 8.5: The RIBA Outline Plan of Work 2007 (**Source**: RIBA, 2012d)

However, in spite of these Post-Practical Completion activities being enshrined in the plan of work, there has still been widespread understanding that buildings underperforms and that wide gap exists between building designers and users, as evident in the results of this study. Despite the provision of stage L2, users still find it difficult to understand how the buildings operate, as evident in the case study in chapter 7. This could possibly be that:

- The designers are not engaged up to phase L of the project, for a number of reasons that could not be determined by the scope of this study; or
- The designers do not handle this task satisfactorily.

However, the 2007 version of the Plan of Work was designed to allow for adaptability to any procurement route, including;

- Fully designed project single stage tender
- Fully designed project with design by contractor
- Design and build project single stage tender
- Design and build project two stage tender (all designed by contractor)
- Management contract/construction management
- Public private partnership and public finance initiatives

8.2.2 BIM Overlay RIBA Outline Plan of Work 2013

Building Information Modelling (BIM) is a collaborative 3D working environment that enables all parties to a project work on a shared platform/data; it allows all stakeholders, access to the same information at all times through interoperability between technology platforms. Such information/data include the physical and functional characteristics of the facility, and as such serves as a reliable basis for decisions during its life-cycle; from cradle to grave.

Following the recent Government Construction Strategy, the UK government is committed to ensuring that BIM remains the operating environment for all public sector projects procurement from the summer of 2012. The Royal Institute of British Architects (RIBA) has therefore welcomed this move, seeing the BIM technology as transforming the modes of working in the construction industry in terms of the ways in which design data is generated, shared and integrated, thereby creating need for new protocols. So the RIBA through her Practice and Professional Committee has developed a new work protocol that overlays the BIM on her Outline Plan of Work 2007 (Amended November 2008). Some of the key points noted as supporting the new Plan of Work are as follows:

- ❖ The RIBA believes that architects have a major role to play in ensuring that the construction industry seizes the opportunities presented by BIM in both public and private sectors, vis-à-vis the new overlay and should see it as an important piece of new guidance for architects and other allied professionals.
- ❖ The Overlay is aimed at assisting design and construction teams in using BIM to provide a more efficient, intelligent and cost effective design process and to offer enhanced services to clients, particularly in relation to the building whole life value.

The RIBA Outline Plan of 2013 as proposed by the Review Group of the RIBA Practice and Profession Committee was aligned with the Construction Industry Council (CIC) model as shown in figure 8.6. The model is also said to have been aligned with other equivalent process models published by other professional organisations, such as ACE, BSRIA, CIOB, CIBSE, ICE and RICS (RIBA, 2012c).

Figure 8.6: Overview of the Proposed RIBA Plan of Work 2013 as Aligned to the 2007 Model and the CIC Work Stage (Source: RIBA, 2012c)

A critical review of the detailed proposed plan of work and presentations submitted by the Review Group shows that the new model was concerned with the following considerations in its final outcome:

- Integrating sustainability in design
- Integrating BIM processes
- Providing flexibility around planning procedures
- Addressing changes in the way building services design is delivered
- Responding to the UK Government Construction Strategy

- Providing straight forward mapping and flexibility for all forms of procurement.

The Review Group also noted that whereas the 2007 model possesses some significant strength, it was lacking in its ability to clearly define stages E and F, thereby resulting in differing interpretations and outputs. Planning was also not embedded, 'Soft landings' and whole life emphasis was not considered, and there was no consideration to performance specified work.

Figure 8.7 is a strategic diagram of the proposed Plan of Work. It reflects a departure from the alphabetical stage notations (A – L) to numeric stage notations (1 – 7), being compatible with the CIC Work stages as also evident in figure 8.6. The detailed draft model illustrating the detailed description of tasks in the overall framework is shown on Appendix D.

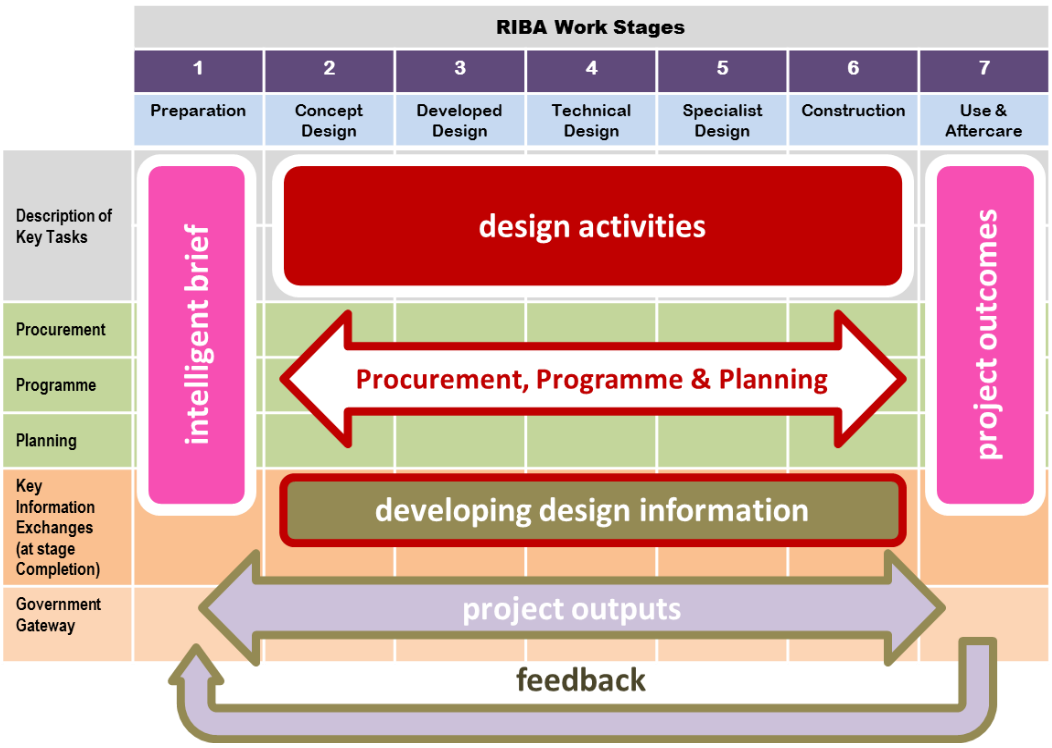


Figure 8.7: RIBA Plan of Work Strategic Diagram (Source: RIBA, 2012c)

8.2.3 Generic Design & Construction Process Protocol

The Generic Design and Construction Process Model as referred to as the Process Protocol was the product of an EPSRC funded research under the Innovative Manufacturing Initiative (IMI). It is a high level process map that provides a framework to help organizations and construction professionals achieve an improved design and construction process. It uses experience drawn from the manufacturing sector as reference point, and maps the entire project process within nine (9) 'Activity Zones' and four (4) main stages (Pre-project, Pre-Construction, Construction and Post-Construction Stages. The stages are further broken into ten (10) phases 0 – 9 as shown on figure 8.8.

The 'Activity Zone' is described in Kagioglou et al. (1998a) to mean a set of sub-processes that involve tasks which guide and support work towards a common objective. The Activity Zones include:

- Development Management
- Resource Management
- Design Management
- Facilities Management
- Health & Safety, Statutory and Legal Management
- Project Management
- Process Management
- Production Management and
- Change Management

The phases are akin to the stages in the RIBA Plan of Work. However, in the Process Protocol, the phases starts from Zero (0) to Nine (9); i.e., from the client demonstrating need for the project through to operation and maintenance of the building. See Appendix E.

One key element of this model is that at the end of each phase, a phase review is carried out and the results are to be fed into the Legacy Archive which is potentially an IT solution. It is a mechanism for recording/storing and retrieving project/process information that can be used on the current and subsequent projects by the project participants (Kagioglou et al, 1998b).

With the coming in of BIM, Soft Landings, new Government Construction Policy and the revised RIBA Plan of Work, the 1998 Process Protocol will require a review to become relevant. However, it is important to note the potential benefits of the Process Protocol as enumerated in Kagioglou et al (1998b) and Isiadinso (2000):

- ❖ It take a whole-project view from start
- ❖ Recognises the interdependency of activities throughout the duration of a project.
- ❖ Focuses on the front-end activities through the identification, definition, and evaluation of clients' requirements.
- ❖ Provides the potential for adopting a standard approach to performance measurement, evaluation, and control to facilitate continuous improvement in construction.
- ❖ Encourages the establishment of multi-functional teams including stakeholders. This fosters a team environment and encourages appropriate and timely communication and decision making.
- ❖ Facilitates a legacy archive whereby all project information is collectively stored and can be used as a future learning vehicle.
- ❖ The Process Protocol can be used to meet the time demands of all projects.

8.2.4 Other Process Models

Various organisations, including research bodies and individual researchers have developed various processes models in response to the need for customer satisfaction and to achieve value for money in the construction industry. Winch and Carr (2001) noted that use of Process Modelling in the construction industry has been on a rapid increase. However, besides the RIBA and the University of Salford developed Generic models, a few other models in construction have been reviewed in this section. Lessons drawn from the reviews also impacted the design and structuring of the proposed OMI Process Model.

8.2.4.1 Deconstruction Process Model (DPM): This model was the result of a PhD research work at the Loughborough University and published in Isiadinso (2010). The model provides a process that could aid deconstructability. It emphasises *'Design for Deconstruction' (DFD)*; an approach to design and construction with the intention of disassembly instead of demolition at the end of life (Ibid). According to the author, DPM is a framework that is aimed at:

- encouraging the implementation of reuse and recycling strategies, early from the project inception
- managing the dynamic process of designing for maximum adaptability and flexibility of design to encourage future reuse instead of demolition
- looking at some aspects sustainable construction that could ensure reduction in waste in the building delivery process
- providing a practical model that could facilitate aspects of sustainable construction practice
- enabling concurrent work on all aspects of the project delivery process to achieve the benefits of integrating 'Design-For-Deconstruction'

The DPM draws knowledge mainly from the Process Protocol already discussed in section 8.2.3; possesses all the features of the Process Protocol, introducing a new Activity Zone; 'Design for Deconstruction Management'. It also consists of phases 0 – 9 as in the Process Protocol, as well as an eleventh phase – 'Phase 10 – Deconstruction phase'. See figure 8.8.

The DPM was chosen among other construction industry protocol for review because of the commonalities that exist between it and the proposed OMI Process Model; such as:

- They are both products of design process management focussed research;
- They also attempt to integrate into the design process, an aspect of design deemed to be lacking in the current operating processes;
- Both works tend to look at how to make the end results of designs more sustainable, right from project inception stages.

However, the DPM approach was not found to be fitting for adoption or to be built upon for the development of the proposed OMI Process Model because it uses the Process Protocol as the base model for integrating the DPM activities. Whereas the 1998 developed Process Protocol has been proven in section 8.2.3 to be inadequate in the face of the birthing of the New Government Construction Strategy, BIM, Soft Landings and the RIBA Plan of Work 2013 (being the most widely used and most recent reviewed design and construction process model in the UK, as discussed in sections 8.2.1 and 8.2.2).

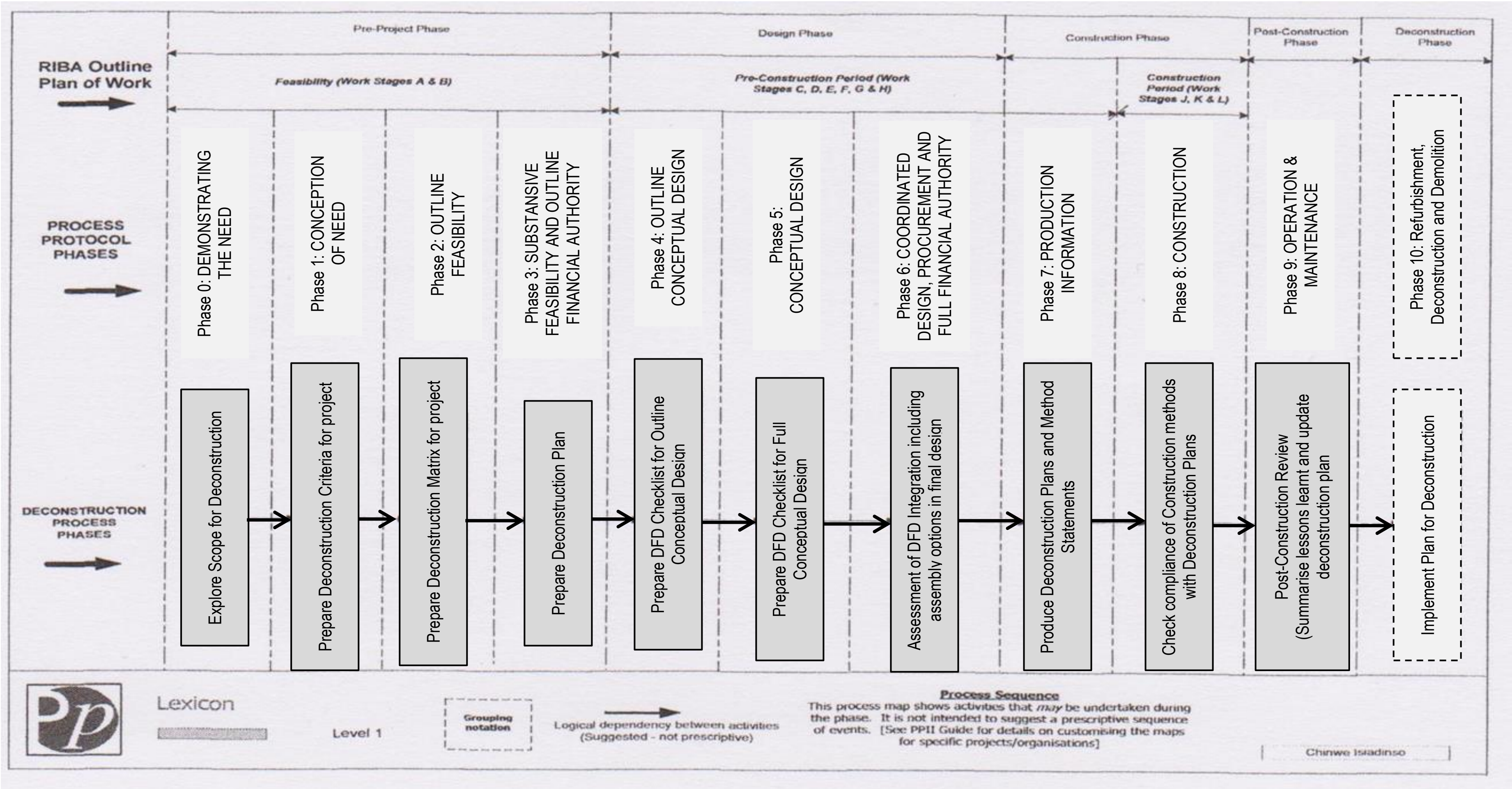


Figure 8.8: Deconstruction Process Model showing the Deconstruction phases in the Process Protocol Phases (Source: Isiadinso, 2010)

<u>8.2.4.2 Soft Landings Process Model</u>: This framework has been discussed in section 3.5.2. Its principle is geared towards ensuring that designers and constructors of buildings extend their services beyond commissioning to 3 – 5 years into the operation and maintenance phase of the project. In addition, soft landings in literature have been described to intend to achieve the following (UBT, 2009; RIBA 2012a):

- ❖ A way of working; a new professionalism that says, *"We have to change the way we do things to deliver better buildings"*.
- ❖ Fosters greater mutual link and understanding between owners, designers, constructors, managers and occupiers about project objectives.
- ❖ Reduces the tensions and frustrations that occur at initial occupancy, and ensure clients and occupiers get the best out of their new facility.
- ❖ Raising awareness of performance in use in the early stages of briefing and feasibility helps to set realistic targets and assigns responsibilities.
- ❖ It also assists the management of expectations through the design stage and up to the initial operation period.
- ❖ The extended aftercare period, with monitoring, performance review and feedback is expected to help occupants in better use of their building, while clients, designers, constructors and managers gain experience for the next time.
- ❖ It provides easy route for POE and feedback.

Figure 8.9 shows the Soft Landings Activities Integrated to RIBA Plan of Work 2007 as proposed by the authors.

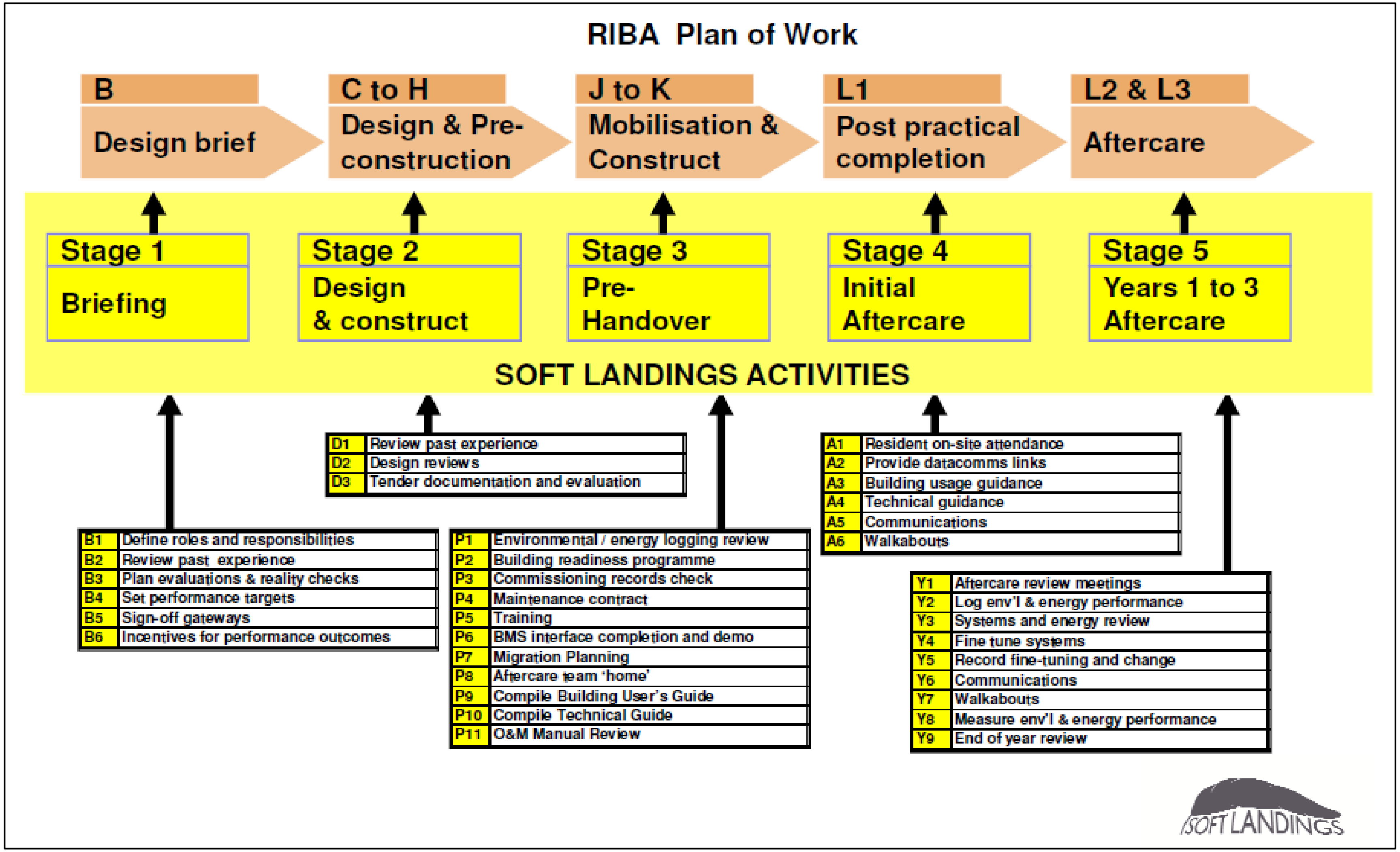


Figure 8.9: Proposed Soft Landings Activities Integrated to RIBA 2007 Plan of Work（Source：Anderson，2013）

The Soft landings protocol table was designed to fit in the RIBA Plan of Work 2007.

- ❖ By the RIBA Plan of Work 2013, this protocol becomes obsolete and will require a review.
- ❖ However, RIBA Plan of Work 2013 has incorporated relevant aspects of Soft landings Protocol.
- ❖ The protocol introduces the FM staff and activities midway the construction stage, rather than at the design stage
- ❖ Stage 5 of the soft landings protocol has been discussed in section 3.5.2 of this thesis as amounting to added cost to the project for up to 3 years. Also discussed in section 3.7; concept of 'Right first time', that is more rational and cost saving to invest in making the building right from beginning instead of investing for another 3 years just to fine tune the systems and interpreting building guide documents that could be made user friendly ab-initio.

8.2.4.3 The University of Nottingham Estates Office Model: As discussed in section 8.1.2, the University of Nottingham Estates Office has in her portfolio myriads of exemplar low carbon buildings distributed across the 7 campuses of the University in the UK and overseas (China and Malaysia). Interview with a top principal officer of the department revealed that they have developed a bespoke model (True Map) of how their numerous projects are being and should be executed.

The model as shown on Appendix F, is scheduled in 7 stages; i) Feasibility; ii) Design; iii) Construction; iv) Commissioning; v) Handover; vi) In-Use and vii) Post Occupancy Evaluation.

within the seven campuses of the university. It encourages flow of information based upon local knowledge that is vital in ensuring that the projects meet the requirements of all stakeholders, resulting in an end product that is not only fit for purpose, but is also easily maintained throughout its life. The model, which is referred to as *'Project Communication Framework'* encourages improved communication between the design team and the In-House Maintenance Group on the project. A critical study of the model reveals some interesting observations, which include:

- Unlike other models reviewed, this did not deal with detailed design and construction activities or stages;
- The Estate operates a Client-Led-Project Team procurement system
- Besides the Project manager who typically is an Estates Office staff, an In-House Facilities Group made up of relevant experienced professionals are engaged with the project right from stage 1 and all through the whole project stages.
- Points to be discussed at stage 1 Communication include issues about Health/Safety and O&M files, known building hazards, etc. this indicates that operation and maintenance issues are considered before the design team is even appointed. These are likely to form part of the 'Design Team guide' passed down to the team at stage 2.
- The earlier mentioned Interview with a top principal officer of the department also revealed that the design teams were usually engaged up to stage C or D of the RIBA 2007 Plan of Work. A contractor is then engaged from that point based on the Develop & Build contract.
- At the Pre-Tender Review Communication level, issues of design details and maintainability are also brought to the fore.

- The Facilities Group who typically represents the client takes over fully, the management of the facility at the end of the 12 months defects liability period.

8.3 REVIEW OF OTHER RELEVANT REGULATIONS

Building delivery processes in the UK are also directly or indirectly being influence by government policies and regulations. This section therefore considers such policies and regulations, as well as contribution from research bodies that could feed the proposed OMI Process Model.

8.3.1 Government Construction Strategy

The Government Construction Strategy published in May 2011 has been discussed in section 4.6. However, it is important to note some of points highlighted which could possibly bear on the proposed OMI Process Model. Government proposed a model which she calls 'the right model' for public sector procurement in the UK. This model requires that;

- clients issue a brief that concentrates on required performance and outcome; designers and constructors work together to develop an integrated solution that best meets the required outcome;
- contractors engage key members of their supply chain in the design process where their contribution creates value (This could possibly include O&M manual editors);
- industry is provided with sufficient visibility of the forward programme to make informed choices (at its own risk) about where to invest in products, services, technology and skills; and
- there is an alignment of interest between those who design and construct a facility and those who subsequently occupy and manage it

- This model also encourages the use of Building Information Modelling (BIM); a collaborative 3D working environment that enables all parties to a project to work on a shared platform/data. This, the government believes will ensure that all project information, documentation and data are in electronic forms by 2016.
- The model also requires designers and constructors to prove the operational performance of the building they designed and construct for a period of say three to five years. That is, adopting the Soft Landings principles.
- Encourage competitive tension, and make cost (derived from agreed principles of value for money) a key driver, rather than an outcome.

8.3.2 Building Regulations 2013

In December 2012, the UK government Announced key changes to the Building Regulations. Although NBS, the Government's official publisher of the Approved Documents to the Building Regulations is reported to have published the documents, they are yet to be at the bookshops as at the time of this write up. However, some of these key changes relevant to this research include those made to Part L (Conservation of fuel and power) of the Building Regulations 2012/13 in England. Relevant information adduced from the consultation documents by Communities and Local Governments include:

- Effective date is October, 2013
- Building Regulations should be used to achieve carbon emission reduction from the UK building stock, to meet its Climate Change Act target, since the market would not make these changes on its own.
- It is expected that Part L will be the regulatory vehicle for the energy and carbon elements of the standards and that the changes for 2013 should provide learning to aid the transition to zero carbon by 2016/19.

- Recent works on 2016 carbon emission targets has suggested that action is needed by industry and government to investigate and tackle the perceived gap between energy performance of new homes as calculated at the design stage and the performance when building is in operation.
- Although the final published copy of the Part L document is yet to be made available, it is presumed that much difference is not likely when compared to the draft prepared for consultation. Some of the relevant clauses noted include:
  - *"No new buildings are exempt from the energy efficiency requirements of the Building Regulations".*
  - *"Building Regulations are made for specific purposes, primarily the health and safety, welfare and convenience of people and for energy conservation. Standards and other technical specifications may provide relevant guidance to the extent that they relate to these considerations. <u>However, they may also address other aspects of performance such as serviceability,</u> or aspects which although they relate to health and safety are not covered by the Regulations".*
  - *"Criterion 2: the performance of the building fabric and the **fixed building services** should achieve reasonable overall standards of energy efficiency following the procedure set out in paragraphs 4.18 to 4.24. <u>This is intended to place limits on design flexibility to discourage excessive and inappropriate trade-offs</u> – e.g. buildings with poor insulation standards offset by renewable energy systems with uncertain service lives. This emphasises the purpose of Criterion 2".*

- *"Criterion 5: the necessary provisions for energy efficient operation of the **dwelling** should be put in place. One way to achieve this would be by following the guidance in Section 6."*
- ***"6.1** In accordance with Regulation 40 paragraph L1(c) of Schedule 1, the owner of the **dwelling** should be provided with sufficient information about the building, the **fixed building services** and their maintenance requirements so that the building can be operated in such a manner as to use no more fuel and power than is reasonable in the circumstances".*
- *"**6.2** A way of complying with the requirement would be to provide a suitable set of operating and maintenance instructions aimed at assisting the occupiers of the home achieve the expected level of energy efficiency. The documentation should be specific to the dwelling, and be in a durable format that can be kept and referred to over the service life of the various systems and components. The documentation should include a "quick start guide" which contains the key information in an easily understood format".*

8.3.3 BSRIA Guide on Building Manual & Building User Guide

The Building Services Research & Information Association, in July 2011 published a guide document titled "Building Manuals and Building User Guides – Guidance and worked examples (BG 26/2011)". The publication was intended to help those responsible for creating documentation that satisfies building regulations requirements with regards to building logbook and building user information for BREEAM. The document noted as follows:

- ❖ The construction industry has a poor reputation when it comes to O&M manuals.

- For upwards of 10 years, BSRIA has been capturing key performance indicators for M&E contractors and noted great improvement over the period, however, 2 aspects of service still return poor scores comparatively:
    - The quality of the O&M manuals and
    - The timeliness of delivery of O&M manuals.
- The guide document was a product of consultation with industry, with the overall aim of enabling efficient and effective use of buildings through better information sharing.
- With new and complex technologies fitted into buildings today calls for ever increasing awareness of how they operate in order to achieve the optimum benefits and cost savings available.
- While the technical details are available to the professional and technical staff involved with operating and maintaining the building through the O&M manual, the key information gets hidden and is rarely made available to the occupants of the building.
- BSRIA therefore proposes that two documents be prepared in addition to the O&M manual for each building:
    - Building Manual
    - Building User Guide.
- The building manual condenses the information contained in the O&M manual, H&S files, standard operating procedures and energy operating procedures and then it is used to compile a Building User Guide
- The Building Manual is not intended to replicate information in the O&M manual, but to address the salient points that an operator will need to operate the building effectively and as the designer intended.

- ❖ The Building User Guide is to provide the end users of the building (occupants) with a simple, quick and easy guide to everyday functions of the building, as to ensure a safe and healthy work environment.

8.4 OPERABILITY & MAINTAINABILITY PROCESS MODEL DESIGN

8.4.1 Why the RIBA Model was chosen as the appropriate model

The RIBA model was chosen as base model in which the Operability and Maintainability' process could be integrated to design and construction process of low carbon buildings in the UK. This model was considered above other models reviewed in this study, due to the following reasons:

- ❖ Over the years, the RIBA Outline plan of Work has been a working guide to all other building consultants. – It is said to be 'the language of construction'.
- ❖ The most widely acknowledged model used and referenced for decades as a guide to organise and manage a construction project.
- ❖ Although it focuses more on the role of the architect as a designer and a project administrator, it still covers a project whole view from Appraisal (stage A) to initial after care (stage L).
- ❖ It is adaptable to varying procurement routes.
- ❖ The 2013 revision, consultation/draft edition changed from her 11 stage (A – L) to 7 stages (1 – 7) and adapted the use of BIM and Soft Landings.
- ❖ Of all available process models in the construction industry, the RIBA 2013 model is the most recent and more adaptable to the new Government Construction Strategy.

- It is also aligned to the Construction Industry Council (CIC) model and other equivalent process models published by other professional organisations, such as ACE, BSRIA, CIOB, CIBSE, ICE and RICS.

In summary, the RIBA model for design and construction is the most widely accepted and the most recent reviewed model for design and construction in the UK. It has also exercised significant influence internationally (RIBA, 2012c). However, some inputs are also drawn from other models reviewed, particularly the Process Protocol and the UoN Estates Office's Model.

8.4.2 Relevant Data Summary

The conclusions reached from the research findings in chapters 6 and 7; including some relevant secondary data from this chapter helped to inform the mapping of the OMI Design and Construction Process Model being proposed by this study. These conclusions are summarised into 7 key points as shown below, and are inputted into the design process of the proposed OMI Process Model.

1. Need to integrate O&M considerations into the design Process
2. Need for Clients awareness of the operation and maintenance implications of their proposed buildings at the design stage
3. Bring in facilities management skills to the design process early enough
4. Designers and Constructors to prove operation and maintenance of the buildings they designed, before construction
5. Bring O&M manual drafting process into the design process
6. O&M manuals be supplied as technical and non-technical manuals and in hard copy and searchable formats including a quick start guide containing the key information in an easily understood format.

7. Develop a first draft of the O&M manuals at the design stage

8.4.3 Lessons from New Product Development (NPD) Process in Manufacturing Industries

A number of studies have shown that in a dynamic economy, developing and introducing new products is very vital for the company's continued operation (Cooper, 1998). So New Product Development (NPD) has become a necessary risk that companies must undertake (Ibid), just as new and innovative low carbon technologies will continue to be a necessary risk the building industry must undertake if we must continue to mitigate and adapt to the changing climate and its effects on the human environment.

Moving a new product idea through the production line and finally to the market involves a number of activities. These activities according to Cooper and Kleinschmidt (1988) are categorised into three (3) main categories: the pre-development activities, development activities and post-development activities. These are further broken down into several sequential phases of development as shown on figure 8.10.

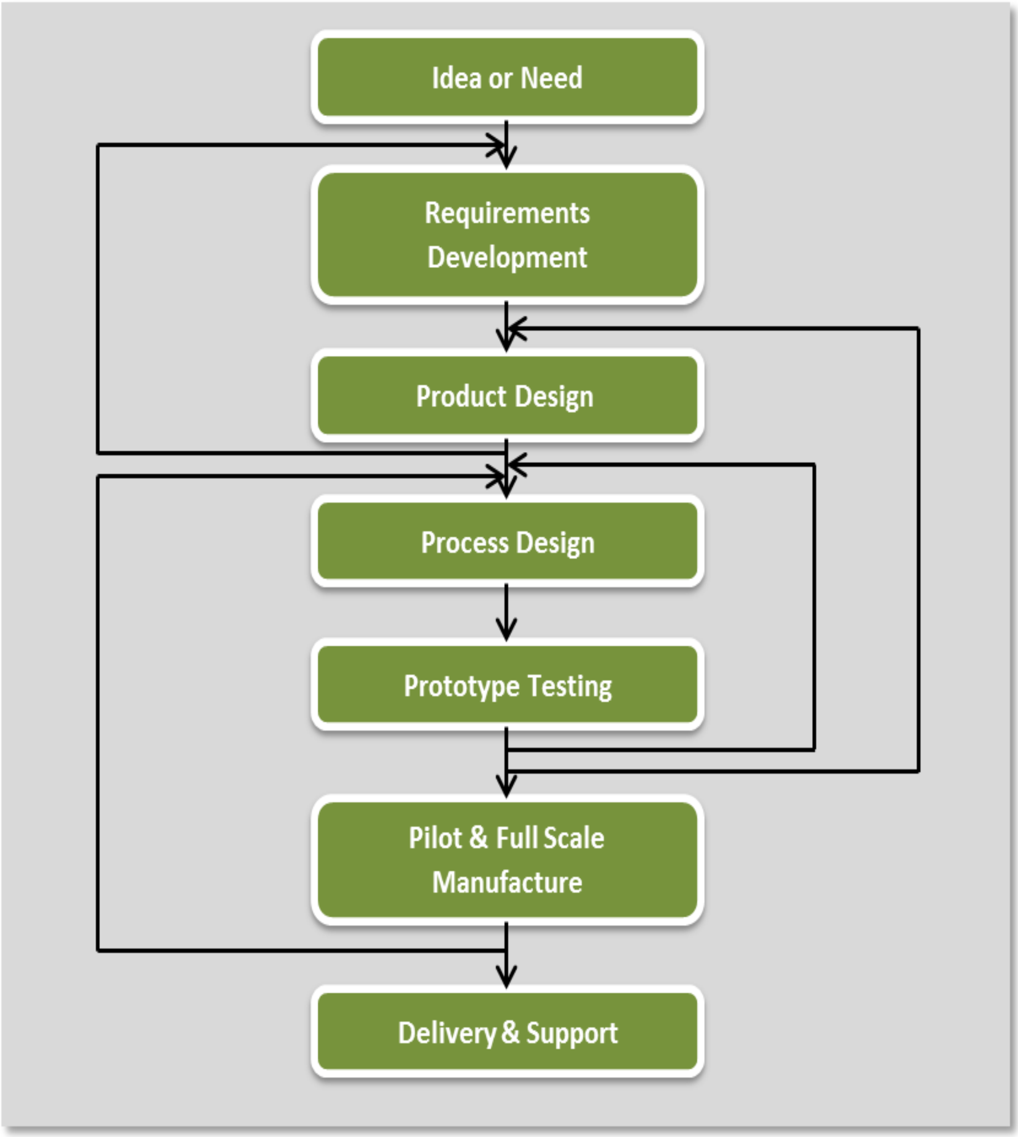


Figure 8.10: Typical Sequence of New Product Development
(Source: Kagioglou et al, 1998b)

According to Kagioglou et al (1998b), this model is referred to as sequential or serial approach to NPD. The model has been used by the National Aeronautics and Space Administration's (NASA) Phased Programme Planning (Ibid). From this model, the following lessons could be learnt:

1) It appears similar to the traditional building delivery models, and can compare with the RIBA and the Process Protocol discussed earlier.
2) However, this model incorporates a 'Prototype Testing' phase that does not exist in any of the reviewed models.

3) Before 'Pilot and Full Scale Manufacture' of any new product, the design has to be tested to examine how the product meets its requirements. Where the designed prototype fails the test, the process reverts back again to an appropriate stage or phase of the process. In essence the design must pass the test before any form of manufacture (akin to construction) takes place and before final delivery to end users.
4) After a pilot manufacture, lessons learnt can be ploughed back to the process design stage and tested again before going through the full scale manufacture before eventually delivering to end users (handing over).

Most buildings are one-off design, so pilot testing may not be possible, but is quite possible to test a design before it is built. The design team should be able to demonstrate that the systems provided are workable, easy and efficient to maintain.

8.4.4. The Proposed OMI Design and Construction Process Model

In figure 8.11 the New Product typical model is compared with the Process Protocol and with the 2007 and 2013 RIBA models. It shows clearly that the Testing phase does not exist in the design and construction models.

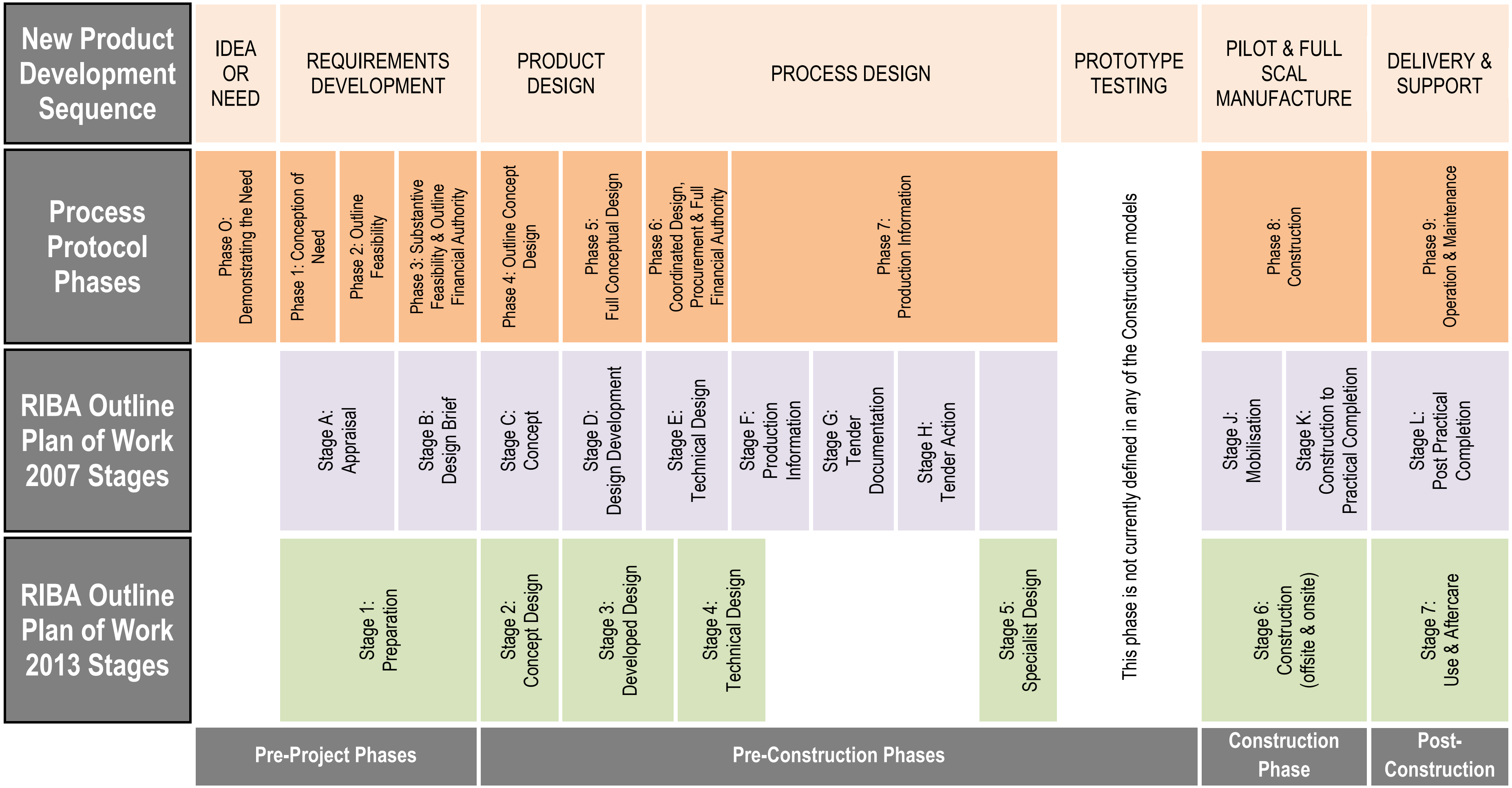


Figure 8.11: Overlaying the New Product Manufacturing Sequence and the Process Protocol on RIBA 2007 and 2013

Also, the Idea or Need stage which is akin to Phase 0 in the Process Protocol does not also exist in the both RIBA models.

8.4.4.1 Proposing Operability and Maintainability Activities

Learning from all the models reviewed, secondary data analysed and research findings, sets of activities that will facilitate operability and maintainability in design were proposed to be integrated into the design and construction process for low carbon buildings, using the RIBA Plan of Work 2013 stages as a base map. (See figure 8.12). Drawing particularly from the NPD model, the Process Protocol and the UoN Estates Office framework, it was necessary to incorporate *'Stage 0'* where the client, prior to engaging or commissioning the design team should be able to establish operation and maintenance expectations that should form part of the brief. Also introduced is *'Stage 3b'* which does not currently exist on any construction industry model reviewed. It is followed from the research findings which require that designers should prove the operability and maintainability of their designs. This is akin to *'Prototype Testing'* in the NPD model.

By RIBA 2013 model stage 3, the design team is required to prepare developed designs including structural designs, services systems, site landscape, outline specifications, cost plans and project strategies. Planning approval also commences at this stage. So in the OMI model, the O&M documents preparation is proposed to commence. Beyond this stage, making changes to design decisions may be though possible, but will be more challenging. The outline documents prepared at this stage could be very helpful at stage 3b. All O&M manuals, including technical and none technical manuals in hard and searchable soft copies are expected to progress from this point and be finalised at the construction stage; prior to commissioning and handover.

	Pre-Project Stage		Pre-Construction Stages					Construction Stage	Post-Construction Stage
RIBA Outline Plan of Work 2013 Stages	Stage 0	Stage 1	Stage 2	Stage 3	Stage 3b	Stage 4	Stage 5	Stage 6	Stage 7
	Demonstrating the Need	Preparation	Concept Design	Development Design		Technical Design	Specialist Design	Construction	Use & Aftercare
Operability and Maintainability Integrated Phases	Explore Scope for Operability & Maintainability	Prepare Operability & maintainability Criteria for Project	Prepare operation and maintenance matrix	Prepare initial Operation and Maintenance Model	Life-Cycle (Operability & Maintainability) Proving	Review Operation & Maintenance Model	Update Operation & Maintenance Model	Review & Finalise Operation and Maintenance Model	Post-Project Review
Government Gateway	Information Exchange through BIM								Feedback via Govt. Gateway

Figure 8.12: Operability and Maintainability Integrated Stages to RIBA 2013 Stages

8.4.4.2 The Proposed Operability and Maintainability Integrated Design & Construction Process Model – Overall Framework Description

As discussed in earlier sections, the OMI Process Model is built on the proposed RIBA 2013 Plan of Work. Two additional stages are introduced, but these do not alter the key tasks described in the RIBA model for each prescribed stage. The O&M tasks proposed by this model are the facilities management (FM) skills required to be brought into the design stage as suggested from the findings of this research. So the O&M tasks are so mapped out to complement the RIBA Key Tasks. It so appear that RIBA is amenable to additional tasks by referring to its stipulated tasks as key tasks. So the RIBA Plan will not struggle to accommodate the complementing FM tasks which could be handled by the client's in-house or a consulting facilities manager.

The OMI model does not also alter the procurement, programme or planning strategy of the RIBA, so no alternative procurement, programme or planning strategy has been proposed for the OMI model. It has been planned to follow the flexibility embedded in the current and future procurement strategy of the RIBA Plan of Work. The RIBA has proposed that;

> *"Stages 1 – 4 outputs may be used for tendering and contract purposes, depending on the procurement strategy and influenced by the client's Risk Profile, time, cost and quality aspirations and how Early Contractor Involvement and Specialist Subcontractors input is to be undertaken".*

It also specifies that;

> *"Stages 4 – 6 activities may occur concurrently depending on the Procurement Strategy. Work may also be undertaken in packages to facilitate its development by Specialist Subcontractors. Early package procurement may also occur during stage 3 depending on the procurement route. The Project Programme should set out the times*

scales for these overlapping design and, where appropriate, construction stages".

Figure 8.13 is a strategic hierarchy map of the proposed model, following from the format proposed by Tzortopoulos (2004) and shown on figure 8.1. The strategic hierarchy map explains the hierarchy level and content of the layout of the overall framework on figure 8.14.

The Process here means the OMI Process Model which is broken down into Sub-Processes (The RIBA Stages), the sub-Process activities and the key actors to be concerned with that sub-process activity either as a facilitator, supplying or benefiting from information for or from that activity stage. The next level is being the level of tasks; which are to be carried out to meet the requirements of the activities.

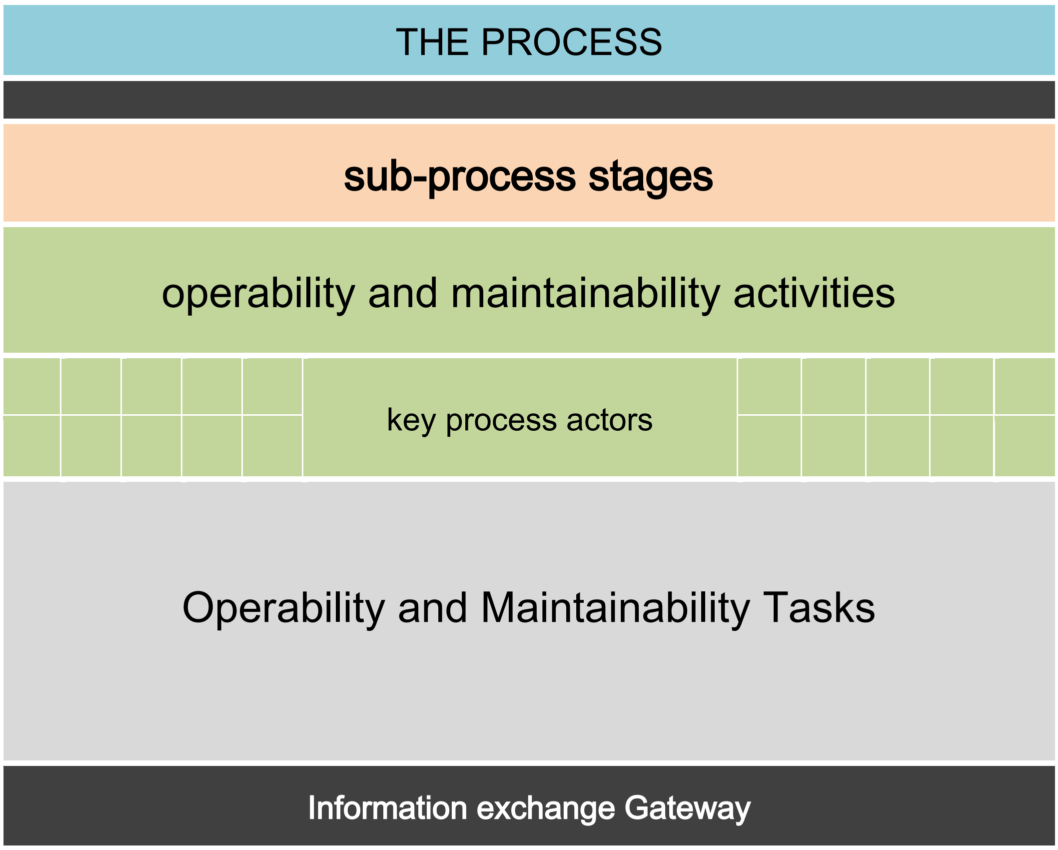


Figure 8.13: Strategic Hierarchical Levels adopted for the Proposed OMI Process Model

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING									
	Pre-Project Stage		Pre-Construction Stages					Construction Stage	Post-Construction Stage
RIBA (Sub-Process) Stages	Stage 0	Stage 1	Stage 2	Stage 3	Stage 3b	Stage 4	Stage 5	Stage 6	Stage 7
	Demonstrating the Need	Preparation	Concept Design	Development Design		Technical Design	Specialist Design	Construction	Use & Aftercare
Operability and Maintainability Activities	Explore Scope for Operability & Maintainability	Prepare Operability & maintainability criteria for Project	Prepare operability and maintainability strategy	Prepare initial Operation and Maintenance Model	Life-Cycle (Operability & Maintainability) Proving	Review Operation & Maintenance Model	Update Operation & Maintenance Model	Review & Finalise Operation and Maintenance Model	Post-Project Review
Key Process Actors	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	CLT ARC FM M&E
	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN
Operability and Maintainability Tasks	Establish Client's specific requirements including need for specific LC technology	Define Client's specific brief, including need for specific LC technology	Develop operability & maintainability matrix to inform choice of appropriate technology & general design decisions	Prepare initial plan for operation & maintenance of specific technologies for the project life-cycle	Prepare life-cycle analysis of project in line with client's business requirements	Review plan for operation & maintenance of specific LC technologies and detailed technical O&M manual for the project life-cycle	Update plan for operation & maintenance of specific LC technologies and detailed technical O&M manual for the project life-cycle	Plan and finalise maintenance contracts, training for aftercare team, BMS interface completion & demo	Implement Soft Landings for not more than 12 months after Practical Completion within the normal Defects liability period
	Identify Key O&M performance Objectives including life expectancy	Identify drivers for operability & maintainability including economic, social/environmental	Review past operation & maintenance experiences with respect to specific technologies					Finalise all technical O&M documents in an interactive digital format	
	Identify any benefits/limitations including Health & Safety, legislation & policy, incentives, risks, etc.	Set performance targets, e.g. BREEAM rating, etc. Review past experience and Plan evaluations & reality checks	Review Client's brief with respect to specified and/or innovative LC technology(ies) that best sit in the overall project design.	Prepare initial plan for detailed technical operation & maintenance for the entire property	Highlight technology/equipment regular operation and maintenance requirements (accessibility, cost & frequency), including life expectancy of the system			Prepare and finalise all non-technical O&M documents in an interactive digital format	Post Occupancy Evaluations to include the state of repair and output of technologies/equipment
	Identify key and relevant Experts	Define roles and responsibilities						Prepare and affix appropriate, legible and understandable signage at relevant positions	On-going life-cycle review of facility
	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM

Lexicon PM – Project Manager or Any Client's Professional Rep; ARC – Architect; FM – Facilities Manager; M&E – M&E Engineer; SPE – Specialist Engineer, e.g., Renewable Energy Tech. Expert; CON – Contractor; O&M – O&M Editor; MAN - Manufacturer

By RIBA Plan 2013, stages 1 – 4 Output can be used for procurement, and stages 4, 5 & 6 activities may occur concurrently

Figure 8.14: Operability and Maintainability Integrated Design and Construction Process Model – Overall Framework

Similar to figure 8.13, figure 8.15 describes how the maps describing the detailed operability and maintainability tasks were laid out and the flow of activities.

The Tasks proposed by RIBA Plan of Work 2013 were also provided at the bottom of the map, so readers could appreciate how complementary the OMI Process tasks are to the RIBA's. Detailed tasks of the stages are described on figure 8.16 – 8.24.

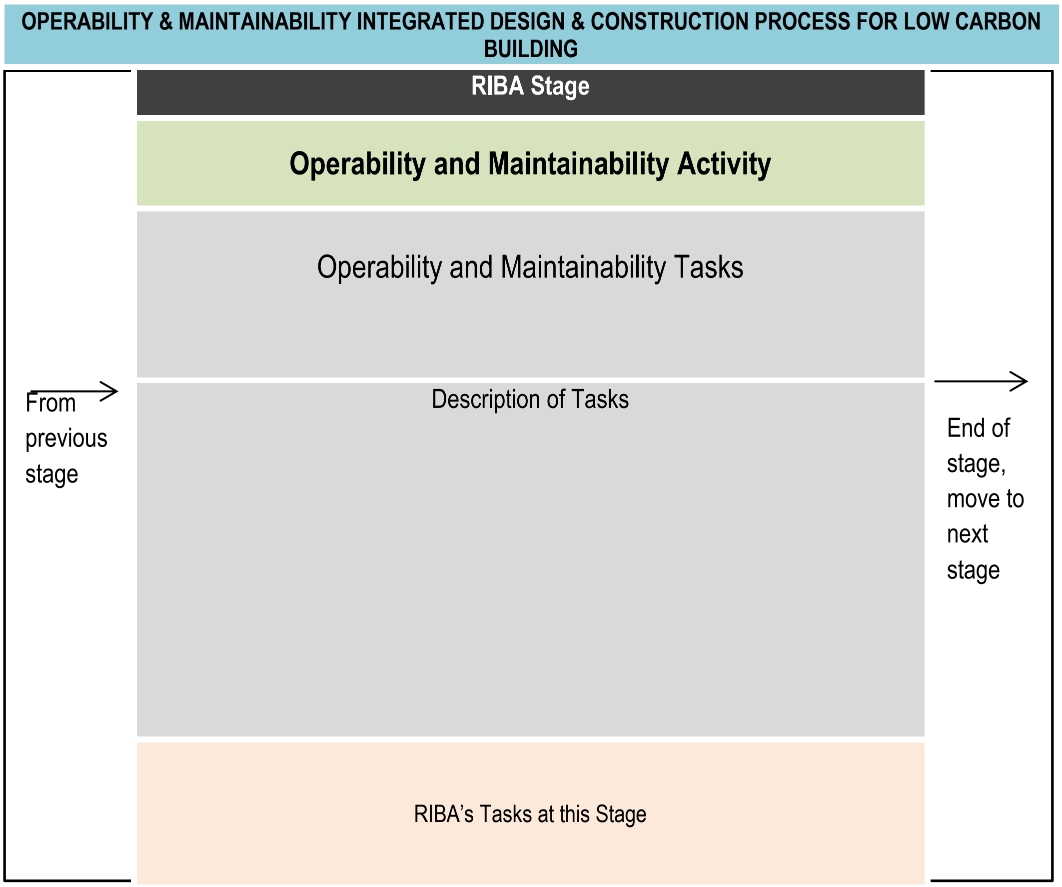


Figure 8.15: Layout of the Different Components of the Operability & Maintainability Process Model as Represented in figures 8.16 – 8.24

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

Start →

Stage 0: Demonstrating the Need

Explore Scope for Operability & Maintainability

Establish Client's specific requirements including need for specific low carbon strategy	Identify Key O&M performance Objectives including life expectancy	Identify any benefits/limitations including Health & Safety, legislation & policy, incentives, risks, etc.	Identify key and relevant Experts
+ Client to establish need for the specific project + Client to also establish any aspiration/incline towards any specific low carbon strategy	+ Identify any operational and maintenance performance target required + Specify client's business case that may affect operation and maintenance of facility + Specify any existing client's maintenance policy + Specify the life expectancy target for the project	+ Identify any specific benefits arising from the use of any specific technology + Identify any government or manufacturers incentives for use of any LC technologies + Identify Government policies (if any) in favour or against the use of any specific LC technologies + Identify any hazards or risks; including H&S, associated with constructing and/or operating any specific LC Technologies	+ identify experts with proven track record in operable and maintainable designs, including architectural and M&E designers + Identify experts with proven track record in the application of specific LC technologies in their designs + Identify other relevant experts including O&M manual editors with proven record in better quality manuals

This stage is not included in the RIBA model

(Note: this stage to be integrated in client-led integrated project team)

End of stage move to next stage

Figure 8.16: Detailed Tasks for Exploring Scope for Operability and Maintainability

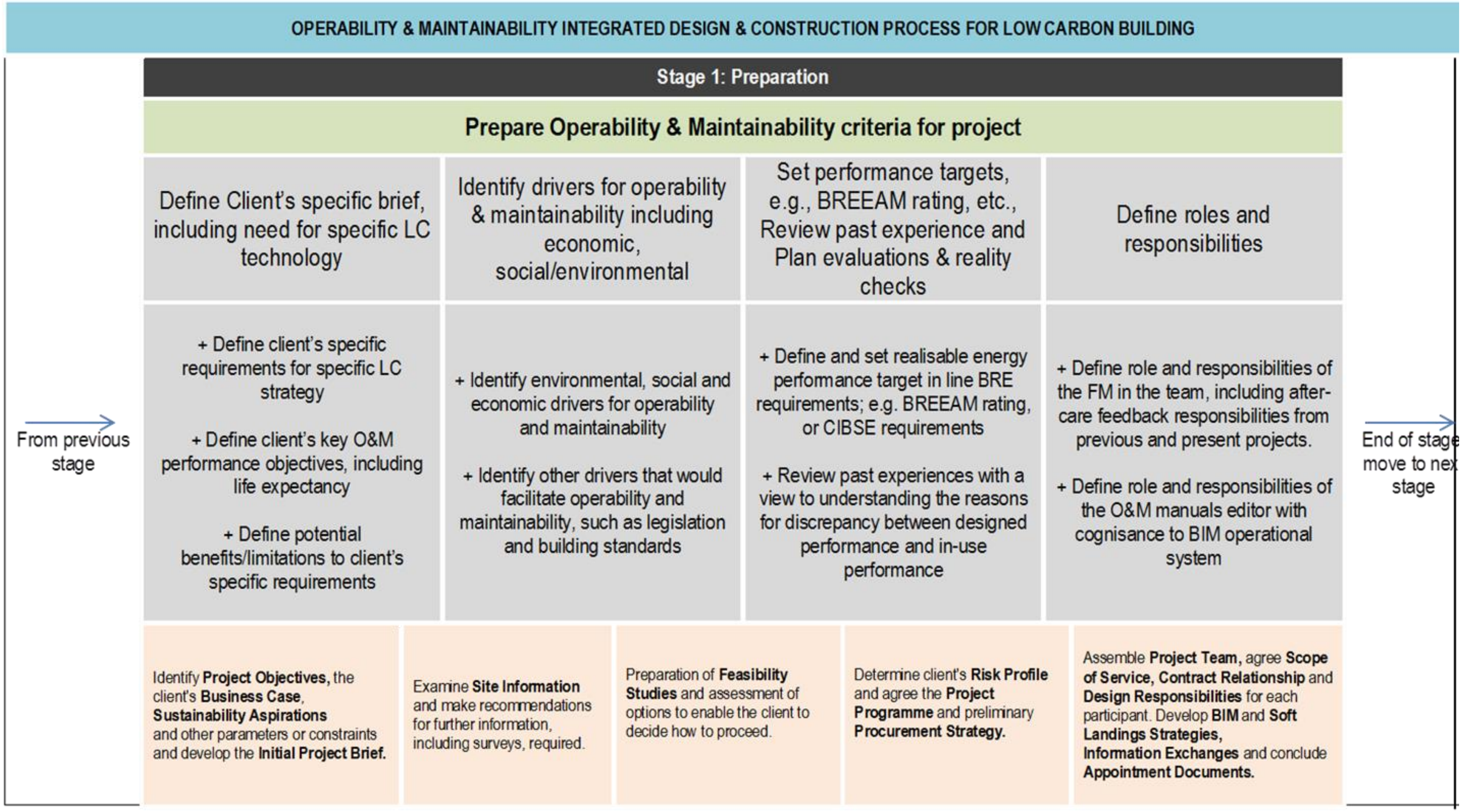


Figure 8.17: Detailed Tasks for Preparing Operability and Maintainability Criteria for Project

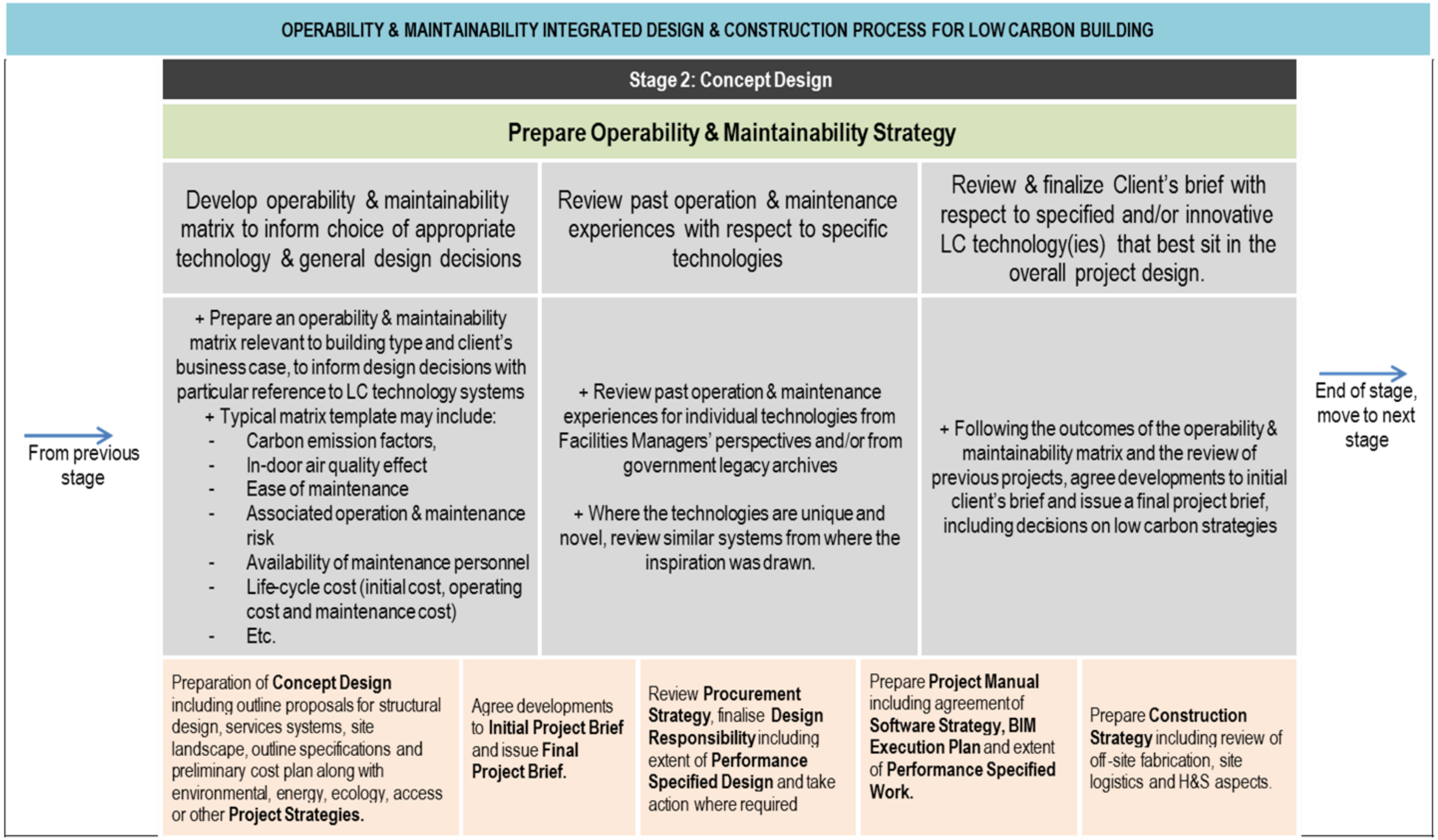


Figure 8.18: Detailed Tasks for Preparing Operability and Maintainability Strategy

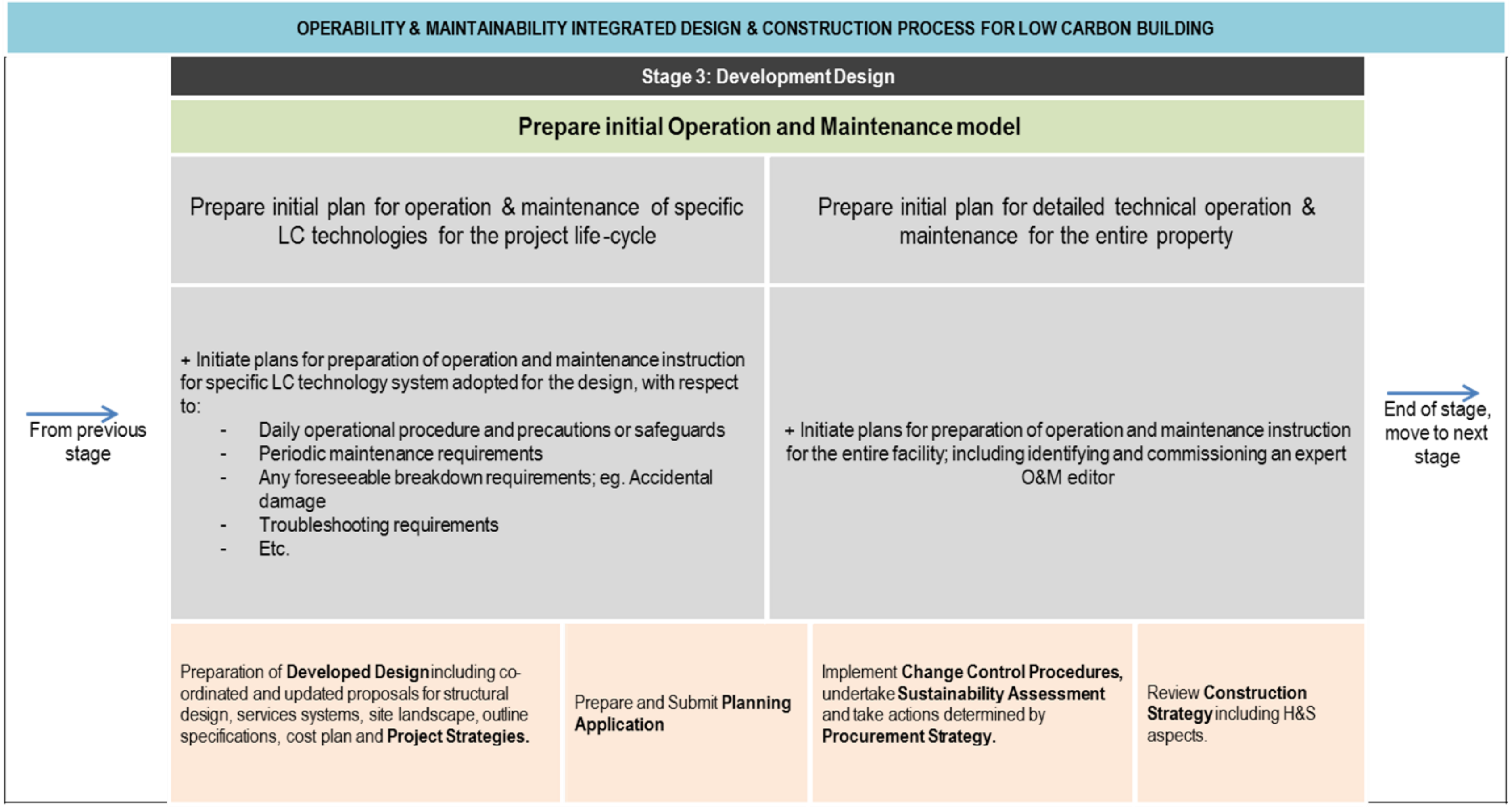


Figure 8.19: Detailed Tasks for Preparing Initial Operation and Maintenance Model

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

From previous stage

Stage 3b:

Life-Cycle (Operability & Maintainability) Proving

Prepare Life-Cycle Analysis of project in line with client's business requirements	Highlight technology/equipment regular operation and maintenance requirements (accessibility, cost & frequency), including life expectancy of the system
+ Prepare detailed whole-life assessment of the entire property in line with client's business case; using the RIBA whole-life assessment methodology for Low Carbon buildings or the BREEAM Assessment methodology + Calculate Energy Performance of building in line with BRE's Energy Performance of Building Directives or any current operative methodology + Prepare Life-Cycle Cost Benefit Analysis for individual LC technology systems, using the Life-Cycle Management Methodology	+ Highlight any periodic maintenance requirements for specific LC technologies adopted indicating methods, costs and frequencies of such maintenance activities + Highlight any availability of trained technicians for any specific LC equipment, where possible + Highlight possible operational precautions and activities that could add to longevity of the system(s) + Highlight foreseeable operational activities and/or environmental factors that could affect the longevity of the system(s) + Highlight feedback from previous projects where the specific LC system(s) were used, through a POE or through Building users survey methodology

This stage is not included in the RIBA Plan

(Note: If the outcome of this stage becomes unsatisfactory, go back to stage 1, 2 or 3 as may be appropriate in the circumstance)

End of stage, move to next stage

Figure 8.20: Detailed Tasks for Life Cycle Proving

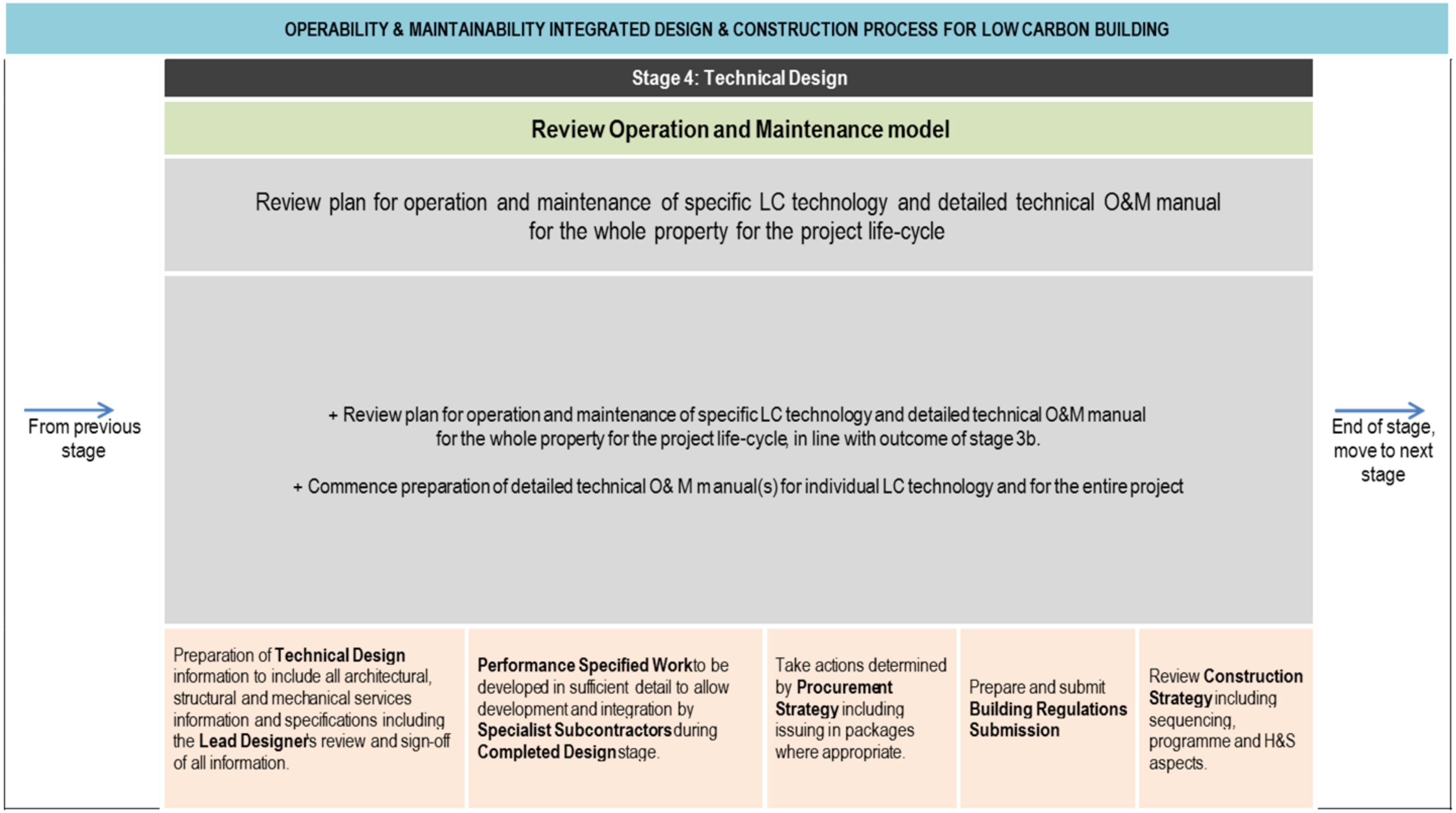


Figure 8.21: Detailed Tasks for Review of Operation and Maintenance Model

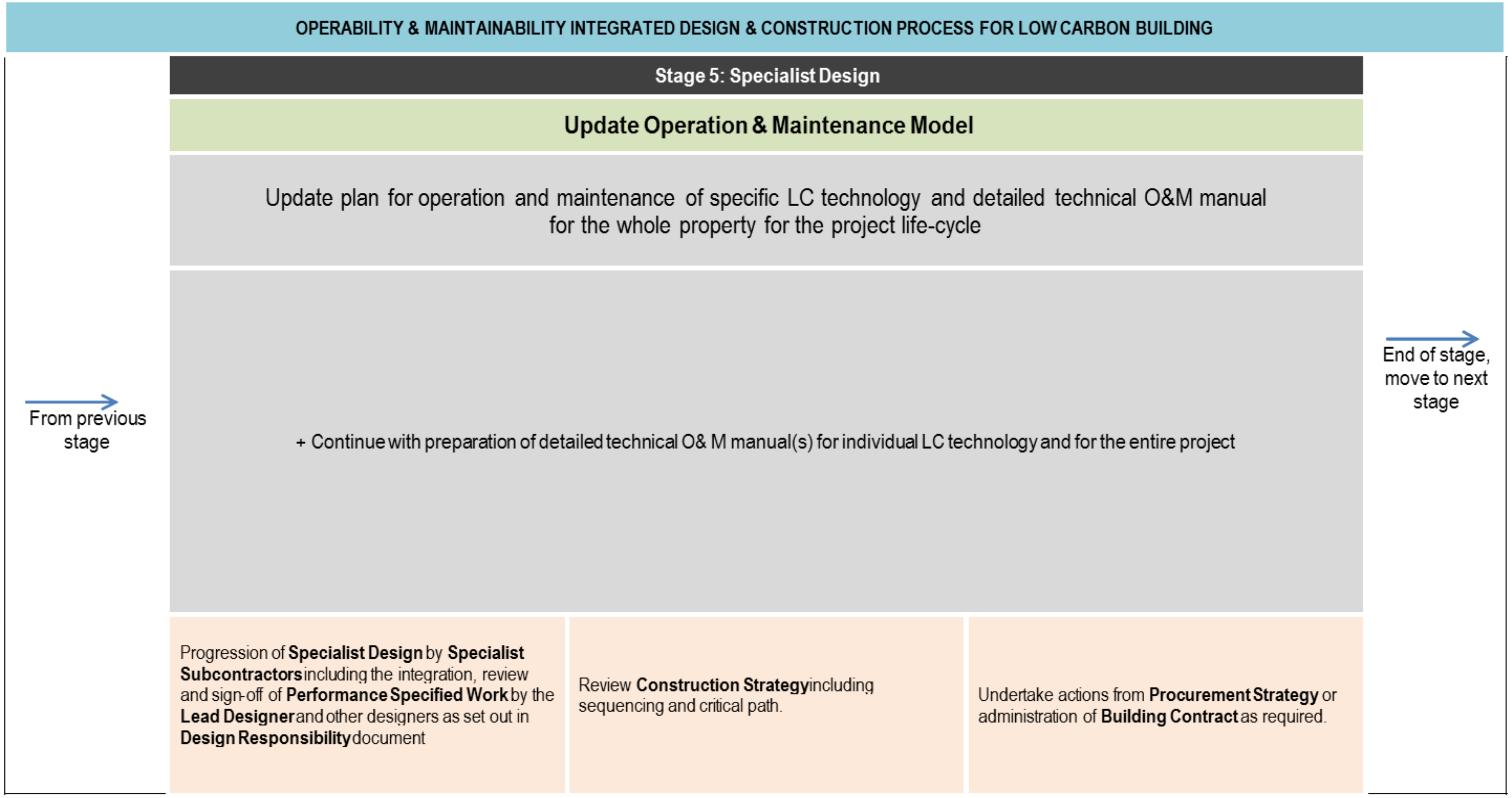


Figure 8.22: Detailed Tasks for Updating Operation and Maintenance Model

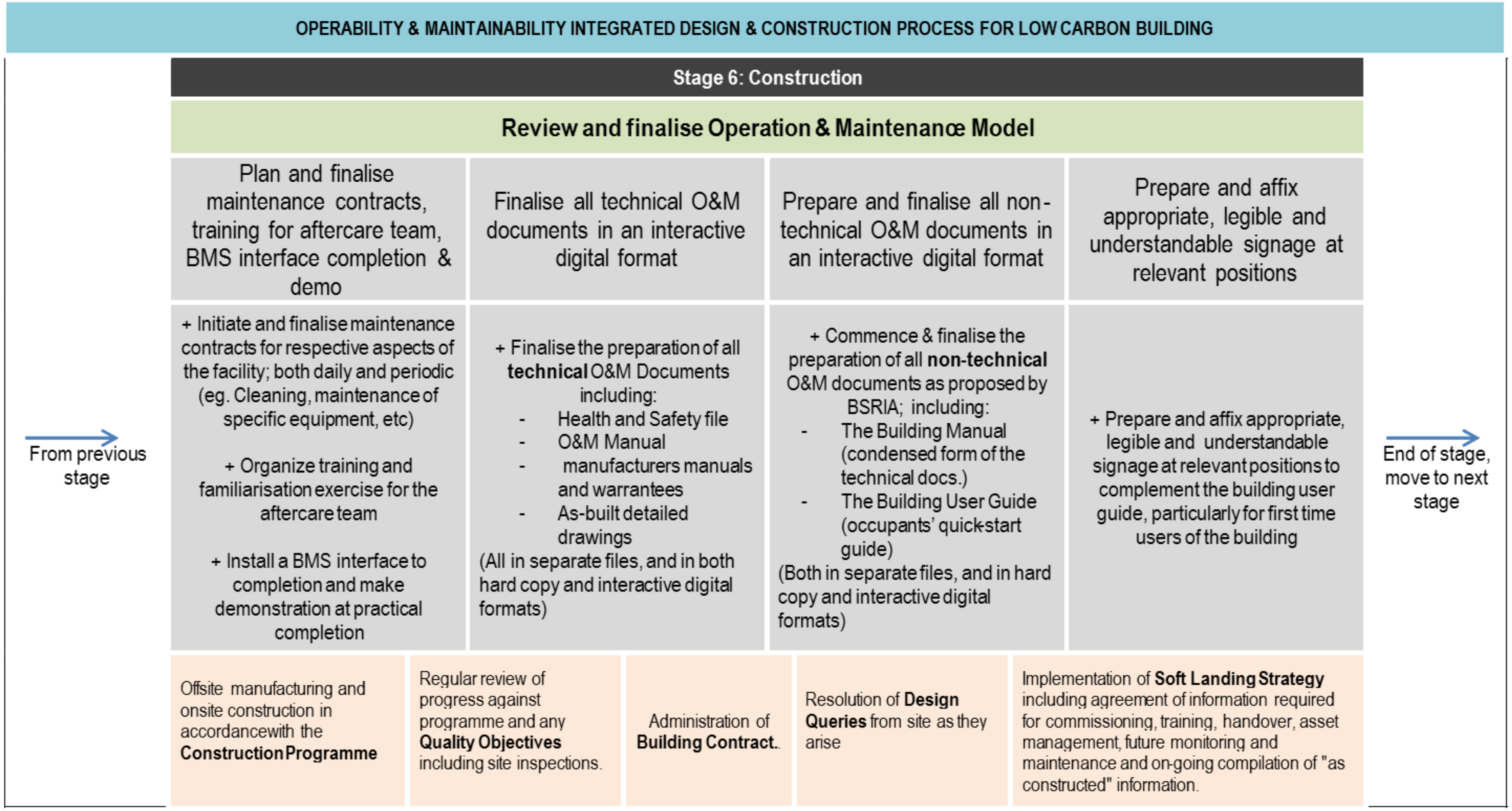


Figure 8.23: Detailed Tasks for Reviewing and Finalising Operation and Maintenance Model

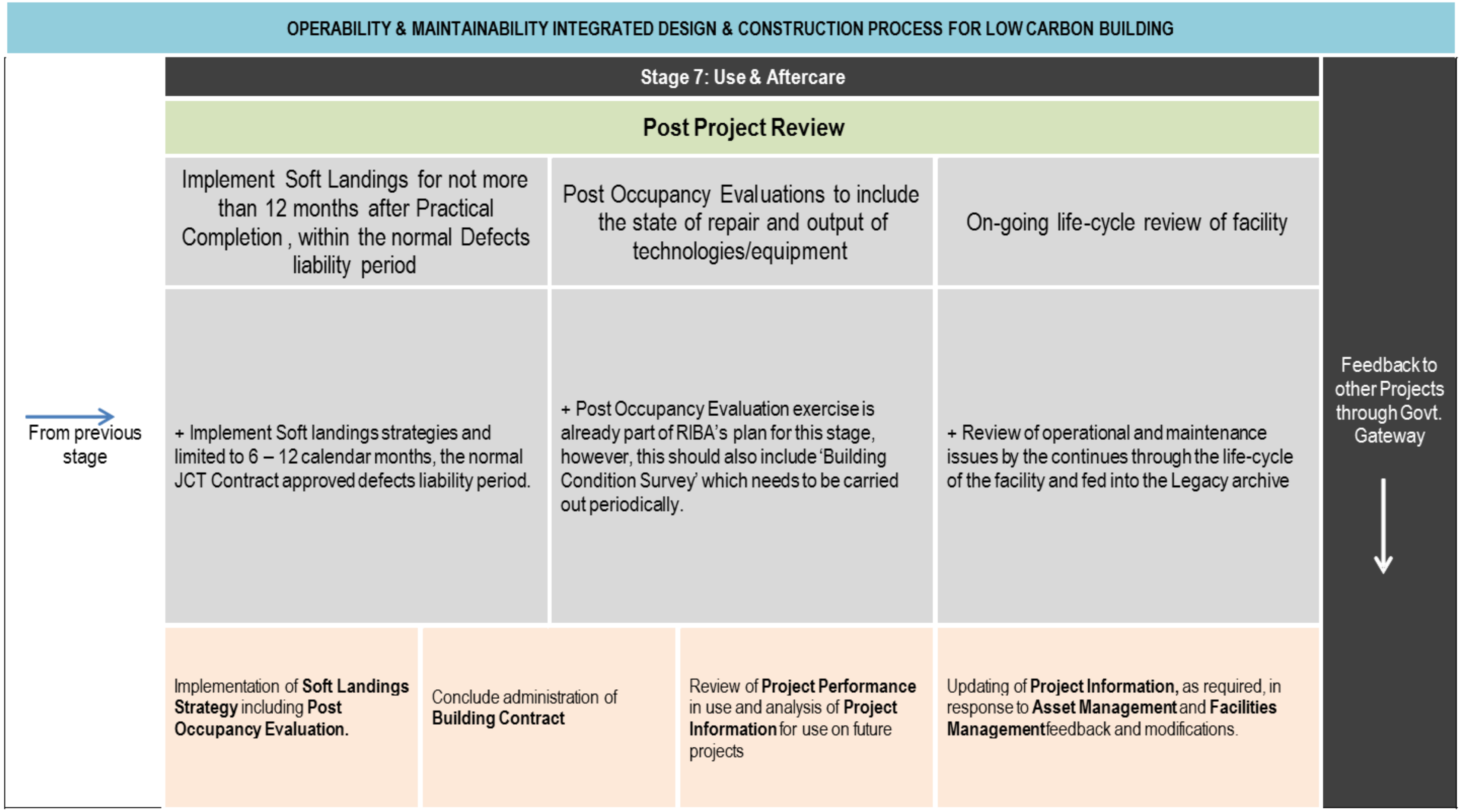


Figure 8.24: Detailed Tasks for Post Project Review

8.5 EVALUATING THE OPERABILITY & MAINTAINABILITY PROCESS MODEL

Section 8.1.2 discusses how the OMI Process Model was evaluated. However, this section discusses in detail; the purpose of the evaluation, composition of the evaluation team, the process and findings from the evaluation exercise. As discussed in section 8.1.2, a Focus-Group approach was adopted; drawing participants from top ranking officials of the UoN Estates Office.

8.5.1 Purpose of the Evaluation

The main purpose of the evaluation is to give validity to the outcome of this research; developing Operability and Maintainability Integrated (OMI) Design and Construction Process Model as a means of ensuring cultural change in the way low carbon buildings (LCBs) are delivered, so as to ensure a best practice approach to operability and maintainability of LCBs in the UK. Specifically, it aims to evaluate the suitability and practicality of using the OMI Process Model as a framework to integrate operability and maintainability into the design and construction process of LCBs in the UK. The objectives set to achieve this purpose are:

- Assessing wider opinions about the need for the OMI Process Model.
- Assessing how well the model could help to ensure that designers give better consideration to O&M issues
- Assessing how effective the model could be in improving the overall design output of LCBs
- Assessing how well the model could ensure efficient operation during the operating life of the project
- Assessing the extent to which the activities and tasks proposed in the model captured and integrated the concept of operability and maintainability

- ❖ Assessing the ability of the model to enhance improvements in the quality of O&M manuals
- ❖ Identifying any improvements to the model that could ensure its effectiveness.

8.5.2 The Focus-Group Population

The focus group population consists of nine (9) high ranking senior members of the UoN Estates Office management staff. In order to keep the anonymity ethics of the University's Research policy, the offices or responsibilities of the participants will not be mentioned, because they could be easily identified by their offices. However, responses from the evaluation forms filled by participants show that about 90% of them, have over 20 years' experience in their respective fields as shown in figure 8.25. Only 1 participant representing 11% have an experience above 10 years, but below and up to 20 years. None has less than years' experience.

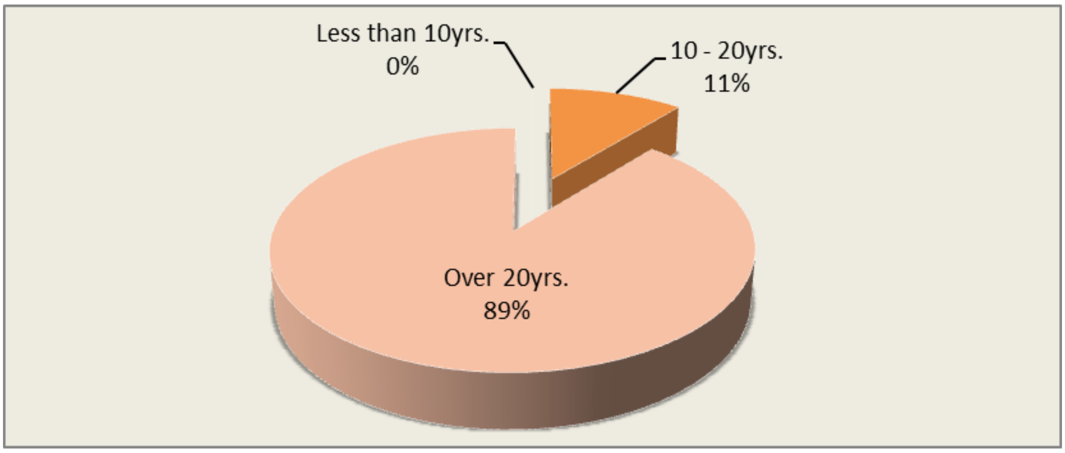


Figure 8.25: Years of Experience of Respondents in the Focus Group

Their respective experiences are as Building Surveyors, Chartered Building Surveyors, Quantity Professionals, Project Managers, Domestic/Facility Managers, Maintenance Managers and Maintenance Engineers.

8.5.3 Evaluation Process

Firstly, the presentation slides were sent to all participants 3 days ahead of the meeting so they could have enough time to go through details and be in position to make appropriate judgement and comments that would impact positively on the exercise.

The focus group meeting held at the Estate Office Committee Room, lasting for roughly 60 minutes. A 15 minute presentation of the slides was made by the researcher; introducing the research aim and objectives, findings and the proposed model. At the end of the 15 minutes presentation, questions and feedback discussions by participants followed, for about 30 minutes. Participants were also requested to complete a feedback evaluation questionnaire at the end of the discussions. One member of the supervisory team for this research was also present to facilitate the exercise. Copy of the Agenda is shown on table 8.1 (although not religiously followed).

Table 8.1: Agenda for the Focus Group Meeting

Process Model Evaluation with the University of Nottingham Estate Office
Date: Friday 22 March 2013
Time: 2.00 – 3.30 pm
Venue: Estate Office Committee Room
Proposed Agenda

Welcome & Introduction	Prof Saffa B Riffat/ Dr Siddig A Omer (supervisors)	- 5 minutes
Presentation	Owaji Frank	- 15 minutes
Questions	Participants	- 15 minutes
Discussions	In Groups	- 10 minutes
Feedback	From Groups	- 15 minutes
Tea & Coffee	Everyone	- 5 minutes
Filling out Evaluation form	Participants	- 5 minutes
Vote of Thanks	Owaji Frank	- 2 minutes

8.5.4 Feedback Evaluation Questionnaire

The feedback Evaluation Questionnaire was handed to the participants after the discussion session. The questionnaire consists of two parts; Part A dealing with the background information about the participant, and Part B consisting of 12 questions (4 – 15) relating to participants' assessment of the proposed process mode. Part B was also divided into two sections; the first section consisted of 7 structured questions answered on a quantitative rating scale, while the second section consisted of 5 open ended questions to allow participants express freely their opinion about the validity of the model. Copy of the questionnaire is attached as Appendix G. In the rating scale questions, participants were expected to rate their opinions on a rating scale of 1 – 5, where 1 = Poor; 2 = Fair; 3 = Good; 4 = Very Good and 5 = Excellent.

Their responses on the questionnaire were collated and keyed into the Survey Monkey tool for analysis.

8.5.5 Results and Discussion

8.5.5.1 Assessing wider opinions about the need for the OMI Process Model:

Although the need for integrating operability and maintainability emanated from conclusions reached through the research findings, but it was necessary to assess the opinions of the subjects being studied in order to validate this finding (respondent validation) as suggested by Silverman (2006).

The participants were asked their opinion about the idea of integrating Operability and Maintainability into the design and construction process of LCBs, indicating their answers on a rating scale of 1 – 5 as described in section 8.6.4. The result returned a rating average of 4.44 out of 5 (89%), indicating that their opinion is midway between very good and excellent. 56% of the respondents see it as an excellent idea (see figure 8.26).

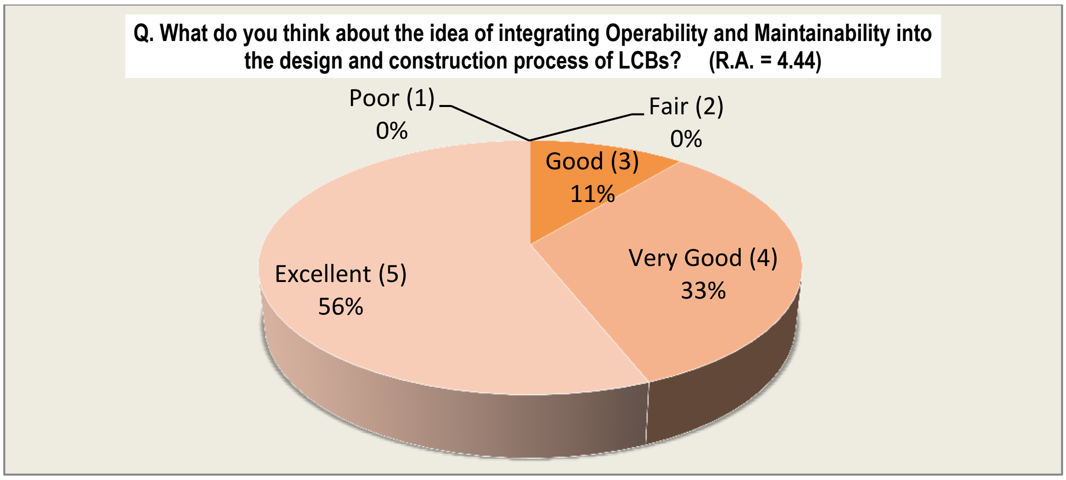


Figure 8.26: Opinions about the idea of integrating Operability and Maintainability into the design and construction process of LCBs

The results and comments presented here convey an indication that the concept of integrating operability and maintainability into the project delivery process of LCBs is a welcome concept; capable of ensuring operability and maintainability of LCBs in the UK.

8.5.5.2 Assessing how well the Model can help to ensure that designers give better consideration to O&M issues: Participants rating of how well the proposed model can help to ensure that LCB designers give better attention to O&M issues returned a rating average of 3.78 out of 5 (76%). This falls between Good and Very Good. All the participants rated the success level of the model to ensure operability and maintainability as Good, Very Good or Excellent as shown on figure 8.27.

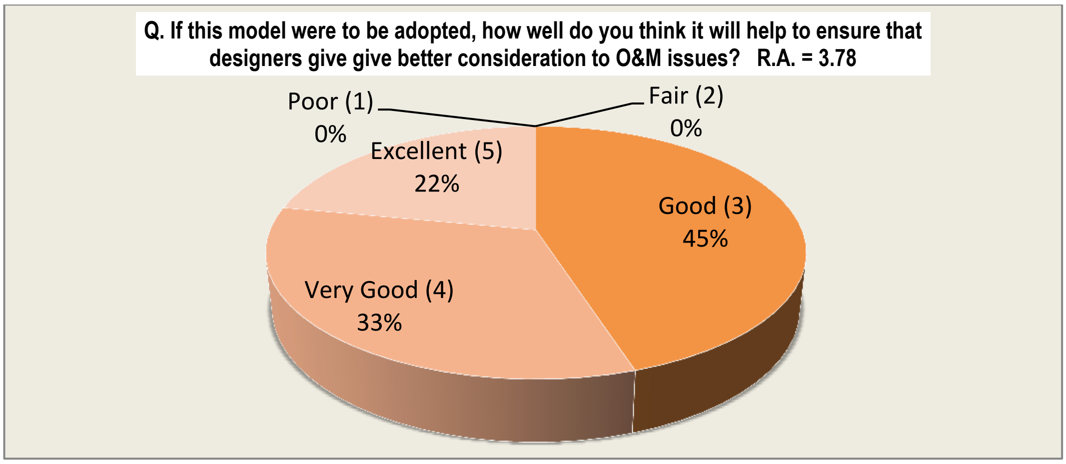


Figure 8.27: Opinions about how well the Model can help to ensure that designers give better consideration to O&M issues

<u>8.5.5.3 Assessing how effective the model could be in improving the overall design output of LCBs:</u> This assessment returned a rating average of 3.22 out of 5 (64%). 78% of the participants rated the perceived effectiveness of the proposed model in ensuring improvement in the overall design output of LCBs as Good, while the rest 22% rated it as Very Good. (See figure 8.28). However, there were some comments calling for improvements of some aspects of the model. For instance, some of the participants believed that with the Design & Build contracts, it might be difficult to apply some aspects of the model. These are discussed further in section 8.6.5.8.

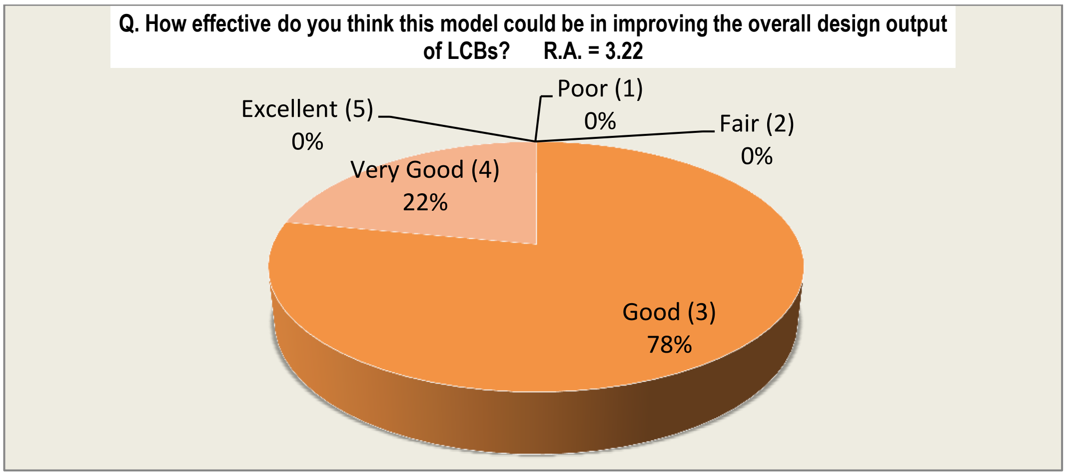


Figure 8.28: Opinions about how effective the model could be in improving the overall design output of LCBs

8.5.5.4 Assessing how well the model could ensure efficient operation:

11% of the participants believed that the proposed model's ability to ensure efficient operation during the project's operating life is excellent, while 33% of rated it as Very Good and another 45% as Good. The remaining 11% (1 participant) rated the model's ability to ensure efficient operation as Fair. Rating average was 3.44 out of 5 (69%); placing the participant average opinion midway between Good and Very Good. (See figure 8.29).

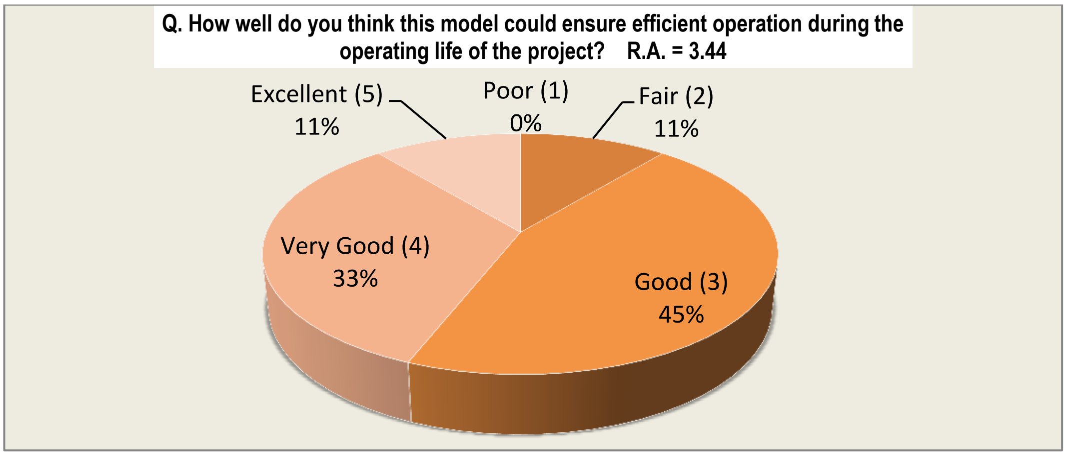


Figure 8.29: Opinions about how well the model could ensure efficient operation

8.5.5.5 Assessing the extent to which the activities and tasks proposed in the model captured and integrated the concept of operability and maintainability:

The participants, haven been well experienced professionals in a team of 'informed client and facilities management body', it was necessary to seek their opinion on how the activities and tasks proposed by the model was able to capture the concept of operability and maintainability, as well as integrating them properly into the design and construction process. The result returned a rating average of 3.22 out of 5 (64%) as shown on figure 8.30. All the participants rated it at either Good or Very Good. This implies that the

O&M activities and tasks are properly seated in the model, although there were few suggestions on how to improve the model.

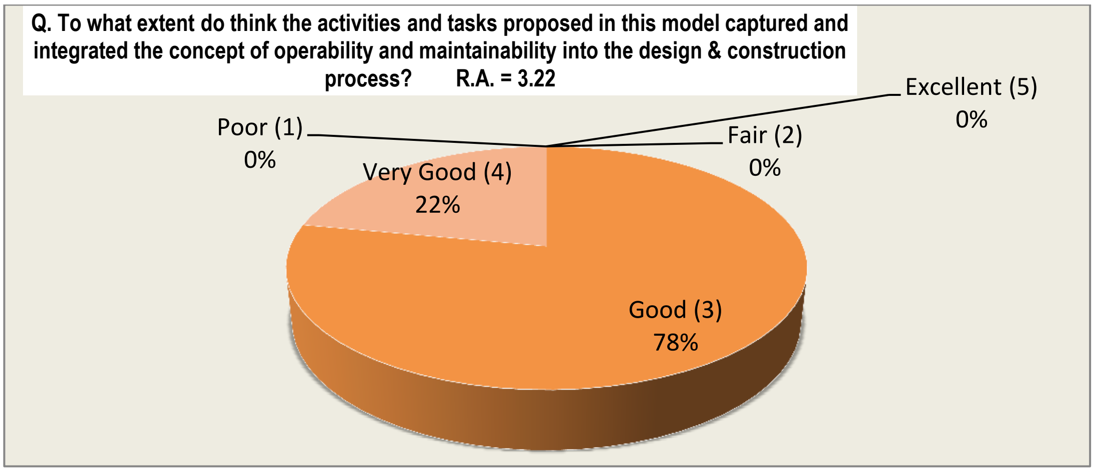


Figure 8.30: Opinions about the extent to which the activities and tasks proposed in the model captured and integrated the concept of operability and maintainability

<u>8.5.5.6 Assessing the Proposal to reduce Soft Landings to One year</u>: Although this is not listed as one of the objectives of the focus group review exercise, it is worthy of discussing. The general view of participants at the review exercise was that it was going to be a Very Good idea to limit the soft landings activities within the normal defects liability period of 12 calendar months. Although there were dissenting opinions here, however the rating average stood at 3.44 out of 5 (69%). See figure 8.31.

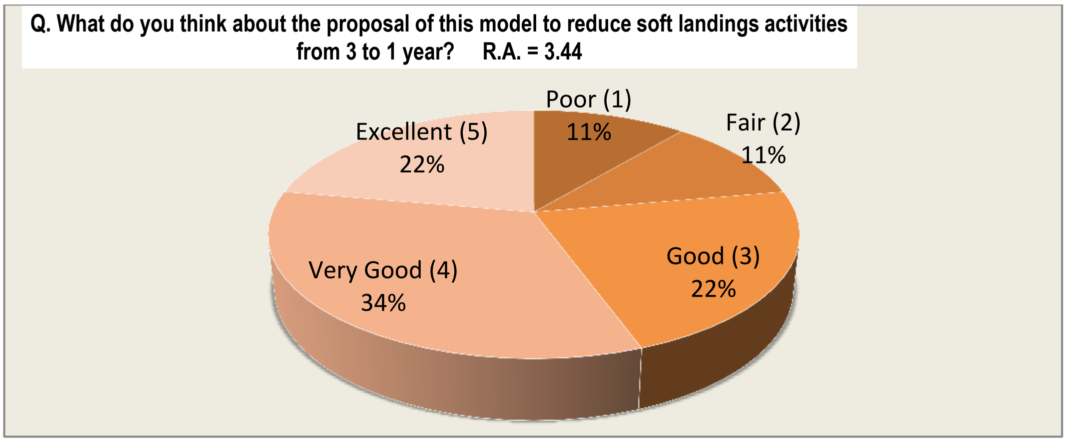


Figure 8.31: Opinions about the Proposal to reduce Soft Landings to One year

<u>8.5.5.7 Assessing the ability of the model to enhance improvements in the quality of O&M manuals:</u> Only 11% representing 1 participant rated the ability of the model to enhance the quality of O&M manuals as Good, all other participants rated it as Very Good, putting the rating average at 3.89 out of 5 (78%). This gives credence to the success of this research in achieving its objectives and aim.

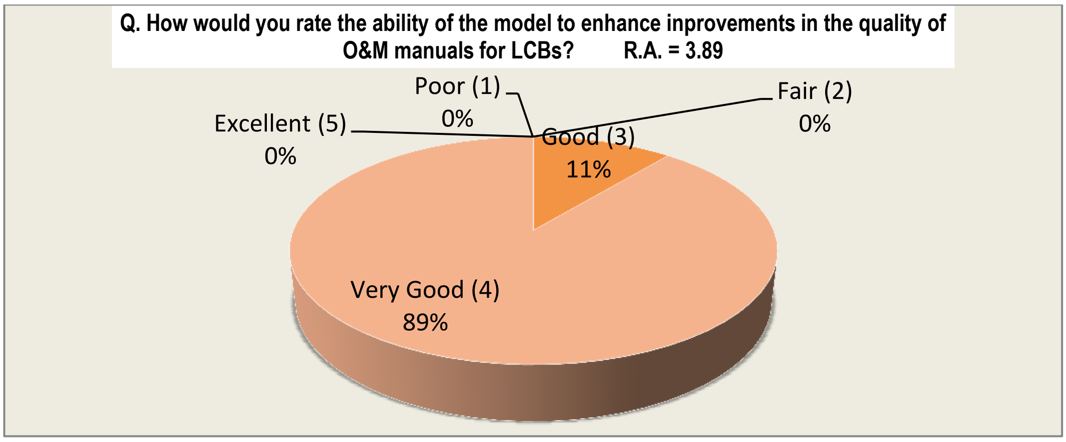


Figure 8.32: Opinions about the ability of the model to enhance improvements in the quality of O&M manuals

<u>8.5.5.8 General Comments:</u>

This section summarises the comments noted during the discussion and the open ended questions on the evaluation questionnaire. These comments are categorised under 3 groups: a) Commendations, b) How the Estates Office works and c) Suggestions for improvements.

a) <u>Commendations</u>

1. The integration of stage 3B – life cycle proving was seen as an aspect of building project that has often been neglected, its introduction was commended.

2. The model was seen as providing better assessment and information on requirements for operability and maintainability, and having a potential of improving the aftercare period.
3. The requirement to think about maintenance early was seen to be capable of ensuring that low carbon installations are operated correctly and efficiently.
4. The early influence of FM staff was commended
5. In the words of some of the participants:
   - *"You have followed through a process which would work".*
   - *"It is a good idea".*
   - *"A useful piece of work".*
   - *"A lot of thought has gone into your plan".*
   - *"It should always be done"* (i.e.; integrating operability and maintainability into the design and construction process).
   - *"Good conclusion regards the shortfall within the existing processes to deal with the maintenance issues raised by the introduction of new low carbon technologies".*

b) <u>How the Estates Office Works</u>

1. The Estates routinely use the Design & Build contracts, and from the very first design team meeting, O&M and CDM Coordinators are usually present. They work through with the various design team members on issues of constructability, demountability, access, etc.
2. At every site meeting during construction, health & safety, CDM and O&M elements of the project are routinely brought in. As such, by practical completion the O&M manual is 95% complete.

3. At the Estates, the O&M manuals are usually delivered in compact discs, fully hyperlinked; linking all technical descriptions to the As-built drawings, etc. The manuals also come in hard copies, a summary manual with key information, simple fire strategy and a user guide.
4. Due to the use of the D&B contract system used by the Estates Office, it is not going to be possible to implement Life-Cycle Proving at stage 3B because by this time most of the low carbon elements are not yet specified. Equipment are specified and installed during construction; quotes for the equipment come with detailed specifications and the maintenance implications, which go into the O&M manuals.

c) Suggestions for improvements

1. There were opinions that the individual low carbon technologies are fairly simple in their own individual ways, but when they connected with traditional systems or sometimes when buildings are interlinked, they become a little more intricate. Suggesting that designers at design stage may not fully understand how these work.
2. Possible application of this approach to D&B projects where elements are only identified during construction phase.
3. More details required for 'Life-Cycle Proving'; needs to be brought to the construction stage for D&B projects.
4. Consideration for types of contracts and types of clients.
5. Introduce FM Plan at the planning stage
6. Development of improved co-ordination between contractor and client on maintenance requirements during construction phase to ensure that variations on construction phase design elements are evaluated and agreed upon to ensure maintenance resource requirements are assessed and accepted by the client and achievable by the client.

7. Practical testing of the facilities straight after completion of the building to ensure compliance ideally by an independent commissioning body, building controls.

8.6 THE MODIFIED PROCESS MODEL

Based on the outcome of the evaluation exercise, amendments were made to the proposed OMI Process Model.

One key point that was stressed by majority of the participants in the evaluation exercise was the need for life-cycle testing activity to be flexible in order to be adaptable to design and build projects as is practiced in the University Estates Office. This flexibility deemed to have been taken care of by the RIBA Plan of Work, on which the OMI Process Models builds. However, for emphasis and clarity, the note quoted below was added to the Overall Framework spread sheet in figure 8.33 and figure 8.34:

> *'Life-Cycle Proving Process is advisable to begin after stage 3 (Development Design) and continue after stages 4 and 5. However, depending on the Procurement Strategy it can be started at any appropriate stage, provided it is before the individual technologies are installed'.*

Figure 8.36 also highlighted RIBA's statements for Procurement, Programme and Planning which allows for flexibility.

The need to *'Review life-cycle proving tasks'* at stages 4 and 5 was also seen to be necessary for the purpose of ensuring that the additional design inputs made during technical and specialist design stages conforms with the life-cycle expectancy of the project. This is reflected on figures 3.35 and 3.36.

On figure 8.35, the task *'Undertake commissioning and Testing Procedure'* was included as an operability and maintainability tasks during *Stage 6 – Construction.* This was in response to Suggestions for Improvements, s/n. 7 in section 8.6.5.8c. The description of this task was highlighted on the task description page in figure 8.39; requiring the commissioning and testing to be carried out by a commissioning body, independent of the main contractor.

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING									
	Pre-Project Stage		Pre-Construction Stages					Construction Stage	Post-Construction Stage
RIBA (Sub-Process) Stages	Stage 0	Stage 1	Stage 2	Stage 3	Stage 3b	Stage 4	Stage 5	Stage 6	Stage 7
	Demonstrating the Need	Preparation	Concept Design	Development Design		Technical Design	Specialist Design	Construction	Use & Aftercare
Operability and Maintainability Activities	Explore Scope for Operability & Maintainability	Prepare Operability & maintainability criteria for Project	Prepare operability and maintainability strategy	Prepare initial Operation and Maintenance Model	Life-Cycle (Operability & Maintainability) Proving	Review Operation & Maintenance Model	Update Operation & Maintenance Model	Review & Finalise Operation and Maintenance Model	Post-Project Review
Key Process Actors	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	CLT ARC FM M&E
	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN
Operability and Maintainability Tasks	Establish Client's specific requirements including need for specific LC technology	Define Client's specific brief, including need for specific LC technology	Develop operability & maintainability matrix to inform choice of appropriate technology & general design decisions	Prepare initial plan for operation & maintenance of specific technologies for the project life-cycle	Prepare life-cycle analysis of project in line with client's business requirements	Review plan for operation & maintenance of specific LC technologies and detailed technical O&M manual for the project life-cycle	Update plan for operation & maintenance of specific LC technologies and detailed technical O&M manual for the project life-cycle	Finalise all technical O&M documents in an interactive digital format	Implement Soft Landings for not more than 12 months after Practical Completion within the normal Defects liability period
	Identify Key O&M performance Objectives including life expectancy	Identify drivers for operability & maintainability including economic, social/environmental	Review past operation & maintenance experiences with respect to specific technologies					Prepare and finalise all non-technical O&M documents in an interactive digital format	
	Identify any benefits/limitations including Health & Safety, legislation & policy, incentives, risks, etc.	Set performance targets, e.g. BREEAM rating, etc. Review past experience and Plan evaluations & reality checks	Review Client's brief with respect to specified and/or innovative LC technology(ies) that best sit in the overall project design.	Prepare initial plan for detailed technical operation & maintenance for the entire property	Highlight technology/equipment regular operation and maintenance requirements (accessibility, cost & frequency), including life expectancy of the system			Prepare and affix appropriate, legible and understandable signage at relevant positions	Post Occupancy Evaluations to include the state of repair and output of technologies/equipment
	Identify key and relevant Experts	Define roles and responsibilities						Plan and finalise maintenance contracts, training for aftercare team, BMS interface completion & demo	On-going life-cycle review of facility
								Undertake commissioning and testing Procedure	
	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM

Lexicon	PM – Project Manager or Any Client's Professional Rep; ARC – Architect; FM – Facilities Manager; M&E – M&E Engineer; SPE – Specialist Engineer, e.g., Renewable Energy Tech. Expert; CON – Contractor; O&M – O&M Editor; MAN - Manufacturer	By RIBA Plan 2013, stages 1 – 4 Output can be used for procurement, and stages 4, 5 & 6 activities may occur concurrently

Life-Cycle Proving Process is advisable to begin after stage 3 (Development Design) and continue after stages 4 and 5. However, depending on the Procurement Strategy it can be started at any appropriate stage, provided it is before the individual technologies are installed.

Figure 8.33: Revised Version - Operability and Maintainability Integrated Design and Construction Process Model – Overall Framework

	Pre-Project Stage		Pre-Construction Stages					Construction Stage	Post-Construction Stage
RIBA Outline Plan of Work 2013 Stages	**Stage 0**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 3b**	**Stage 4**	**Stage 5**	**Stage 6**	**Stage 7**
	Demonstrating the Need	Preparation	Concept Design	Development Design		Technical Design	Specialist Design	Construction	Use & Aftercare
Operability and Maintainability Integrated Phases	**Explore Scope for Operability & Maintainability**	**Prepare Operability & maintainability criteria for Project**	**Prepare operability and maintainability strategy**	**Prepare initial Operation and Maintenance Model**	**Life-Cycle (Operability & Maintainability) Proving**	**Update Operation & Maintenance Model**	**Update Operation & Maintenance Model**	**Review & Finalise Operation and Maintenance Model**	**Post-Project Review**
Life-Cycle Proving Strategy				Life-Cycle Proving Process is advisable to begin after stage 3 (Development Design) and continue after stages 4 and 5. However, depending on the Procurement Strategy it can be started at any appropriate stage, provided it is before the individual technologies are installed.					
RIBA 2013 Procurement Statement		The stage 1, 2, 3 and 4 outputs may be used for tendering and contract purposes depending on the **Procurement Strategy** as influenced by the clients **Risk Profile**, time, cost and quality aspirations and how **Early Contractor Involvement** and **Specialist Subcontractor** input is to be undertaken.							
RIBA 2013 Programme Statement						Stage 4, 5 and 6 activities may occur concurrently depending on the Procurement Strategy. Work may also be undertaken in packages to facilitate its development by Specialist Subcontractors. Early package procurement may also occur during stage 3 depending on the procurement route. The Project Programme should set out the timescale for these overlapping design and, where appropriate, construction stage.			
RIBA 2013 Planning Statement			Planning Applications typically be made using the stage 3 (Development Design) output, however, certain clients may wish this task to be undertaken earlier. The project or practice specific Plan of Work identifies when the Planning Application is to be made. Certain aspects of the Technical Design may also be required as part of the application or in response to planning conditions.						
Government Gateway	**Information Exchange**								

Figure 8.34: Revised Version - Operability and Maintainability Integrated Stages to RIBA 2013 Stages

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

From previous stage →

Stage 4: Technical Design

Update Operation and Maintenance model

Update plan for operation and maintenance of specific LC technology and detailed technical O&M manual for the whole property for the project life-cycle

+ Review plan for operation and maintenance of specific LC technology and detailed technical O&M manual for the whole property for the project life-cycle, in line with outcome of stage 3b.

+ Commence preparation of detailed technical O& M manual(s) for individual LC technology and for the entire project.

+ Review Life-Cycle Proving as may be influenced by any changes imputed by the technical design.

Preparation of **Technical Design** information to include all architectural, structural and mechanical services information and specifications including the **Lead Designer**'s review and sign-off of all information.	**Performance Specified Work** to be developed in sufficient detail to allow development and integration by **Specialist Subcontractors** during **Completed Design** stage.	Take actions determined by **Procurement Strategy** including issuing in packages where appropriate.	Prepare and submit **Building Regulations Submission**	Review **Construction Strategy** including sequencing, programme and H&S aspects.

End of stage, move to next stage →

Figure 8.35: Revised Version – Stage 4 Tasks Description

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

Stage 5: Specialist Design

Update Operation & Maintenance Model

From previous stage

Update plan for operation and maintenance of specific LC technology and detailed technical O&M manual for the whole property for the project life-cycle

+ Continue with preparation of detailed technical O& M manual(s) for individual LC technology and for the entire project.

+ Review Life-Cycle Proving as may be influenced by any changes imputed by the Specialist design.

Progression of **Specialist Design** by **Specialist Subcontractors** including the integration, review and sign-off of **Performance Specified Work** by the **Lead Designer** and other designers as set out in **Design Responsibility** document	Review **Construction Strategy** including sequencing and critical path.	Undertake actions from **Procurement Strategy** or administration of **Building Contract** as required.

End of stage, move to next stage

Figure 8.36: Revised Version – Stage 5 Tasks Description

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

Stage 6: Construction

Review and finalise Operation & Maintenance Model

From previous stage →

Finalise all technical O&M documents in an interactive digital format	Prepare and finalise all non-technical O&M documents in an interactive digital format	Prepare and affix appropriate, legible and understandable signage at relevant positions	Plan and finalise maintenance contracts, training for aftercare team, BMS interface completion & demo	Undertake commissioning and testing Procedure
+ Finalise the preparation of all **technical** O&M Documents including: - Health and Safety file - O&M Manual - manufacturers manuals and warrantees - As-built detailed drawings (All in separate files, and in both hard copy and interactive digital formats)	+ Commence & finalise the preparation of all **non-technical** O&M documents as proposed by BSRIA; including: - The Building Manual (condensed form of the technical docs.) - The Building User Guide (occupants' quick-start guide) (Both in separate files, and in hard copy and interactive digital formats)	+ Prepare and affix appropriate, legible and understandable signage at relevant positions to complement the building user guide, particularly for first time users of the building	+ Initiate and finalise maintenance contracts for respective aspects of the facility; both daily and periodic (eg. Cleaning, maintenance of specific equipment, etc) + Organize training and familiarisation exercise for the aftercare team + Install a BMS interface to completion and make demonstration at practical completion	Undertake facilities commissioning and testing by a commissioning body, independent of the main contractor

Offsite manufacturing and onsite construction in accordance with the **Construction Programme**	Regular review of progress against programme and any **Quality Objectives** including site inspections.	Administration of **Building Contract.**.	Resolution of **Design Queries** from site as they arise	Implementation of **Soft Landing Strategy** including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and on-going compilation of "as constructed" information.

End of stage, move to next stage →

Figure 8.37: Revised Version – Stage 6 Tasks Description

8.7 The OMI Model and the RIBA Plan of Work 2013

The proposed OMI model was developed using the RIBA Outline Plan of Work 2013 as proposed for the Consultative Forum. It recognises the widespread adoption of the RIBA model for execution of construction projects in the UK since 1963, and its flexibility for adaptation to varying procurement routes. It also identifies the RIBA model as the most recent design and construction process models, at least in the UK, at the time of this study. However, issues of operability and maintainability were not addressed in the proposed RIBA model at the time of consultation. It covered 7 stages of work as shown on Appendix D.

It is worthy of note however, that the final published version of the RIBA 2013 Plan of Work presented to the stakeholders forum on June 26, 2013. Incorporated some key elements of the OMI Process Model which has already been presented for evaluation/validation on 22 March 2013, and writing-up of the thesis was near completion already by June. See Appendices H and J. Some of the common elements include:

1. Stage 0; which was absent in the RIBA model on appendix D was adopted for the final published model on appendix J. While the OMI model referred to the stage as 'Demonstrating the Need', RIBA referred to it as 'Strategic Definition'.
2. The RIBA final version also incorporated tasks for maintenance and operational strategy in stages 2, 3 and 4; which was not included in the consultation version that provided basis for the development of the OMI model.

The possibility that this research may have influenced the RIBA published Plan of Work cannot be overlooked, as the online questionnaire for this research was published on RIBA's knowledge communities blog (see Appendix K). Questionnaires and invitation for interviews were also sent individually to key members of RIBA and the ACA. The invitations were usually accompanied by a brief description of the research. It is not unlikely that their inputs to the review committee may have been influenced by the introductory statement of this work.

Lastly, that RIBA incorporating elements of operation and maintenance into her final Plan of Work suggests that the need to boldly introduce operability and maintainability into the main stream of design for low carbon buildings can no longer be swept under the carpet. This therefore indicates that the OMI model excels.

8.8 CHAPTER CONCLUSION

This chapter has described the approach adopted in this study to develop a model that integrates operability and maintainability into the design and construction process of low carbon buildings in the UK, which it has referred to as *'OMI Design & Construction Process Model'*. It uses the proposed RIBA 2013 model as a base, also taking reference from other construction process models; the Process Protocol, Deconstruction Process Model, Soft Landings Framework and the UoN Estates Office Model. Lessons were also drawn from the New Product Development (NPD) process in the manufacturing industries, and in line with the Government Construction Strategy 2011 and the Building Regulations Part L. The chapter also reported the evaluation process undertaken to validate the model.

The OMI Design and Construction Process Model is an innovative framework initiated to fill the gap created by insufficient attention to operation and maintenance consideration in the delivery process of LCBs, which has often resulted in continued client dissatisfaction with the general performance of low carbon buildings at their operational stage. The evaluation results indicate that:

i) The concept of integrating operability and maintainability into the project delivery process of LCBs was seen as a welcome concept; capable of ensuring operability and maintainability of LCBs designs. The evaluators rating of the concept came to nearly 90%.
ii) The success level of the proposed model in ensuring operability and maintainability of LCB designs was rated at about 76%
iii) The model's ability to improve the overall design output of LCBs was rated at 64%
iv) The ability of the model to ensure that LCBs are operated efficiently during their operating life was rated at 69%

v) Also, the evaluators' rating of the ability of the model to enhance improvements in the quality of O&M manual was 78%.

On a general note, the model was seen as a good resolution to the shortfall within the existing processes, to deal with the issues raised by the introduction of new low carbon technologies. Its practicability is demonstrated by the evaluation exercise availed by Principal Officers of The University of Nottingham Estates Office who have within the last few years been consistently involved with the procurement and management of LCBs within her 7 campuses in the UK and overseas.

Hence the proposed OMI Design and Construction Process Model holds out valuable potential of supporting the desired cultural shift in work attitudes and thinking on the part of both clients and designers in the way LCBs are delivered. It is also capable of meeting the industry's yearnings for efficiency in LCBs operation. The model also holds the potential of filling in the space; 'Suggested Key Support Tasks' provided for in the revised RIBA Plan of Work 2013. By these the research excels.

Chapter 9:

SUMMARY AND CONCLUSIONS

9.0 INTRODUCTION

The purpose of this chapter is to summarise the findings of this research and assessing how the research aim was achieved. The research aim was to explore how best the operation and maintenance challenges of low carbon buildings can be minimised with the use of an effective building operation and maintenance manuals regime within the current practices in the building delivery process in the UK.

The chapter also discusses the conclusions reached and how this research contributes to knowledge as well as the opportunities it availed for future research work.

9.1 RESEARCH SUMMARY

The research was impelled by the growing concern of issues of low carbon buildings operation and maintenance, amongst industry stakeholders in the face of climate change and its realities. Another factor was the perceived gap between calculated energy performance and the as-built performance which has been linked to information gap existing between the building designers and the end users. Hence suggesting that clients/users of LCBs may not be receiving long-term value for investment, and/or that current processes of LCB delivery do not deliver satisfactory results; therefore calling for change in the way low carbon buildings are delivered, so that they are operated efficiently and maintained long into the future.

The research was accomplished through a multi-method research approach. It adopted the methodological triangulation; an approach involving gathering of data with more than one method. In realising the objectives set for meeting the overall aim of the study, the 'within-method' and 'across-method' methodological triangulation were employed. The methods include qualitative interviews and quantitative surveys as well as an in-depth case study involving quantitative surveys and qualitative interviews and physical evaluation. However, the study began with trying to establish relevance and identifying gaps in knowledge through a review of literature on relevant topics within the research domain.

Besides providing good foundation for the research by highlighting some relevant issues and making the contemporary issues clearer, while highlighting the gaps in knowledge and practice, the literature review also acted in conjunction with the field results (as secondary data) to provide basis for the formulation of the proposed operability and maintainability integrated design and construction process model.

Some of the findings from literature include:

- That building maintenance is an under-researched field; with remarkable growth in the awareness of its importance, but yet to be matched with sufficient research and development.
- To achieve a sustainable maintenance regime, the maintenance operation needs to be thought out from inception of design, and the design solution needs to be influenced by the operation and maintenance considerations.
- By the concept of 'Duty of Care' in the English law of Tort, designers are to take reasonable care to ensure that their clients or third party users do not suffer any foreseeable physical injury or economic loss as a consequence of their omission or negligence.
- That the most appropriate maintainability optimization strategy should be that which employs the principles of 'Right First Time'; tackling it from inception.
- The O&M manual was identified as a vital tool that could be employed to close the perceived gap between designers and end users of LCBs, if properly harnessed.
- That the need to put maintenance at the centre of present day construction reform process was long overdue and that new or refurbished projects needs to work properly and be in continual use.
- House of Commons (HC) reports on PFI indicates that the requirement for buildings being maintained to a high standard over the contract life was supposed to be a key benefit of PFI, yet some hospital Trusts were not satisfied with the maintenance services.
- The HC reports added that there were no mechanisms in place to test the continued value for money of maintenance work during the contract period, and called for need to identify how value for money

test and incentives to improve maintenance could be built into the life of PFI Contracts.

- ❖ A sustainable approach adopted by the UK and other governments of the world to tackle climate change is to ensure that buildings are low carbon from materials and equipment selection to construction and operating mechanisms; encouraging the adoption of what is called 'Clean Technology', 'Green Technology' or 'Low Carbon Technology'
- ❖ A green (low carbon) building needs to be economic to run, simple to maintain and gimmick-free.

Summary of findings from the field studies indicate that it was imperative for designers and their clients to take steps early enough to get the building right at the outset, to avoid the extra costs that would be involved in early replacement of components and unnecessary repairs. It therefore became necessary to put in place a system or process that can facilitate compliance to operability and maintainability in the design output. Some activities necessary for this system as identified from the field results include:

- ❖ Attitudinal change on the part of designers towards maintainability
- ❖ Clients to be made aware of the Operation and maintenance implications of their proposed buildings before they are erected
- ❖ Designers to prove the operability and maintainability of the buildings they have designed, before construction
- ❖ Acknowledge the indispensability of a properly prepared O&M manual as a maintainability tool by
    - Integrating the O&M manual process into the design process
    - Involving O&M manual specialists in the design process
    - Developing a first draft of the manual at the design stage
    - Providing information in a user-friendly and web format

- Separating technical details from users' operation and maintenance guide
- Provide reference to physical examples where specific technologies included in the design may have been used.

The field study identified some common problems with low carbon technologies, particularly with the biomass technology. 100% of the buildings identified in the study that were fitted with biomass technologies all had one issue or the other with the technology. The in-depth case study revealed that the problem was a design issues, slow heat-up time and high running cost. It was proven to be more expensive to run the biomass than using energy from the grid gas.

PVs were also noted to be one of the least challenging LCTs, however, one case indicated a reduction in output due to lack of care and the accumulation of dust and bird droppings. This was also confirmed from literature sources as a common problem with PVs.

There were difficulties recorded in finding service personnel for some LCTs, particularly, Ground Source Heat Pumps. The Lake source freezes at lower temperatures when they are most needed.

The case study also illuminated the facts that O&M manuals within the current practices in the UK, lack the needed details that could aid effective operation and maintenance, and they contain too many technical details that render them too difficult to use.

Part L of the building regulation for England and Wales requires that owners of buildings be provided with suitable set of operation and maintenance instructions aimed at achieving economy in use of fuel and power in a way that householders can understand.

All the above findings suggested the need to introduce some elements that could enhance the efficient operation and maintenance of low carbon buildings, early in the building delivery process. Hence, the need to propose an innovative design and construction process model.

The proposed 'Operability and Maintainability Integrated (OMI) Design and Construction Process Model uses the RIBA 2013 model as a base, also drawing from other construction process model reviewed, with lessons drawn from the New Product Development process of the manufacturing industries. The Government Construction Strategy and the Building Regulation Part L also provided support for the design of the OMI model.

The proposed model is also capable of serving as a mechanism to test the continued value for money of maintenance work during the contract period, if adopted into the PFI contracting process and other forms of contracting.

The proposed model was evaluated using a Focus Group that draws participants from amongst top management staff of the University of Nottingham Estates Office; who have within the last few years been involved with the procurement and management of LCBs. Summarily the model was adjudged to be practicable. It was described as *"a good solution to the shortfall within the existing processes, to deal with the issues raised by the introduction of new low carbon technologies".*

9.2 CONCLUSIONS

From findings of the research and as highlighted in the Research Summary, it can be deduced that the research concludes as follows:

1. There is need for a cultural or process change in the way low carbon buildings are delivered to end users if the operation and maintenance challenges associated with such buildings needs to be minimised.
2. That there should be in place a process that will cause clients to demand proof of operability and maintainability from their project designers early in the project life, and designers on their own part will be motivated to think through operability and maintainability from design inception.
3. It is also concluded that properly prepared O&M Manuals are indispensable documents in the effective and efficient operation and maintenance of low carbon buildings, since they are not conventional buildings with conventional technologies. It is therefore required that:
   a) O&M manual process be integrated to the design process
   b) O&M manual specialist be involved in the design process
   c) A first draft of the manual be developed at the design stage
   d) Technical details be separated from user operating guide
4. The proposed OMI Design and Construction Process Model is a framework that is capable of ensuring that the operation and maintenance challenges of low carbon buildings are minimised, and can be adapted to any procurement route.

The proposed OMI model was developed to serve as a best practice approach to ensure operability and maintainability of low carbon buildings in the UK. It uses the RIBA Outline Plan of Work 2013 as proposed for the Consultative Forum. It also draws impute from other design and construction process models such as the GDCPP, DPM, CSNP and the manufacturing industry NPD models. However, the RIBA model did not specify details of this task which it referred to as 'Suggested Key Support Tasks'. This suggests that the OMI model can actually fill this gap as it was designed not as a replacement to the RIBA or any other model, but to integrate operability and maintainability tasks into the RIBA Plan of Work. In addition, the OMI model proposes the integration of the O&M manual editors' roles from stage 3.

It is therefore necessary to conclude that the OMI model potentially satisfies the research aim of 'exploring how best the operation and maintenance challenges of low carbon buildings can be minimised with the use of an effective building operation and maintenance manual regime within the current practices in the building delivery processes in the UK.

9.3 CONTRIBUTION TO KNOWLEDGE

The principal contribution of this research to knowledge is that of creating an innovative OMI design and construction process model. Literature sources indicate that the call for building designers to give consideration to operation and maintenance has been age-long. Findings from the research also indicate that designers were required by law to think through maintenance, yet they rarely do it. So this innovative process model introduced by this study will incentivise designers of low carbon buildings to deliver operable and maintainable buildings to their clients; hence, constituting a valid contribution to knowledge.

Secondly, this research has brought to fore the concept of 'Life-Cycle Operability and Maintainability Proving' which does not exist on any construction process model before now. This and other aspects of the OMI Process Model is capable of serving as a mechanism to test the continued value for money of maintenance work during the contract period of PFI projects, including the various forms of Design and Build projects as well as the traditional projects. This also, constitutes a contribution to knowledge.

Thirdly, bringing the O&M manual process into the design process is also a valid contribution to knowledge. By the current practice, O&M editors are usually independent of both design and construction teams, they come in mid-way the construction stage. This research has recommended that they should be part of the integrated design and project themes.

Lastly, this research is very timely; it could not have been undertaken at a better time than now. It started from 2010, seeking how to improve the delivery process of today's buildings in the UK. In 2011, the Government Construction Strategy was launched; aiming to achieve efficient construction delivery. By 2012, when data collection and analysis for this research was at its last lap, the RIBA proposed a review to her 50 year old Plan of Work with a view to improve building delivery processes. By June 2013, when this research was concluding its writing-up phase, a revised version of the RIBA's model was launched. A comparison of the OMI Process Model and the final RIBA Plan of Work 2013 shows a good blend, with possible influence of the data stage for this work on the RIBA model. This therefore concludes that this research is very relevant to the industry's current needs. And by this, the research excels.

9.4 RECOMMENDATIONS FOR FURTHER RESEARCH

Like any other research, the scope, time and resources available for the study was limited, so could not delve into researching other elements which opened up in course of this study. These elements could lend themselves as possible areas for further research.

1. The OMI Design and Construction Process Model was developed as a paper based model like the RIBA Outline Plan of Work, its effectiveness and practicability has also been evaluated by industry practitioners. However, an IT-enabled format could be further developed to enhance wider industry exploration of the potential benefits of the model
2. Further assessment of the effectiveness and practicability of the OMI Design and Construction Process Model can be achieved by using this model to procure a real life project from inception, through design, construction and operation within a couple of years.
3. The research also brought to fore a known problem with roof mounted PVs, which is depreciation in output occasioned by accumulation of dust and bird droppings. Accessing them for periodic cleaning as often required by manufacturers may proof difficult to private home owners. So it is possible to research further how 'the principle of car screen wash and wiper blade can be adopted for periodic cleaning of the PVs.
4. During this research, the biomass technology surfaced as one technology that is more prone to O&M issues. Due to the limitations of the research, it was not possible to explore in detail these issues, and how they could be solved, in order to fully tap the potential benefits the technology. This is another possible area of research uncovered by this study.

Finally, further research on any aspects of the OMI Design and Construction Process Model can enhance its adoptability to mainstream project implementation process.

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Appendices

Appendix A: Graduate School Training Certificate

Appendix B: Faculty Research Ethics Committee Decision/Approval to Data Collection Methods

Appendix C: Interview Data Analysis

Appendix D: RIBA 2013 Plan of Work (Consultation Version)

Appendix E: Generic Design and Construction Process Protocol

Appendix F: University of Nottingham Estates Office Model

Appendix G: Sample of the Evaluation Survey

Appendix H: The Proposed OMI Design and Construction Process Model

Appendix J: Final Published Version of RIBA 2013 Plan of Work

Appendix K: Letter from RIBA affirming the Publishing of the Online Survey Link on the RIBA Knowledge Community Blog

Appendix L: Publications so far in the course of this research

Appendix A

'raining Certificate - University of Nottinghamhttp://www.nottingham.ac.uk/~cczappdv/training/pta/mycertificate.ph...

Certificate printed on: 11th October 2010

The University of Nottingham

Certificate of Attendance

Mr Owajionyi Lysias Frank

Department of Architecture and Built Environment

has completed the following short research training course(s)

Social Media

Further qualitative research
2 training points

Planning your research
1 training point

Introduction to the literature review process
3 training points

Meet the editors (Faculty of Engineering)

'roject managing your PhD or research (a moderated online learning course)
2 training points

Referencing for researchers (an online learning course)
1 training point

Introduction to qualitative research
2 training points

Proposal writing for scientists & engineers
1 training point

Engineering young entrepreneurs scheme (YES)
6 training points

Professor Claire O'Malley
Dean of the Graduate School

Cerficate of Attendance is issued by the Graduate School, University of Nottingham, for attendance at short es offered at the University for research students. 1 training point is equivalent to half a day of tutor contact time or independent study.

10/11/2010 20:43

Appendix B

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator (Richard Adams) from a University of Nottingham email address, or may be completed in paper form and delivered to the Faculty of Engineering Research Office.

Applicant full name: Owajionyi Lysias Frank   Application ID: 2012-31 Frank

Reviewed by:

Name: R.J. Houghton   Date 18/4/12

Signature (paper based only) ……………………………..………………………………………

- [ ] Approval awarded - no changes required
- [x] Approval awarded - subject to required changes (see comments below)
- [ ] Approval pending - further information & resubmission required (see comments)
- [ ] Approval declined – reasons given below

Comments:

To consent form - add that the Pp has the right to withdraw from the study at any time.

This is in case they fill it in and think better of it the next day.

……

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……

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Please note:

1. The approval only covers the participants and trials specified on the form and further approval must be requested for any repetition or extension to the investigation.
2. The approval covers the ethical requirements for the techniques and procedures described in the protocol but does not replace a safety or risk assessment.
3. Approval is not intended to convey any judgement on the quality of the research, experimental design or techniques.
4. Normally, all queries raised by reviewers should be addressed. In the case of conflicting or incomplete views, the ethics committee chair will review the comments and relay these to the applicant via email. All email correspondence related to the application must be copied to the Faculty research ethics administrator.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee

Appendix C

001) C.J. (Very high ranking Executive officer of the University of Nottingham Estate Department)

i	**Professional Background**	Engineer (Chartered)
ii	**Professional Group (according to nature of job)**	Property Owner/Manager
iii	**Professional Group (according to type of organization)**	Academic/Research Body
iv	**Years of Experience**	30
v	**LCBs involved with**	- CSET building in China Campus - Gateway building at Suton Bonington Campus
	Technologies in the building	CSET (details on the Web) Gateway (Straw bale construction, timber external fenestration material
	Any challenges with the techs	-
	Age of building	CSET (About 4yrs); Gateway – Very recent
	Building docs available/how helpful	O&M manuals, H&S files/ very helpful
Vi	**Cost of O&M if it were to be none LCB**	Less by about 20%
vii	**Cost of Construction if it were to be none LCB**	Less
viii	**At what stage should Client be aware of operation and maintenance implications**	Design stage *"At the university we always assign a skilled member of the estate office; project officer to work with the design team and he will use his experience to identify any concern on the proposal as regards maintenance or operational challenges that are reasonable and we have what we call project management group which are responsible for all of the individual projects and we receive regular reports and presentations from the design team and we will use our collective skills also to voice out our opinions on certain proposals if we got reservations".*
ix	**Possible Reasons for the poor reputation of O&M manual**	
x	**If O&M manual is really a necessity for LCBs**	Yes: *"Sometimes some materials and some technologies do need a different approach to the maintenance".* *"Good practice dictates that you should always receive comprehensive operation and maintenance manual for your developments. And even if they are new technologies, the suppliers are still duty bound to provide you with information on how to maintain them".*
xi	**Opinion about O&M regime:**	
	Transfer responsibility of collating to lead designer	
	O&M manual is a potential document that could bridge the gap btw designers and users	
	Integrating the O&M manual Process into the design process could enhance manuals' quality	
	It will be good practice to make	

	1st draft of O&M manual during design	
	Involving O&M specialists at design stage could ensure maintainability	
	Involving O&M specialists could stifle innovations	Agree *"why I don't ask my cleaners for example to impute on the design when you are building or my engineers and direct labour staff who are dealing with repairs and maintenance because they will just ask for everything to be the same as they have been used to and so you will stifle in innovation and technological advancement in building design by always being conservative and always wanting everything to be the same as you've been used to in the past".*
	O&M manual Specialists are not usually involved in the design process	
	Most Architects pay less attention to O&M challenges at design stage	Agree "*There is a school of thought that signature architects pay less attention to the issue of maintenance and operation challenges of the building in use"*
	Need to demonstrate maintainability by the design team	*Q. Considering that every client may not be an informed client, don't you think that if there is a procedure put in place along the procurement route for the design team to show how this building is going to be maintained it will help to solve that maintenance problem?* *A. <u>Yes in theory</u> because that is already an obligation under their appointment and the CDM regulations as in the construction industry also requires designers to think through these things the issue is how well they do this?*
	Other Comments about O&M manual regime	*"I feel that a lot of people don't either receive or don't read and use the operation and maintenance manuals which they should have after the development is completed".* ***Q.*** *Do you have an idea why people don't use them?* ***A.*** *I think it is a skills gap. Here in the university, we have a comprehensive estate department which employs qualified engineers, building surveyors and people with the right skills to provide life cycle support to the facilities. Many people, their core activities does not involve or connected to buildings and they can often be driven to minimum cost, and normally do things when things break or don't work.* *"I think if the O&M manuals are put together properly they should include the entire maintenance requirement throughout the life cycle of that building".*
xii	**General Comments**	*"Again the university is what I would class as informed client because we have some skills in-house, so we should be better than most people".* *"It should be the skills of the design team to make sure that there is a reasonable good practice of maintenance that is built into the building design".* *"At the university we tend to favour in a lot of cases of taking the design to a certain stage, may be stage D or a little further than stage D, but then procuring a contractor under the develop and construct type contract where he is able to come on board and build and add some build-ability expertise into*

		the design, so he can propose alternative materials and some changes as part of the design development process. We found that this the best of both worlds because he will often under his responsibility for development contract which manifests itself in a form of design and build contract that requires him usually to employ in his team architects and engineers whose assess the design information they have been given by the principal designers and final detailing can be improved". *"I think this has to be a balance, if you put too much emphasis on minimizing the maintenance cost, then you will get a very average, potentially poor quality building in terms of or in a very cheap form of curtain edge technology".* *"And preventive maintenance is often much cheaper than reactive one and many studies I think have shown that the cost of preventive maintenance and planned maintenance should be about a third of reactive maintenance".*

002) <u>A.H. (A Representative of Blueprint, an award winning Low carbon property developer in the East Midlands)</u>

i	**Professional Background**	Planning and Development Surveyor
ii	**Professional Group (according to nature of job)**	Property Owner (Client)
iii	**Professional Group (according to type of organization)**	Private Client Organization
iv	**Years of Experience**	-
v	**LCBs involved with**	- No. 1 Nottingham Science Park - Green street in the Meadows - Phoenix Square in Leicester
	Technologies in the building	Mix mode Adiabatic cooling and natural ventilation; Biomass boiler; Al. & Timber composite frames for the windows and curtain walling. Green street – 1st phase timber frame. Phoenix Sq. – Heating problem.
	Any challenges with the techs	+Monitoring and regularly cleaning the biomass pit, the design of the biomass pit allows water getting in. +Cooling system is kind of complex: *"It is still not 100% whether on the hottest days, whether it is better to have the windows closed and just the adiabatic going or whether it is better to have the windows open and the adiabatic. I have had conflicting advice on that".*
	Age of building	About 4yrs (practical completion in 2008)
	Building docs available/how helpful	+O&M Manual – Not helpful +Building Manuals for tenant and another for the Building Manager +BMS
Vi	**Cost of O&M if it were to be**	Less

	none LCB	*"……. it is more complex to run a building like this".*
vii	**Cost of Construction if it were to be none LCB**	-
viii	**At what stage should Client be aware of operation and maintenance implications**	Design stage
ix	**Possible Reasons for the poor reputation of O&M manual**	
x	**If O&M manual is really a necessity for LCBs**	Very Necessary
xi	**Opinion about O&M regime:**	
	Transfer responsibility of collating to lead designer	*"I don't think the design team necessarily understands."*
	O&M manual is a potential document that could bridge the gap btw designers and users	
	Integrating the O&M manual Process into the design process could enhance manuals' quality	Yes *"I think you need someone who understands management and facilities management to come in at design phase and oversee that kind of knowledge transfer process and for them to assemble a manual. I don't think the design team necessarily understands."*
	It will be good practice to make 1st draft of O&M manual during design	
	Involving O&M specialists at design stage could ensure maintainability	Yes *"I don't think the design team necessarily understands. They do care but it is not their primary concern how the building operates after construction. So you need someone with a good understanding of facilities management I would say".*
	Involving O&M specialists could stifle innovations	
	O&M manual Specialists are not usually involved in the design process	
	Most Architects pay less attention to O&M challenges at design stage	Yes *"…….. it is not their primary concern how the building operates after construction".*
	Need to demonstrate maintainability by the design team	
	Other Comments about O&M manual regime	*"….another building we have got in Leicester, Phoenix square. That is quite a complex building sustaining with a lot different users in there and it has quite a complex heating system and we have had a lot of difficulties managing that which more so than this building and that again was through a lack of knowledge being passed on from the design team to the management team".* *"And also you have got the tenants or owners of the apartments who don't know how to use the heating system properly and hot water because they have a thermal store*

		which draws from the central boiler for 24 hours period in a day and it was communicated in their handover pack but probably not in a language that everyone would understand because some people living in there are sort of 75 years old and they are only ever used to having a gas boiler and in some cases they are being hit with quite big bills because they haven't known how to use the system, so again there, I have gone to a company and commissioned a manual all about the heating and hot water system".
xii	**General Comments**	*".....we are undergoing the process of post occupancy evaluation on all of our buildings at the moment".*

003) <u>T.G. (A fellow of the Royal Institution of Chartered Surveyors and a shareholding Director of Inness England; A firm of Chartered Surveyors involved in managing mostly Commercial buildings in the East Midlands</u>

i	**Professional Background**	Building Surveyor (Chartered)
ii	**Professional Group (according to nature of job)**	Facilities Manager
iii	**Professional Group (according to type of organization)**	Private Consulting firm
iv	**Years of Experience**	30
v	**LCBs involved with**	- No.1 Nottingham Science Park
	Technologies in the building	EPC rating – A; High level of Insulation; Double glazed; Adiabatic cooling system; Biomass boiler; Concrete Thermal Mass; Solar PV (retrofitted); Sustainable Urban Drainage system *"When the building was built, it didn't have PV, but they were retrofitted, last year September".*
	Any challenges with the techs	Balancing of the cooling system; Biomass boiler; *"I guess the principal challenge has been, initially, the balancing of system in terms of cooling and that took us a while to get it sorted out. One of the problems in buildings like this, we always use PCs, printers, laptops and all these cause a lot of heat and I think the building was challenged to try to manage that level of heat gain from within. I think it is better now, but I think if you are a very big IT user, am not sure the adiabatic cooling could handle that level of cooling required".* *"The more significant issue is the biomass boiler, we have had quite a number of problems with design issues with the pit in which the pellets are; we've had water leak into it, racking the stock".* *"The management regime for the biomass boiler is higher than we had expected"*
	Age of building	4 yrs
	Building docs available/how helpful	O&M manual, Building manual

Vi	**Cost of O&M if it were to be none LCB**	No significant difference *"My experience is that it is not hugely different from everywhere else"*
vii	**Cost of Construction if it were to be none LCB**	
viii	**At what stage should Client be aware of operation and maintenance implications**	Design stage
ix	**Possible Reasons for the poor reputation of O&M manual**	Difficult to use (searching for a particular information) *"What a contractor does at the end is that he get a young member of staff to photocopy everything he ever received about everything in the building and he very kindly puts it in a series of ring binders folders for you. If you're lucky, you get an index, but finding things and getting that information from the O&M manual is very painful".* *"They are not in searchable form, they are not in digital form and people's answer to digital form I find frustrating, because what they tend to do is to give you a PDF, you can't search a PDF".*
x	**If O&M manual is really a necessity for LCBs**	
xi	**Opinion about O&M regime:**	
	Transfer responsibility of collating to lead designer	Yes
	O&M manual is a potential document that could bridge the gap btw designers and users	
	Integrating the O&M manual Process into the design process could enhance manuals' quality	Yes *"……..irrespective of who handles it, my preference is that it is not done as an after-thought. The contractor hands you the keys and a week or two he says now I've got the O&M manual, they've all arrive, there you go, no. I think as the process goes on, it's a good idea that the O&M manuals grow with the building, so that people understand what they are getting".*
	It will be good practice to make 1st draft of O&M manual during design	
	Involving O&M specialists at design stage could ensure maintainability	Yes *"So I think clients or their advisers need to be involved much earlier in the process to understand how these windows work and why they are like this".*
	Involving O&M specialists could stifle innovations	
	O&M manual Specialists are not usually involved in the design process	
	Most Architects pay less attention to O&M challenges at design stage	
	Need to demonstrate maintainability by the design	Yes

	team	*"…how it operates before it is up".*
	Other Comments about O&M manual regime	*"The O&M manual files are as long as this table, and we had a steep learning curve when we took this building on, and in some way we are still learning, 4½ years on".* *"But I will say that sending me PDF is a waste of time, that won't help me at all. I'll end up printing them out. And a printed manual is so old fashioned now compared to every other thing we do in our lives".*
xii	**General Comments**	*"My experience of the biomass itself, I'm not convinced that our climate is totally suited with this system. By that I mean, we tend to need short sharp bursts of heat to smooth the troughs and the biomass time from lighting to how it heats is slow. Whereas if I take gas on I have instatnt heat. and whether we are not used to (when I say we, I mean as the organization, my building manager, we are not used to that ability to get it started instantly, at a go, so that now I want heat, now I don't want heat. Gas you turn it on, it on; biomass it burns in and it burns out, that's quite a difficult to do".* *I think it's not easy to use the biomass and it has a number of inherent problems with it that make it more difficult to commit to doing it.* *Q. is it difficult in terms of the cost involved?* *A. "Cost is one thing, you have to pay some cost any way so I don't get hung up on cost what is more difficult is the manpower required; I need a man to come and sort it out. If it gets blocked now, then I need to unblock it now, not in 4 hours or tomorrow, it needs doing now. If it gets cold as it has done today, I need that ability to get this building heated now, if it blocked, it's not going to work, so I think the cost comes secondary to me really, it's more about the practical issue of getting someone here to clean it up".* *"I don't get the impression that the biomass is any cheaper, and I think the biomass may be pushes it slightly higher, and the other thing they do say, we don't have massive amount of heat, because we don't use lots of heat".* *"You also have this horrible thing called value engineering which means that during that process, some of the things get taken out because they are too expensive and ……. as an industry that is a huge problem, because you keep picking out little bits and you don't know which piece you are picking out, you might be picking out the most important piece. ……… the architect needs to be saying, if that's the building you want to have, you can't change those things, for instance, when this building was opened it has standard taps in the toilets rather than percussion taps. That to me was a value engineering thing; but actually it was a very short sighted value engineering thing. Now you start getting to the problem of the industry; ……."*

004) J.M. (A Professor and a practicing architect based in Nottingham and one of the leading design practices in the Midlands)

i	**Professional Background**	Architect
ii	**Professional Group (according to nature of job)**	Building Design Practitioner
iii	**Professional Group (according to type of organization)**	Private Consulting Firm
iv	**Years of Experience**	30
v	**LCBs involved with**	- Phoenix Square in Leicester - Own house
	Technologies in the building	+Phoenix –(Solar Hot Water; Ground Source Heat Pump; Solar shading; Natural Ventilation With Courtyard; Rain Water Harvesting; Low Energy Lights) +Own House – (Zero Carbon; Ground Source Heat Pump; Solar Hot Water; Solar PV; Compost toilet; Rain Water Recycling; Night Cooling; etc
	Any challenges with the techs	Difficulty finding maintenance personnel for the GSHP
	Age of building	+Phoenix – 2 yrs. +Own House – 2 yrs.
	Building docs available/how helpful	O&M Manual - Phoenix
Vi	**Cost of O&M if it were to be none LCB**	Higher *"The running cost will be much higher in an ordinary building because energy cost will be more".*
vii	**Cost of Construction if it were to be none LCB**	No significant difference *"I don't think it makes much difference in this case, because a lot of money went into insulation actually, they are very heavily insulated in the flats, so the energy use is kept down, it is all naturally ventilated. I think there will be more plants in a non-low energy building and so the plat cost will be a more and the shell cost will be more in this case, so I will say it balances out more or less".*
viii	**At what stage should Client be aware of operation and maintenance implications**	
ix	**Possible Reasons for the poor reputation of O&M manual**	
x	**If O&M manual is really a necessity for LCBs**	Yes *"I think it is definitely a useful thing to have whether it helps you do the maintenance, it will certainly help you find spare parts and that kind of stuff".* *"As a law building of this type and size, you need to have operation & maintenance manual as part of health and safety".*
xi	**Opinion about O&M regime:**	
	Transfer responsibility of collating to lead designer	
	O&M manual is a potential	

	document that could bridge the gap btw designers and users	
	Integrating the O&M manual Process into the design process could enhance manuals' quality	
	It will be good practice to make 1st draft of O&M manual during design	
	Involving O&M specialists at design stage could ensure maintainability	Yes
	Involving O&M specialists could stifle innovations	
	O&M manual Specialists are not usually involved in the design process	
	Most Architects pay less attention to O&M challenges at design stage	Yes *"Absolutely right"*
	Need to demonstrate maintainability by the design team	*"The first thing that is going to happen is that as the standards for low carbon buildings gets tighter, then architects will be required to prove that their buildings are going to perform and I suspect what is going to happen is that the building regulations will start to incorporate a maintenance regime or some kind of test after a year to see how it is working".*
	Other Comments about O&M manual regime	*"We've done buildings before, when they are finished we handed over the maintenance manual and 6 months later, we get a phone call saying 'what do we do with this?'"* *"Most times the users are just overwhelmed with the whole stuff".*
xii	**General Comments**	*"They've all got challenges with maintenance. No building remains low-carbon if you don't look after them".* *"The client started with the city council to the first stage, then Blue Print took over as the client for the development stage as developers and then because it was a design and build contract, the contractor was our client when it was being built, so it changed. It's quite a complicated arrangement".* *"In construction, low energy housing is a bit more expensive than ordinary housing, but on a building where you got some quite big spaces and you will normally have lots of plants any way, you can offset that extra construction cost with plant cost".* *"Maintaining these technologies are more expensive"*

005) <u>D.N.C. (A Teaching & Research Staff in Sustainable Skyscrapers in the School of Built Environment in the University of Nottingham</u>

i	**Professional Background**	Architect
ii	**Professional Group (according to nature of job)**	Researcher
iii	**Professional Group (according to type of organization)**	Academic/Research Body
iv	**Years of Experience**	37 years (https://www.nottingham.ac.uk/engineering/departments/abe/people/david.nicholson-cole)
v	**LCBs involved with**	- Own House - Green Street Housing
	Technologies in the building	+Own House – (PV, Ground-Source Heat Pump, Evacuated tubes and the Solar Sun-Box) +Green St – (Condensing Gas boilers; High fabric Insulation; Automatic Window Blinds; Heat recovery system; *"In my case, my house is more complex, it is like a research rig and needs frequent monitoring, and sometimes needs adjustment".* *"My house is just extremely complicated; I've got several different systems which interact…."* *"…… the Solar Sun-Box which is a unique product I developed".*
	Any challenges with the techs	
	Age of building	
	Building docs available/how helpful	User Manual *"I just wrote a few notes which expanded into a user manual. If I fall from my motor bike and die, this is basically information for my son and my wife to read, basically how is it done, and what they would have to do if they have to sell the house. Who did it, who provided it, dates and history, and additional work done since, and most importantly, maintenance - daily tasks, weekly tasks and monthly tasks, troubleshooting - what goes wrong and how to deal with it".*
Vi	**Cost of O&M if it were to be none LCB**	
vii	**Cost of Construction if it were to be none LCB**	Less
viii	**At what stage should Client be aware of operation and maintenance implications**	
ix	**Possible Reasons for the poor reputation of O&M manual**	
x	**If O&M manual is really a necessity for LCBs**	Yes
xi	**Opinion about O&M regime:**	
	Transfer responsibility of collating to lead designer	
	O&M manual is a potential document that could bridge	

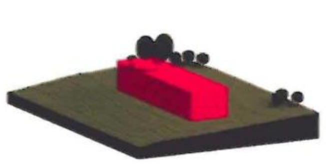
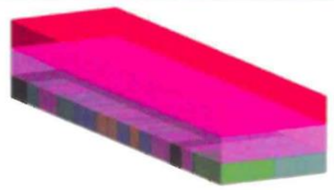
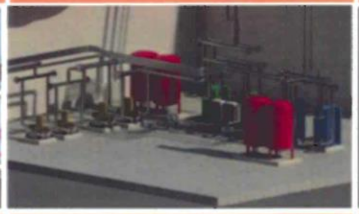
	the gap btw designers and users	
	Integrating the O&M manual Process into the design process could enhance manuals' quality	
	It will be good practice to make 1st draft of O&M manual during design	
	Involving O&M specialists at design stage could ensure maintainability	
	Involving O&M specialists could stifle innovations	
	O&M manual Specialists are not usually involved in the design process	
	Most Architects pay less attention to O&M challenges at design stage	
	Need to demonstrate maintainability by the design team	
	Other Comments about O&M manual regime	*"I just wrote a few notes which expanded into a user manual. This is basically information for my son and my wife to read, basically how is it done, and what they would have to do if they have to sell the house. Who did it, who provided it, dates and history, and additional work done since, and most importantly, maintenance - daily tasks, weekly tasks and monthly tasks, troubleshooting - what goes wrong and how to deal with it".* *"This needs to be updated of course because some things have changed since it's been written".*
xii	**General Comments**	*"Yes it would increase the cost a bit. But compared to the overall cost of the house, it's not a great deal. It's the cost of a Jacuzzi or the cost a nice kitchen, I mean your kitchen fitting is 15 grand. If people want to be Net-Zero, they will be motivated to try this. People spend money on cars, kitchens, nice carpet in the living room, fancy fireplace, expensive Italian tiles on the floor. People will spend money on things which are luxuries. They don't ask 'what's the payback' on expensive Italian tiles but when it comes to heating systems they get very sort of 'ooh what's the payback?' and I always find it all very strange. I get pleasure from having the house Net-Zero, like I would from seeing nice Italian tiles in the kitchen".*

Appendix D

RIBA Plan of Work 2013

The Plan of Work organises the progress of designing, constructing, maintaining and operating building projects into a number of key Work Stages. The sequence or content of Work Stages may vary or they may overlap to suit the procurement method, the project programme and the clients risk profile.

RIBA Work Stages

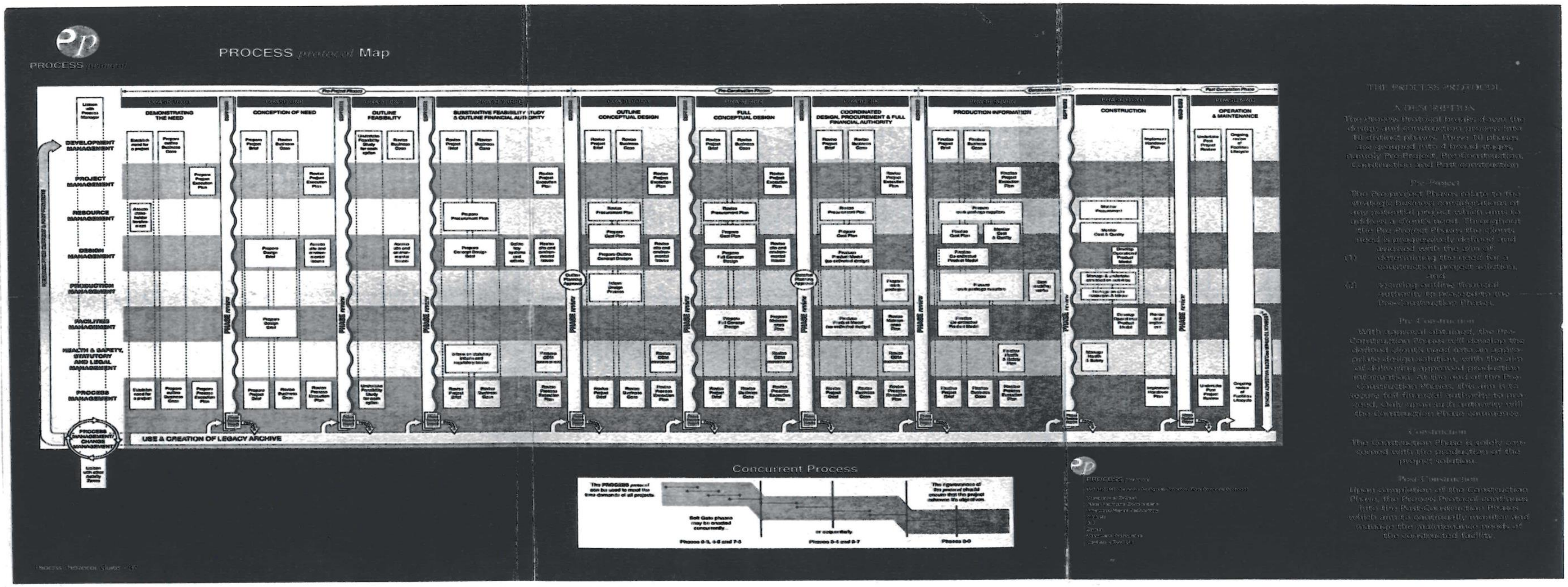
	1	2	3	4	5	6	7
	Preparation	**Concept Design**	**Developed Design**	**Technical Design**	**Specialist Design**	**Construction**	**Use & Aftercare**
Description of Key Tasks	- Identify **Project Objectives,** the client's **Business Case, Sustainability Aspirations** and other parameters or constraints and develop the **Initial Project Brief.** - Examine **Site Information** and make recommendations for further information, including surveys, required. - Preparation of **Feasibility Studies** and assessment of options to enable the client to decide how to proceed. - Determine client's **Risk Profile** and agree the **Project Programme** and preliminary **Procurement Strategy.** - Assemble **Project Team,** agree **Scope of Service, Contract Relationship** and **Design Responsibilities** for each participant. Develop **BIM** and **Soft Landings Strategies, Information Exchanges** and conclude **Appointment Documents.**	- Preparation of **Concept Design** including outline proposals for structural design, services systems, site landscape, outline specifications and preliminary cost plan along with environmental, energy, ecology, access or other **Project Strategies.** - Agree developments to **Initial Project Brief** and issue **Final Project Brief.** - Review **Procurement Strategy**, finalise **Deisgn Responsibility** including extent of **Performance Specified Design** and take action where required. - Prepare **Project Manual** including agreement of **Software Strategy, BIM Execution Plan** and extent of **Performance Specifed Work.** - Prepare **Construction Strategy** including review of off-site fabrication, site logistics and H&S aspects.	- Preparation of **Developed Design** including co-ordinated and updated proposals for structural design, services systems, site landscape, outline specifications, cost plan and **Project Strategies.** - Prepare and Submit **Planning Application** - Implement **Change Control Procedures,** undertake **Sustainability Assessment** and take actions determined by **Procurement Strategy.** - Review **Construction Strategy** including H&S aspects.	- Preparation of **Technical Design** information to include all architectural, structural and mechanical services information and specifications including the **Lead Designer**'s review and sign-off of all information. - **Performance Specified Work** to be developed in sufficient detail to allow development and integration by **Specialist Subcontractors** during **Completed Design** stage. - Take actions determined by **Procurement Strategy** including issuing in packages where appropriate. - Prepare and submit **Building Regulations Submission** - Review **Construction Strategy** including sequencing, programme and H&S asepcts.	- Progression of **Specialist Design** by **Specialist Subcontractors** including the integration, review and sign-off of **Performance Specified Work** by the **Lead Designer** and other designers as set out in **Design Responsibility** document - Review **Construction Strategy** including sequencing and critical path. - Undertake actions from **Procurement Strategy** or administration of **Building Contract** as required.	- Offsite manufacturing and onsite construction in accordance with the **Construction Programme** - Regular review of progress against programme and any **Quality Objectives** including site inspections. - Administration of **Building Contract.**. - Resolution of **Design Queries** from site as they arise - Implementation of **Soft Landing Strategy** including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and ongoing complilation of "as-constructed" information.	- Implementation of **Soft Landings Strategy** including **Post Occupancy Evaluation.** - Conclude administration of **Building Contract** - Review of **Project Performance** in use and analysis of **Project Information** for use on future projects. - Updating of **Project Information,** as required, in response to **Asset Management** and **Facilities Management** feedback and modifications.
Procurement	The stage 1, 2, 3 and 4 outputs may be used for tendering and contract purposes depending on the **Procurement Strategy** as influenced by the clients **Risk Profile,** time, cost and quality aspirations and how **Early Contractor Involvement** and **Specialst Subcontractor** input is to be undertaken.						
Programme				Stage 4, 5 and 6 activities may occur concurrently depending on the **Procurement Strategy.** Work may also be undertaken in packages to facilitate its development by **Specialist Subcontractors.** Early package procurement may also occur during stage 3 depending on the procurement route. The **Project Programme** should set out the timescales for these overlapping design and, where appropriate, construction stages.			
Planning		**Planning Applications** typically be made using the stage 3 **(Developed Design)** output, however, certain clients may wish this task to be undertaken earlier. The project or practice specific **Plan of Work** identifies when the **Planning Application** is to be made. Certain aspects of the Technical Design may also be required as part of the application or in respond to planning conditions.					
Key Information Exchanges (at stage Completion)	The **Initial Project Brief**	The **Concept Design** including **Outline Structural and Mechanical Services Design,** associated **Design Strategies, Preliminary Cost Information** and **Final Project Brief.**	The **Developed Design** including the **Co-ordinated Architectural, Structural and Mechanical Services Design** and **Developed Cost Information.**	The **Technical Design** of consultant aspects in sufficient detail to enable construction or **Performance Specified Work** to commence.	The **Specialist Design** including the integration of **Performance Specified Work.**	**"As Constructed" Information.**	**"As constructed" Information** updated in response to on-going client feedback, **Asset Management** updates and **Facilities Management** information.
							
Government Gateway	Information Exchange 1	Information Exchange 2	Information Exchange 3			Information Exchange 6	As Required

Royal Institute of British Architects

Figure 3: Draft diagram of the proposed new stages and overall framework

6

Appendix E



Clearer image of this Appendix can be viewed at: http://www.processprotocol.com/PP%20Leaflet%20revised%20and%20final%20map.pdf

Or at: Kagioglou et al. (1998b)

Appendix F

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

ESTATE OFFICE: PROJECT COMMUNICATION FRAMEWORK

Project Progress	Project Managers Actions	Communication
STAGE 1 Feasibility	Project Manager meets Facilities Group User ↓	Points for discussion * Principles of Project/Client requirements * Know ledge of existing buildings including condition information * Existing Health/Safety and Operations/ Maintenance Files to be developed or new * Feasibility of completing other w orks at the same time * Are any concurrent w orks planned? * Know n building hazards?
	Appoint Design Team ↓	
STAGE 2 Design	Commence Design ↓	
	Issue University Standards/ Local rules to the Design Team ↓	Design Team guide? Environmental Best Practice Guide? Permit to Work? This procedure Any standard docs Handover Checklist
Note 1	Pre Tender Review Meeting w ith Facilities Group ↓	* Discuss specification * Client/User * Maintainability * Domestic Services * Design Details * Safety Office * Programme * Security * NB/Formally Record mtng content/actions & distrib * Summary of agreements reach so far
	Tender Aw ard ↓	* Facilities comments * Design to go to tender
STAGE 3 Construction	Facilities Grp, Safety Office & User invited to Pre-Start Meeting if required by Project Manager ↓	* First part of meeting only * Agree future site visits during construction * Permits to w ork?
	Facilities Grp, Safety Office & User visit site at specific dates during construction as per programme agreed above ↓	* Formal recording of observations made and actions to be taken if any * Formal tour of site * Meet specialists (Lift, Plant etc.)
STAGE 4 Commissioning	Facilities Grp informed of commissioning dates in good time ↓	Witness commissioning of major plant items by Facilities Group staff
Note 2	3 months to planned completion review ↓	Review meeting
	Pre handover meetings Checklists completed. ↓	
	Project Team Project Manager Review Handover checklists ↓	Facilities Group as required

STAGE 5 Handover	Practical completion Defects List issued.	* Hand over of manuals as fitted drwgs & keys * Tour of project * Commissioning of plant and equipment / familiarisation * Handover snagging list * Acceptance Certificate * Insurance in place * Training & Demonstrations for users * PPM list provided by Project Manager
	Making good defects Decision, who follows through	Defects List issued and reviewed with Maintenance Group & User. Appropriate person to follow through to end of defects period, normally the Project Manager.
	End of defects period 12 months Signed off by Project Manager	Certificate of signing off defects issued to Facilities Group
STAGE 6 In use	Facilities Group Manage the building	Continued liasion with Building User Group Continued liasion with Project Manager on defects rectification
	Continuous commissioning and fine tuning	Documentation kept upto date throughout the life of the building
STAGE 7 Post Occ Evaluation	Post Occupancy Evaluation	POE Facilitator appointed if required Facilities Group, User group established.

NB

* **All meetings are to be recorded with suggestions put forward and actions taken noted**
* **Implementation of this communication framework is the responsibility of the Project Managers**

_ Bold boxes are formal meetings

NOTE 1 - Maintenance Team includes: Senior Engineer, Controls Engineer, Data, Comms, Phones, PPM Manager, Security, Safety Office, Senior Representatives in Facilities Group. Operations & Facilities Director at present.

NOTE 2 - Considerations: Fire precautions, keys/locks/ironmongery/door controls, security/alarms, finishes, engineering controls and BMS, signage, furniture, fixtures and fittings, data/phones/comms, DDA issues, list of PPM on completion, centrally bookable rooms, recycling and bins, car parking layout, utilities, environmental issues, safety office, insurance, post occupancy review planning, asset number issued, space planning data to be developed.

PROJECT COMMUNICATION

Adequate formal communication is essential to any successful Refurbishment/New Build project within the University. It allows a flow of information based upon local knowledge that is invaluable in ensuring that development works meet the requirements of all stakeholders, producing an end product that is both fit or purpose and is easily maintainable throughout its life.

The following procedure is aimed at improving communication between the Design Team and the In-House Maintenance Group on Project Developments and is supplementary to the general stakeholder communication process that is followed during Construction Projects

* The appointed Project Manager is responsible for appropriate, formal communication with the In-House Maintenace Group.

Appendix G

The University of Nottingham

Operability & Maintainability Integrated Design & Construction Process Model

Evaluation Questionnaire

Part A: Background Information

1. Name of participant (optional) ____
2. Profession Background ____
3. Years of Experience:

☐ Less than 10 ☐ 10 – 20 ☐ Over 20

Part B: Evaluation of the O&M Process Model

Please tick the box that best represents your opinion of the question where:

1 = Poor 2 = Fair 3 = Good 4 = Very Good 5 = Excellent

		1	2	3	4	5
4	What do you think about the idea of integrating operability & maintainability into design and construction process of low carbon buildings?					
5	If this model were to be put to adopted, how well do you think it will help to ensure that designers give better consideration to maintenance and operation issues?					
6	How effective do you think that this model could be in improving the overall quality of design output for low carbon buildings?					
7	How well do you think this model could ensure efficient operation during the building's operating life?					
8	To what extent do you think the activities and tasks proposed in the model captured and integrated the concept of operability & maintainability into the design and construction process?					
9	What do you think about the proposal of this model to reduce Soft Landings activities from 3 years to 1 year?					
10	How would you rate the ability of this model to enhance improvement in the quality of O&M manuals for low carbon buildings?					

11. Which component in this model impresses you most and why?

12. Which aspect of the model did not meet your expectation and why?

13. In your own view, what do you think could be the possible potential of integrating operability and maintainability in the design and construction process of low carbon buildings?

14. What new Activity or Task would you love to see introduced to the model?

15. Any General Comments please?

Thank you so much!

Owajionyi L Frank – *PhD Researcher*
laxolf@nottingham.ac.uk;
0783 198 2350

	Pre-Project Stage		Pre-Construction Stages					Construction Stage	Post-Construction Stage
RIBA Outline Plan of Work 2013 Stages	**Stage 0**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 3b**	**Stage 4**	**Stage 5**	**Stage 6**	**Stage 7**
	the Need	Preparation	Concept Design	Development Design		Technical Design	Specialist Design	Construction	Use & Aftercare
Operability and Maintainability Integrated Phases	**Explore Scope for Operability & Maintainability**	**Prepare Operability & maintainability criteria for Project**	**Prepare operability and maintainability strategy**	**Prepare initial Operation and Maintenance Model**	**Life-Cycle (Operability & Maintainability) Proving**	**Update Operation & Maintenance Model**	**Update Operation & Maintenance Model**	**Review & Finalise Operation and Maintenance Model**	**Post-Project Review**
Life-Cycle Proving Strategy				Life-Cycle Proving Process is advisable to begin after stage 3 (Development Design) and continue after stages 4 and 5. However, depending on the Procurement Strategy it can be started at any appropriate stage, provided it is before the individual technologies are installed.					
RIBA 2013 Procurement Statement		The stage 1, 2, 3 and 4 outputs may be used for tendering and contract purposes depending on the **Procurement Strategy** as influenced by the clients **Risk Profile**, time, cost and quality aspirations and how **Early Contractor Involvement** and **Specialist Subcontractor** input is to be undertaken.							
RIBA 2013 Programme Statement						Stage 4, 5 and 6 activities may occur concurrently depending on the Procurement Strategy. Work may also be undertaken in packages to facilitate its development by Specialist Subcontractors. Early package procurement may also occur during stage 3 depending on the procurement route. The Project Programme should set out the timescale for these overlapping design and, where appropriate, construction stage.			
RIBA 2013 Planning Statement			Planning Applications typically be made using the stage 3 (Development Design) output, however, certain clients may wish this task to be undertaken earlier. The project or practice specific Plan of Work identifies when the Planning Application is to be made. Certain aspects of the Technical Design may also be required as part of the application or in response to planning conditions.						
Government Gateway	**Information Exchange**								

Operability and Maintainability Integrated Process Stages

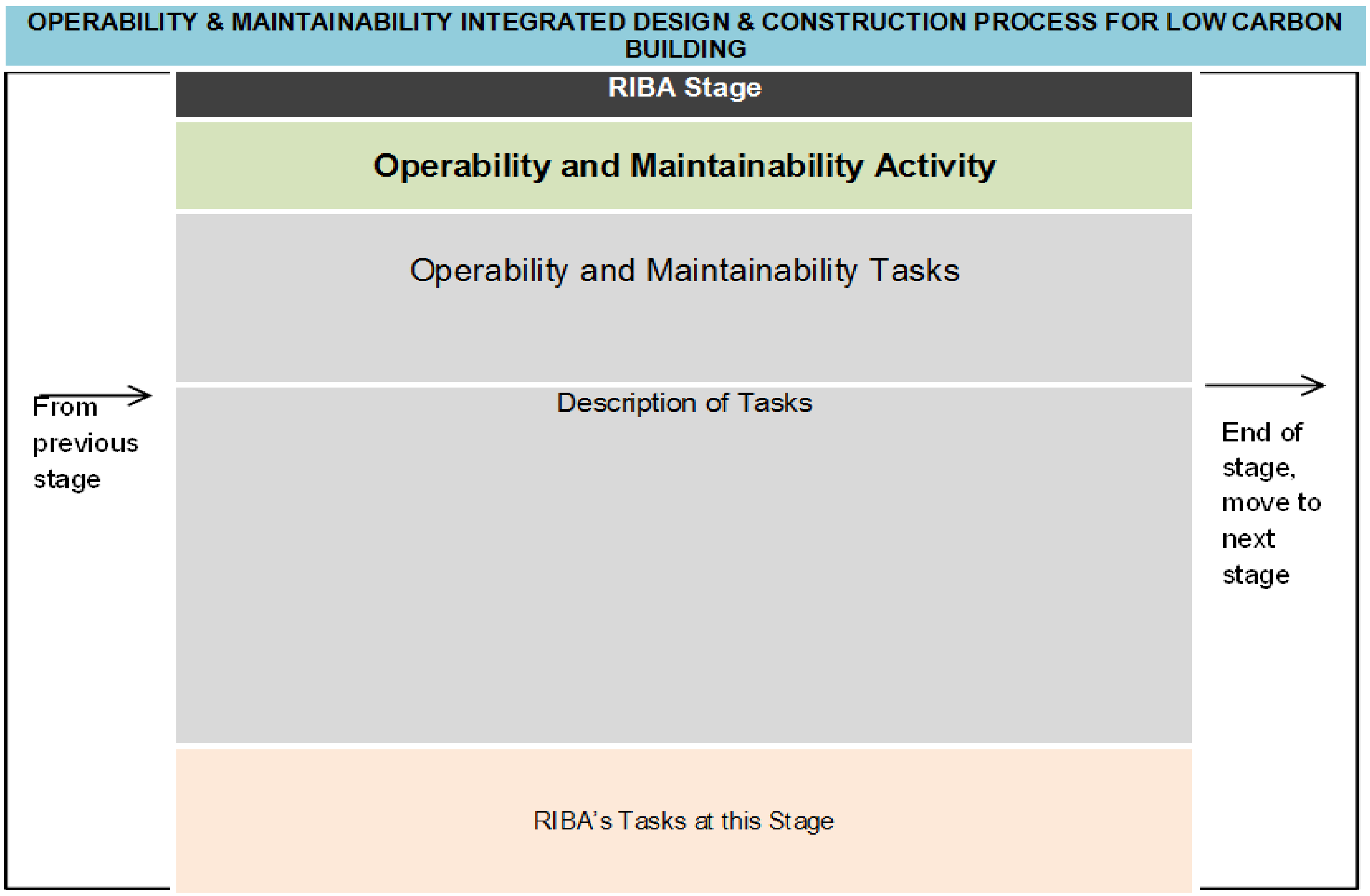
OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING									
	Pre-Project Stage		Pre-Construction Stages					Construction Stage	Post-Construction Stage
RIBA (Sub-Process) Stages	Stage 0	Stage 1	Stage 2	Stage 3	Stage 3b	Stage 4	Stage 5	Stage 6	Stage 7
	Demonstrating the Need	Preparation	Concept Design	Development Design		Technical Design	Specialist Design	Construction	Use & Aftercare
Operability and Maintainability Activities	Explore Scope for Operability & Maintainability	Prepare Operability & maintainability criteria for Project	Prepare operability and maintainability strategy	Prepare initial Operation and Maintenance Model	Life-Cycle (Operability & Maintainability) Proving	Review Operation & Maintenance Model	Update Operation & Maintenance Model	Review & Finalise Operation and Maintenance Model	Post-Project Review
Key Process Actors	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	PM ARC FM M&E	CLT ARC FM M&E
	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN	SPE CON O&M MAN
Operability and Maintainability Tasks	Establish Client's specific requirements including need for specific LC technology	Define Client's specific brief, including need for specific LC technology	Develop operability & maintainability matrix to inform choice of appropriate technology & general design decisions	Prepare initial plan for operation & maintenance of specific technologies for the project life-cycle	Prepare life-cycle analysis of project in line with client's business requirements	Review plan for operation & maintenance of specific LC technologies and detailed technical O&M manual for the project life-cycle	Update plan for operation & maintenance of specific LC technologies and detailed technical O&M manual for the project life-cycle	Finalise all technical O&M documents in an interactive digital format	Implement Soft Landings for not more than 12 months after Practical Completion within the normal Defects liability period
	Identify Key O&M performance Objectives including life expectancy	Identify drivers for operability & maintainability including economic, social/environmental	Review past operation & maintenance experiences with respect to specific technologies					Prepare and finalise all non-technical O&M documents in an interactive digital format	
	Identify any benefits/limitations including Health & Safety, legislation & policy, incentives, risks, etc.	Set performance targets, e.g. BREEAM rating, etc. Review past experience and Plan evaluations & reality checks	Review Client's brief with respect to specified and/or innovative LC technology(ies) that best sit in the overall project design.	Prepare initial plan for detailed technical operation & maintenance for the entire property	Highlight technology/equipment regular operation and maintenance requirements (accessibility, cost & frequency), including life expectancy of the system			Prepare and affix appropriate, legible and understandable signage at relevant positions	Post Occupancy Evaluations to include the state of repair and output of technologies/equipment
	Identify key and relevant Experts	Define roles and responsibilities						Plan and finalise maintenance contracts, training for aftercare team, BMS interface completion & demo	On-going life-cycle review of facility
								Undertake commissioning and testing Procedure	
	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM	Information exchange through BIM

Lexicon PM – Project Manager or Any Client's Professional Rep; ARC – Architect; FM – Facilities Manager; M&E – M&E Engineer; SPE – Specialist Engineer, e.g., Renewable Energy Tech. Expert; CON – Contractor; O&M – O&M Editor; MAN - Manufacturer

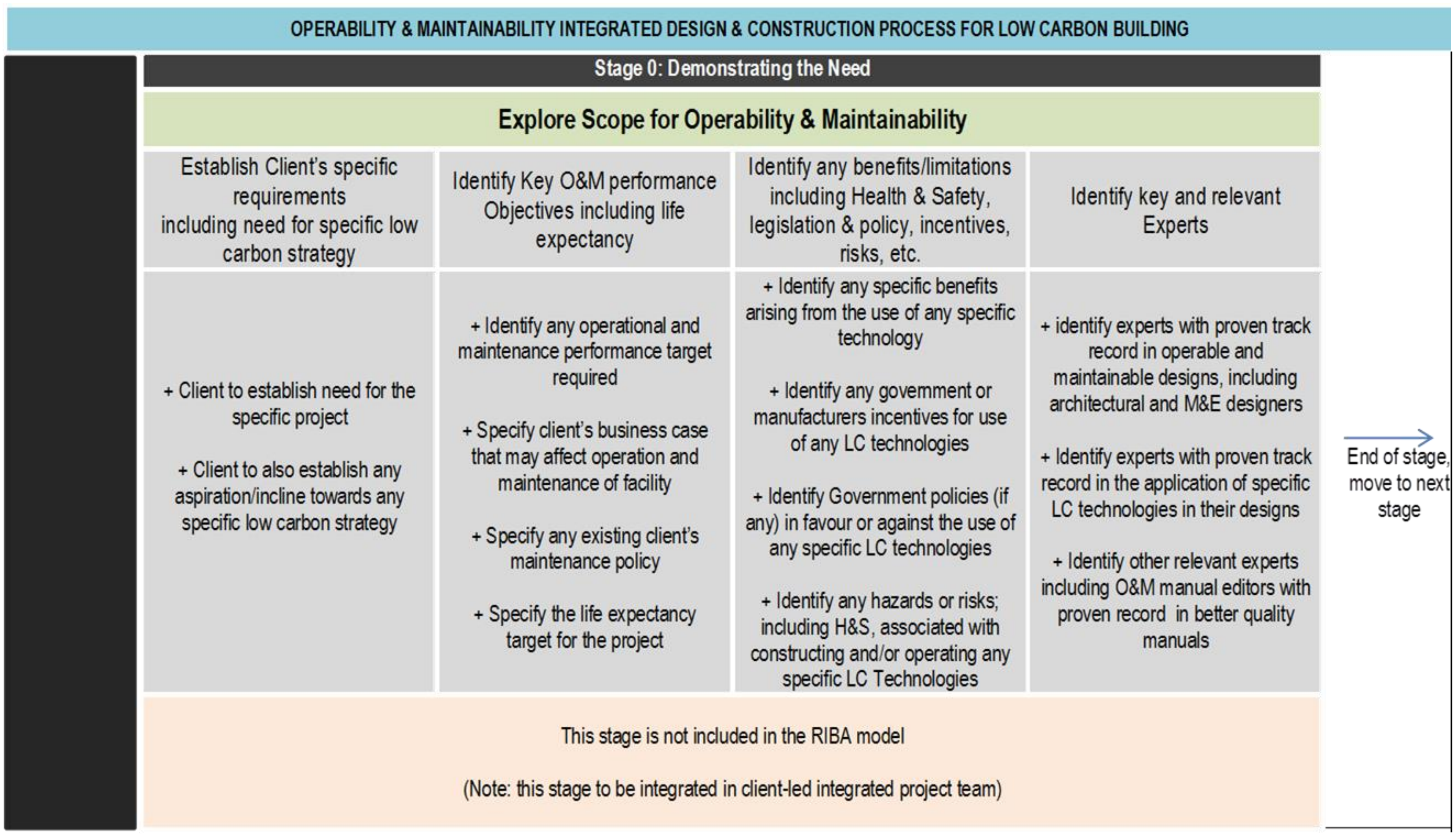
By RIBA Plan 2013, stages 1 – 4 Output can be used for procurement, and stages 4, 5 & 6 activities may occur concurrently

- Life-Cycle Proving Process is advisable to begin after stage 3 (Development Design) and continue after stages 4 and 5. However, depending on the Procurement Strategy it can be started at any appropriate stage, provided it is before the individual technologies are installed.

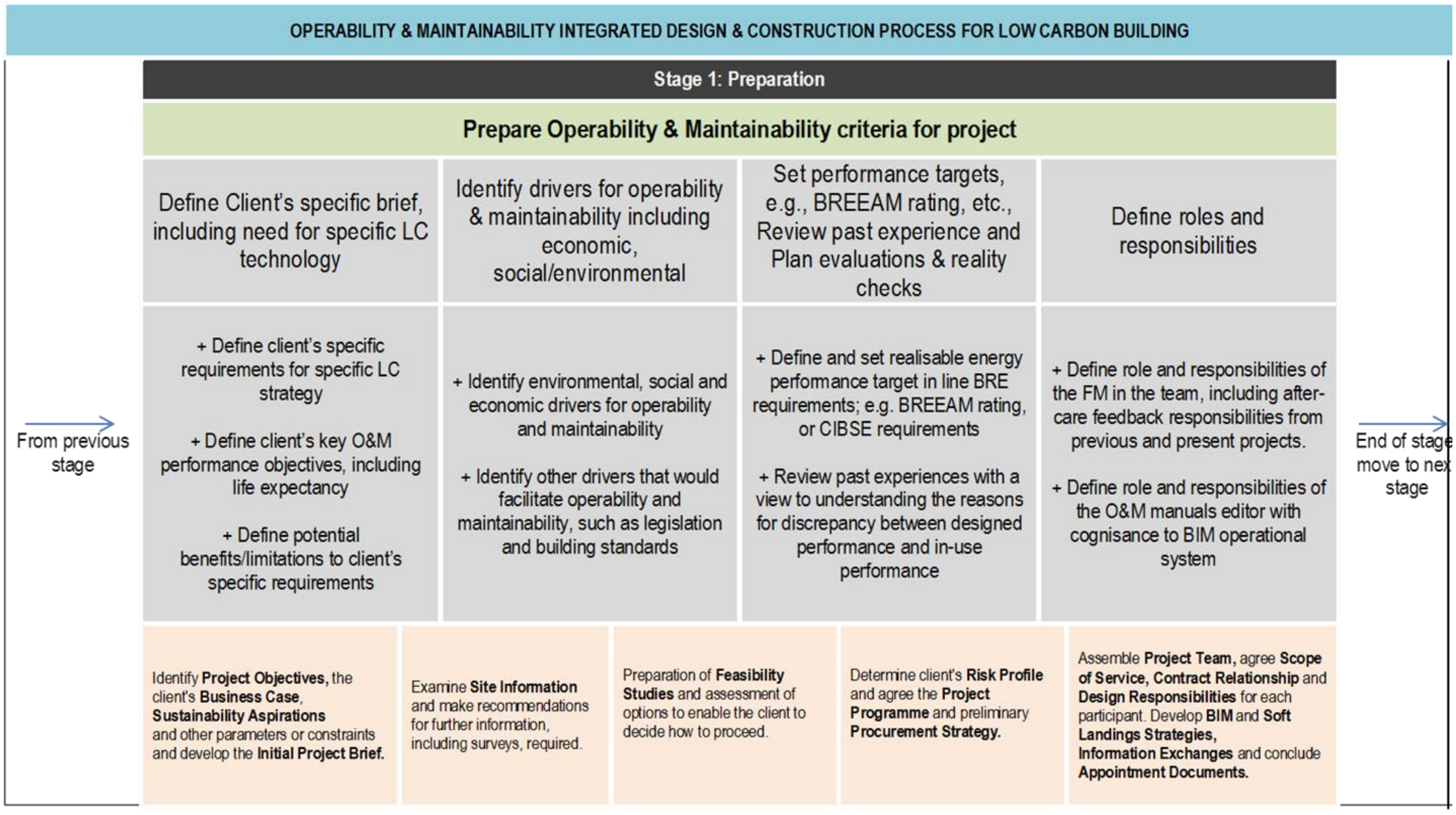
OMI Design and Construction Process Model (Process Layout Map)



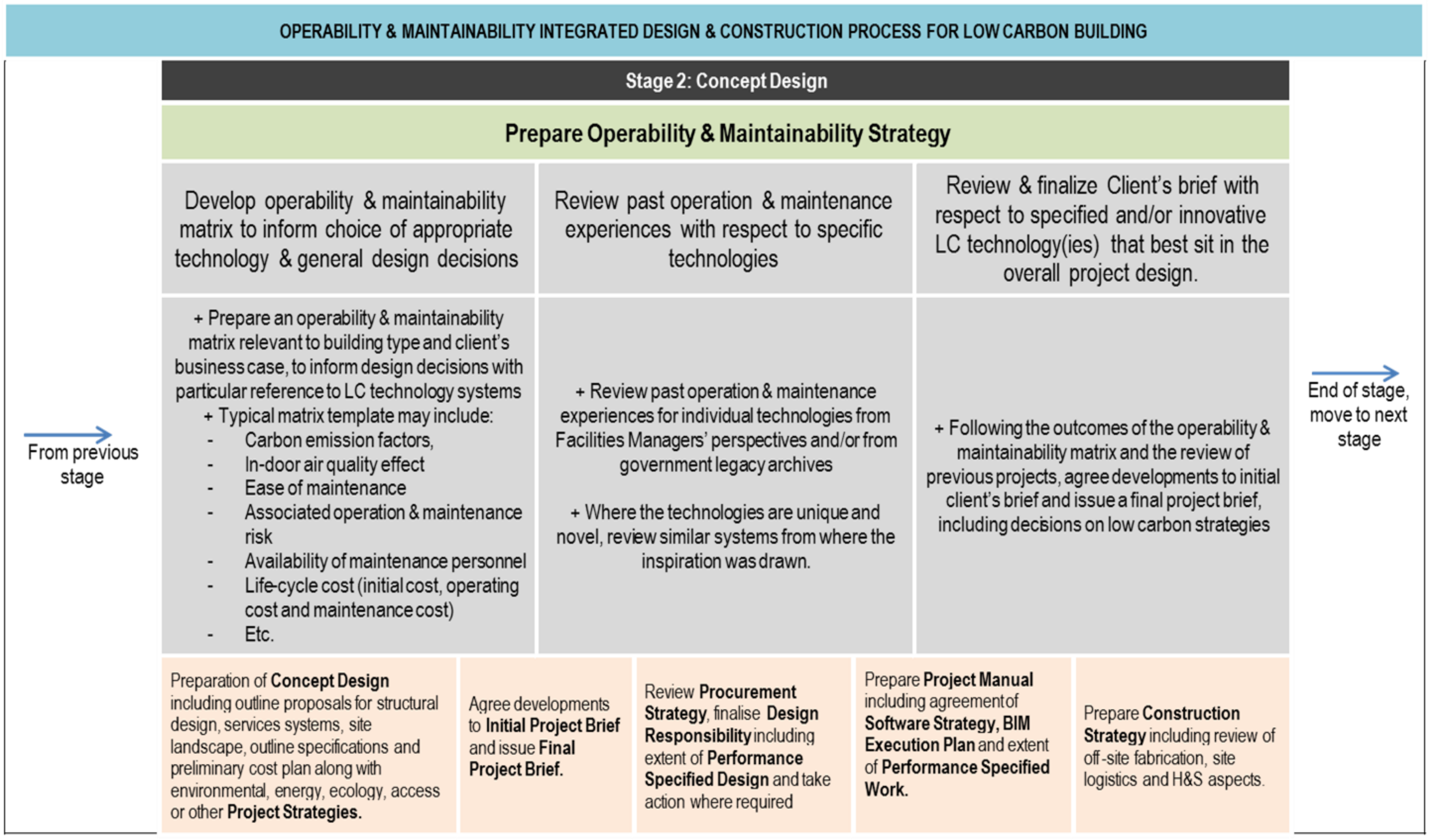
Layout of the Different Components of the Operability & Maintainability Process Model



Stage 0 Tasks Descriptions



Stage 1 Tasks Descriptions



Stage 2 Tasks Descriptions

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

Stage 3: Development Design

Prepare initial Operation and Maintenance model

From previous stage

Prepare initial plan for operation & maintenance of specific LC technologies for the project life-cycle	Prepare initial plan for detailed technical operation & maintenance for the entire property
+ Initiate plans for preparation of operation and maintenance instruction for specific LC technology system adopted for the design, with respect to: - Daily operational procedure and precautions or safeguards - Periodic maintenance requirements - Any foreseeable breakdown requirements; eg. Accidental damage - Troubleshooting requirements - Etc.	+ Initiate plans for preparation of operation and maintenance instruction for the entire facility; including identifying and commissioning an expert O&M editor

Preparation of **Developed Design** including co-ordinated and updated proposals for structural design, services systems, site landscape, outline specifications, cost plan and **Project Strategies.**	Prepare and Submit **Planning Application**	Implement **Change Control Procedures,** undertake **Sustainability Assessment** and take actions determined by **Procurement Strategy.**	Review **Construction Strategy** including H&S aspects.

End of stage, move to next stage

Stage 3 Tasks Descriptions

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

Stage 3b:

Life-Cycle (Operability & Maintainability) Proving

From previous stage

Prepare Life-Cycle Analysis of project in line with client's business requirements	Highlight technology/equipment regular operation and maintenance requirements (accessibility, cost & frequency), including life expectancy of the system
+ Prepare detailed whole-life assessment of the entire property in line with client's business case; using the RIBA whole-life assessment methodology for Low Carbon buildings or the BREEAM Assessment methodology + Calculate Energy Performance of building in line with BRE's Energy Performance of Building Directives or any current operative methodology + Prepare Life-Cycle Cost Benefit Analysis for individual LC technology systems, using the Life-Cycle Management Methodology	+ Highlight any periodic maintenance requirements for specific LC technologies adopted indicating methods, costs and frequencies of such maintenance activities + Highlight any availability of trained technicians for any specific LC equipment, where possible + Highlight possible operational precautions and activities that could add to longevity of the system(s) + Highlight foreseeable operational activities and/or environmental factors that could affect the longevity of the system(s) + Highlight feedback from previous projects where the specific LC system(s) were used, through a POE or through Building users survey methodology

This stage not included in the RIBA Plan

(Note: If the outcome of this stage becomes unsatisfactory, go back to stage 1, 2 or 3 as may be appropriate in the circumstance)

End of stage, move to next stage

Stage 3b Tasks Descriptions

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

From previous stage

Stage 4: Technical Design

Update Operation and Maintenance model

Update plan for operation and maintenance of specific LC technology and detailed technical O&M manual for the whole property for the project life-cycle

+ Review plan for operation and maintenance of specific LC technology and detailed technical O&M manual for the whole property for the project life-cycle, in line with outcome of stage 3b.

+ Commence preparation of detailed technical O& M manual(s) for individual LC technology and for the entire project.

+ Review Life-Cycle Proving as may be influenced by any changes imputed by the technical design.

Preparation of **Technical Design** information to include all architectural, structural and mechanical services information and specifications including the **Lead Designer**'s review and sign-off of all information.

Performance Specified Work to be developed in sufficient detail to allow development and integration by **Specialist Subcontractors** during **Completed Design** stage.

Take actions determined by **Procurement Strategy** including issuing in packages where appropriate.

Prepare and submit **Building Regulations Submission**

Review **Construction Strategy** including sequencing, programme and H&S aspects.

End of stage, move to next stage

Stage 4 Tasks Descriptions

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

From previous stage

Stage 5: Specialist Design

Update Operation & Maintenance Model

Update plan for operation and maintenance of specific LC technology and detailed technical O&M manual for the whole property for the project life-cycle

+ Continue with preparation of detailed technical O& M manual(s) for individual LC technology and for the entire project.

+ Review Life-Cycle Proving as may be influenced by any changes imputed by the Specialist design.

Progression of **Specialist Design** by **Specialist Subcontractors** including the integration, review and sign-off of **Performance Specified Work** by the **Lead Designer** and other designers as set out in **Design Responsibility** document

Review **Construction Strategy** including sequencing and critical path.

Undertake actions from **Procurement Strategy** or administration of **Building Contract** as required.

End of stage, move to next stage

Stage 5 Tasks Descriptions

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

From previous stage → **Stage 6: Construction** → End of stage, move to next stage

Review and finalise Operation & Maintenance Model

Finalise all technical O&M documents in an interactive digital format	Prepare and finalise all non-technical O&M documents in an interactive digital format	Prepare and affix appropriate, legible and understandable signage at relevant positions	Plan and finalise maintenance contracts, training for aftercare team, BMS interface completion & demo	Undertake commissioning and testing Procedure
+ Finalise the preparation of all **technical** O&M Documents including: - Health and Safety file - O&M Manual - manufacturers manuals and warrantees - As-built detailed drawings (All in separate files, and in both hard copy and interactive digital formats)	+ Commence & finalise the preparation of all **non-technical** O&M documents as proposed by BSRIA; including: - The Building Manual (condensed form of the technical docs.) - The Building User Guide (occupants' quick-start guide) (Both in separate files, and in hard copy and interactive digital formats)	+ Prepare and affix appropriate, legible and understandable signage at relevant positions to complement the building user guide, particularly for first time users of the building	+ Initiate and finalise maintenance contracts for respective aspects of the facility; both daily and periodic (eg. Cleaning, maintenance of specific equipment, etc) + Organize training and familiarisation exercise for the aftercare team + Install a BMS interface to completion and make demonstration at practical completion	Undertake facilities commissioning and testing by a commissioning body, independent of the main contractor

Offsite manufacturing and onsite construction in accordance with the **Construction Programme**	Regular review of progress against programme and any **Quality Objectives** including site inspections.	Administration of **Building Contract.**	Resolution of **Design Queries** from site as they arise	Implementation of **Soft Landing Strategy** including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and on-going compilation of "as constructed" information.

Stage 6 Tasks Descriptions

OPERABILITY & MAINTAINABILITY INTEGRATED DESIGN & CONSTRUCTION PROCESS FOR LOW CARBON BUILDING

From previous stage → **Stage 7: Use & Aftercare** → Feedback to other Projects through Govt. Gateway

Post Project Review

Implement Soft Landings for not more than 12 months after Practical Completion , within the normal Defects liability period	Post Occupancy Evaluations to include the state of repair and output of technologies/equipment	On-going life-cycle review of facility
+ Implement Soft landings strategies and limited to 6 – 12 calendar months, the normal JCT Contract approved defects liability period.	+ Post Occupancy Evaluation exercise is already part of RIBA's plan for this stage, however, this should also include 'Building Condition Survey' which needs to be carried out periodically.	+ Review of operational and maintenance issues by the continues through the life-cycle of the facility and fed into the Legacy archive

Implementation of **Soft Landings Strategy** including **Post Occupancy Evaluation.**	Conclude administration of **Building Contract**	Review of **Project Performance** in use and analysis of **Project Information** for use on future projects	Updating of **Project Information,** as required, in response to **Asset Management** and **Facilities Management** feedback and modifications.

Stage 7 Tasks Description

RIBA Plan of Work 2013

The RIBA Plan of Work 2013 organises the process of briefing, designing, constructing, maintaining, operating and using building projects into a number of key stages. The content of stages may vary or overlap to suit specific project requirements. The RIBA Plan of Work 2013 should be used solely as guidance for the preparation of detailed professional services contracts and building contracts.

www.ribaplanofwork.com

Stages / Tasks	0 Strategic Definition	1 Preparation and Brief	2 Concept Design	3 Developed Design	4 Technical Design	5 Construction	6 Handover and Close Out	7 In Use
Core Objectives	Identify client's **Business Case** and **Strategic Brief** and other core project requirements.	Develop **Project Objectives**, including **Quality Objectives** and **Project Outcomes**, **Sustainability Aspirations**, **Project Budget**, other parameters or constraints and develop **Initial Project Brief**. Undertake **Feasibility Studies** and review of **Site Information**.	Prepare **Concept Design**, including outline proposals for structural design, building services systems, outline specifications and preliminary **Cost Information** along with relevant **Project Strategies** in accordance with **Design Programme**. Agree alterations to brief and issue **Final Project Brief**.	Prepare **Developed Design**, including coordinated and updated proposals for structural design, building services systems, outline specifications, **Cost Information** and **Project Strategies** in accordance with **Design Programme**.	Prepare **Technical Design** in accordance with **Design Responsibility Matrix** and **Project Strategies** to include all architectural, structural and building services information, specialist subcontractor design and specifications, in accordance with **Design Programme**.	Offsite manufacturing and onsite **Construction** in accordance with **Construction Programme** and resolution of **Design Queries** from site as they arise.	Handover of building and conclusion of **Building Contract**.	Undertake **In Use** services in accordance with **Schedule of Services**.
Procurement *Variable task bar	Initial considerations for assembling the project team.	Prepare **Project Roles Table** and **Contractual Tree** and continue assembling the project team.	<----- The procurement strategy does not fundamentally alter the progression of the design or the level of detail prepared at a given stage. However, **Information Exchanges** will vary depending on the selected procurement route and **Building Contract**. A bespoke **RIBA Plan of Work 2013** will set out the specific tendering and procurement activities that will occur at each stage in relation to the chosen procurement route. ----->			Administration of **Building Contract**, including regular site inspections and review of progress.	Conclude administration of **Building Contract**.	
Programme *Variable task bar	Establish **Project Programme**.	Review **Project Programme**.	Review **Project Programme**.	<-- The procurement route may dictate the **Project Programme** and may result in certain stages overlapping or being undertaken concurrently. A bespoke **RIBA Plan of Work 2013** will clarify the stage overlaps. The **Project Programme** will set out the specific stage dates and detailed programme durations. -->				
(Town) Planning *Variable task bar	Pre-application discussions.	Pre-application discussions.	<------ Planning applications are typically made using the Stage 3 output. A bespoke **RIBA Plan of Work 2013** will identify when the planning application is to be made. ------>					
Suggested Key Support Tasks OMI model comes in here	Review **Feedback** from previous projects.	Prepare **Handover Strategy** and **Risk Assessments**. Agree **Schedule of Services**, **Design Responsibility Matrix** and **Information Exchanges** and prepare **Project Execution Plan** including **Technology** and **Communication Strategies** and consideration of **Common Standards** to be used.	Prepare **Sustainability Strategy**, **Maintenance and Operational Strategy** and review **Handover Strategy** and **Risk Assessments**. Undertake third party consultations as required and any **Research and Development** aspects. Review and update **Project Execution Plan**. Consider **Construction Strategy**, including offsite fabrication, and develop **Health and Safety Strategy**.	Review and update **Sustainability**, **Maintenance and Operational** and **Handover Strategies** and **Risk Assessments**. Undertake third party consultations as required and conclude **Research and Development** aspects. Review and update **Project Execution Plan**, including **Change Control Procedures**. Review and update **Construction** and **Health and Safety Strategies**.	Review and update **Sustainability**, **Maintenance and Operational** and **Handover Strategies** and **Risk Assessments**. Prepare and submit Building Regulations submission and any other third party submissions requiring consent. Review and update **Project Execution Plan**. Review **Construction Strategy**, including sequencing, and update **Health and Safety Strategy**.	Review and update **Sustainability Strategy** and implement **Handover Strategy**, including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and ongoing compilation of **'As-constructed' Information**. Update **Construction** and **Health and Safety Strategies**.	Carry out activities listed in **Handover Strategy** including **Feedback** for use during the future life of the building or on future projects. Updating of **Project Information** as required.	Conclude activities listed in **Handover Strategy** including **Post-occupancy Evaluation**, review of **Project Performance**, **Project Outcomes** and **Research and Development** aspects. Updating of **Project Information**, as required, in response to ongoing client **Feedback** until the end of the building's life.
Sustainability Checkpoints	**Sustainability Checkpoint — 0**	**Sustainability Checkpoint — 1**	**Sustainability Checkpoint — 2**	**Sustainability Checkpoint — 3**	**Sustainability Checkpoint — 4**	**Sustainability Checkpoint — 5**	**Sustainability Checkpoint — 6**	**Sustainability Checkpoint — 7**
Information Exchanges (at stage completion)	**Strategic Brief**.	**Initial Project Brief**.	**Concept Design** including outline structural and building services design, associated **Project Strategies**, preliminary **Cost Information** and **Final Project Brief**.	**Developed Design**, including the coordinated architectural, structural and building services design and updated **Cost Information**.	Completed **Technical Design** of the project.	**'As-constructed' Information**.	Updated **'As-constructed' Information**.	**'As-constructed' Information** updated in response to ongoing client **Feedback** and maintenance or operational developments.
UK Government Information Exchanges	Not required.	Required.	Required.	Required.	Not required.	Not required.	Required.	As required.

*Variable task bar – in creating a bespoke project or practice specific RIBA Plan of Work 2013 via www.ribaplanofwork.com a specific bar is selected from a number of options.

Appendix J

From: Anne Dye [mailto:Anne.Dye@riba.org]
Sent: 06 June 2012 14:02
To: laxolf@nottingham.ac.uk
Cc: Adrian Dobson; Michelle Kent; Alex Tait
Subject: FW: Invitation to Participate in a Research

Dear Owajionyi,

Thank you for your email about your survey the operation and maintenance of low-carbon buildings. I'm very pleased to be able to disseminate the link to the survey to our members and other building environment professionals via the RIBA's knowledge communities (we post a digest of survey links received on Fridays, so your link will go out on the 8th) and via twitter. These are an excellent route to a large number of interested professionals, so hopefully you'll get a good response. You'll be able to see the links here:

http://www.riba-knowledgecommunities.com/node (login required; registration is free)
https://twitter.com/#!/AnneDyeResearch

As I'm sure you can imagine Angela Brady receives a very large number of requests for interviews, and unfortunately cannot participate in all of these. Our senior RIBA members who specialise in the field of sustainability are in a similar situation, and on this occasion do not have the time to be interviewed. I can however suggest that you might investigate the following bodies who are involved in the operation and maintenance of buildings of all types, and who may be able to help:

The Facilities Management Association - http://www.fmassociation.org.uk/
Worshipful Company of Environmental Cleaners - http://www.wc-ec.com/

Further the College of Estate Management may also be a fruitful source of information: http://www.cem.ac.uk/

Good luck with the research, and please don't hesitate to get in contact if we can be of any further assistance.

All the best,

Anne

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Head of Technical Research

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From: Owajionyi Frank [mailto:laxolf@nottingham.ac.uk]
Sent: 10 May 2012 12:56
To: President
Subject: Invitation to Paticipate in a Research

Dear Angela Brady,

I am a research student of the department of Architecture & Built Environment in the University of Nottingham. I am researching on how to combat the operation and maintenance challenges of low-carbon buildings, and I am trying to understand the views of building professionals on this issue.

As part of the research, I have elected to have a one-on-one interview with the President of RIBA to understand her views on the subject. I have attached a formal letter of invitation to participate in the study which gives more details about the research. It also include sample questions and a consent form as required by the University Research Ethics.

If you would recall, I had discussed this provisionally with you at the 2011 ECOBUILD and again at the ACA debate on the 16th of April this year. I shall be glad if you could schedule a date, time and place convenient for you for the interview, if you please. It will last for just about 30minutes. Although it is an academic exercise, but the findings of this research is likely to chart a new course to projects delivery methods and the roles of architects; regaining some of the roles relinquished to other professionals and maintain her pride of place as the Master-Builder.
If you would not mind, will it be possible to circulate an online survey for this research also to all RIBA members. The link is: https://www.surveymonkey.com/s/LCB-OandMMsurvey

Thank you so much madam,

Owajionyi Frank

<Interview-Invitation to Participate.docx><Interview-Concent form.docx>

Appendix L

Publications so far in the course of this research

A. Published Conference Papers

1. Frank, O. L. (2011). Exploring the Potential of the O&M Manual as the Designers' Tool for Solving Maintenance Problems of Public Buildings in Nigeria. *3rd International Postgraduate Conference on Infrastructure and Environment* (pp. 2 - 9). Hong Kong: Faculty of Construction and Land Use, The Hong Kong Polytechnic University.

B. Journal Paper Submitted and under Review

1. Frank, O. L., Omer, S. A., Saffa, R. B., & Mempouo, B. (under review). The Indispensability of good operation & maintenance (O&M) manuals in the operation and maintenance of low carbon buildings. *Sustainable Cities and Societies*.

C. Journal Papers under Preparation

1. Frank, O. L., Omer, S. A., Saffa, R. B., & Mempouo, B. (n.d.). Operability and maintainability of low carbon buildings - part 2.
2. Frank, O. L., Omer, S. A., Saffa, R. B., & Mempouo, B. (n.d.). Operability and maintainability of low carbon buildings - reviews part 1 .