Energy-led, non-domestic building refurbishment: Decision support for a whole-building approach to improvement of operational performance

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Abstract

Pressure is growing upon non-domestic building owners and occupiers to measure and improve the energy performance, and associated carbon emission levels, of the portfolio in which they operate. In line with this, the need for energy-led refurbishment of existing buildings is increasingly evident, with approximately 60% of the current building stock expected to still exist in 2050 and less than 1% being replaced annually. However, energy-led refurbishment of existing non-domestic property faces a number of barriers, including an ill-defined decision-making process and a lack of low carbon skills required to guide building owners in this complex transition.

This thesis examines first, the need for a re-alignment of disciplines within the construction industry to fulfil the growing requirement for low carbon skills, specific to energy-led refurbishment. A comprehensive desk study was undertaken, evaluating the competencies of the established construction industry professions, as defined by their governing bodies. This was supported by structured interviews with users of large, non-domestic property and industry professionals to establish whether a need existed and how they proposed it be fulfilled. A deficiency in expertise was identified, and from this a competency specification for professionals leading energy-led refurbishment in existing, non-domestic property has been developed.

Second, this thesis explores the different forms of automated decision support within the construction sector, identifying opportunities for a structured decision-making approach to energy-led refurbishment. An optimum decision support tool (DST) process was proposed, consisting of seven steps from assessment of the existing building's state through to continuous evaluation and improvement of the refurbished building. A key module within this process was developed in detail to address the complex multiple attribute decision making (MADM) approach required during selection of energy performance improvement measure (EPIM). A set of assessment criteria, addressing a variety of performance characteristics, was designed using an online Delphi survey with a select group of 'energy in buildings' experts. The criteria range from short term impact (EPIM installation) to long term impact (EPIM operation and disposal) upon the existing property's performance. Subsequent weighting of the assessment criteria in terms of their relative importance was undertaken using the same expert group through a paired comparison survey methodology. This revealed the relative importance of each

criterion, consequently aiding prioritisation of EPIMs within the optimum DST and supporting decision-making.

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Strachan, M., and Banfill, P., (2012) ‘Decision-making criteria to aid energy-led refurbishment of existing office buildings’, In *Proceedings of the RICS COBRA Conference 2012,* Las Vegas, USA, 10-13 September, 2012

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Chapter 1: Introduction

Globally, countries are committing themselves to emission reduction targets. Under the mantle of the European Union (EU), the United Kingdom (UK) Government have assigned a stringent, legally binding target of an 80% reduction in carbon emissions by 2050 (versus 1990 levels) (DECC, 2013). This ambitious goal has significant environmental, financial and political consequences if not met.

A major source of emissions arises from the generation of fuel for energy, and efforts are therefore being focused upon macro-scale energy generation solutions that are considered sustainable. However, responsibility for emission levels also rests with the energy consumers. The transition to a low carbon economy would support the reaching of reduction targets, as well as align with the sustainable development principles.

The built environment and construction industry are major energy consumers and therefore responsible for a significant proportion of carbon emissions in the UK. The new build construction sector has been the target of Government policy; with domestic and non-domestic zero carbon targets set for 2016 and 2019 respectively. Although no such targets have been specified for the existing built environment, it cannot be ignored. Approximately 60% of the current building stock will still exist in 2050 (Carbon Trust, 2009), and existing buildings therefore pose a significant challenge in meeting the overarching 2050 target. Wood (2012) states that "Even if all new buildings were to be constructed to be low (or even zero) carbon designs, the size and rate of the development programme required would be inadequate to avoid the projected, terminal global warming." (Wood, 2012, pp. 219 – 231). A sustainable future is therefore unattainable without consideration of the existing built environment (Wood, 2006). The emissions associated with the operation of existing buildings is notable, the multiple energy applications within this sector account for approximately 40% of UK carbon emissions (Carbon Trust, 2009).

The existing UK domestic building stock undergoes considerable examination regularly, with data regarding condition, value and energy collected through various mechanisms, such as the English Housing Survey in England, UK (Ravetz, 2008). Comparatively, the understanding of the existing, non-domestic building stock is limited. Kohler and Hassler (2002) propose a primary reason being political interests lying in the understanding of social housing. Furthermore, the complexity of the non-domestic building stock creates numerous data points to be included within a systematic survey of the stock to achieve a representative sample, and therefore would result in an expensive and time consuming process (UKGBC, 2007). The physicality, operation and ownership hierarchies of the non-domestic building stock are heterogeneous in nature, all of which contribute to its complexity. Although the stock can be quite broadly sub-divided into private and public sector facilities, a vast range of construction forms, sizes, functions and ages are present (Carbon Trust, 2009). Even within these sub-categories, considerable differences in asset energy performance; building fabric, mechanical and electrical systems, and controls, as well as operational energy performance; small power and equipment, and energy management strategies exist.

The solution to reducing the energy consumed within the existing non-domestic building stock involves, first, establishing an understanding of its energy performance, and second, portfolio-wide improvement with the primary driver of improving energy performance and consequently reducing associated carbon emission levels. This improvement is a specific form of building refurbishment, and is currently within its embryonic stages within the construction industry. Although the sustainability agenda has been present and relevant within the built environment for at least ten years, with the introduction of the Energy Performance of Buildings Directive (EPBD) in 2002 (Council Directive 2002/91/EC), the successful application of its principles in existing property refurbishment is still an emerging area that requires investigation to support the industry in this current transition. The refurbishment of existing, non-domestic property faces a range of barriers, the Better Buildings Partnership (2010) identifies the five key barriers as: commercial (the landlord and tenant divide), roles and processes (lack of clarity, methodologies and evaluation criteria), financial (shortage of capital finance, and unattractive payback periods), technology (in terms of available technologies and their performance, limitations associated with existing property, and industry professionals' skills shortages), and policy (lack of emphasis and support for improvement of existing property). It is evidently a highly complex activity but one that must be addressed if we are to, not only, meet our emission reduction targets, but also future-proof our existing non-domestic building stock.

The approach to energy-led refurbishment requires definition, a recognised methodology that will structure this complex activity, and ultimately overcome the barrier associated with 'roles and processes'. It is within such a methodology that decision support sits to aid property professionals through the various steps required to achieve the desired outcome, of a building operating at its optimum efficiency.

In addition to the need for a recognised methodology, there is a dearth in low carbon skills that currently exists within the construction industry. Janda and Parag (2013) describe the industry as fragmented with regard to low carbon skills, and consequently identify the transformation of the existing building stock as an overwhelming challenge. DECC (2010) acknowledge that the Government must ensure that their communication of low carbon issues, relevant to the construction industry, is effective, but emphasise that they are reliant upon industry expertise to provide "innovative solutions", specifically within the refurbishment sector. The non-domestic sector draws together a community of different industries (Carbon Trust, 2010), that includes property investors, owners and occupiers who will also look to construction professionals for guidance through energy-led refurbishment.

The overarching aim of the research described in this thesis is to therefore develop an approach to the energy-led refurbishment of existing, non-domestic buildings that could be adopted as a standard methodology by property professionals. There are two research objectives designed to deliver this aim, and these lead to three individual studies presented within this thesis. These research objectives are not linear in the delivery of the thesis aim; instead they address two separate, yet interrelated components within the energy performance of existing, non-domestic property, as illustrated within Figure 1.

1.1 Research Objective One: Competency Specification

- Examine existing construction professionals' competencies as defined by their professional governing bodies.
- Determine a need for the development of existing professionals' competencies to respond to changing client requirements in the energy in buildings field.

- Design a competency specification for a new built environment professional, one that is capable of leading and delivering a truly innovative, compatible and comprehensive energy-led refurbishment of an existing, non-domestic property.

1.2 Research Objective Two: Decision Support Methodology

- Examine and review existing decision support tools for building performance improvements.
- Identify a need for, and define a new decision support process that is optimum in supporting energy performance improvements in existing, non-domestic buildings.
- Develop one module of the decision support process, in detail, that addresses a specific, non-domestic property type and function; an office building, classed as hard to treat in terms of energy performance.
- Examine a case study building that has recently undergone energy-led refurbishment, drawing parallels and opportunities between industry practice and the decision support process designed within this research.

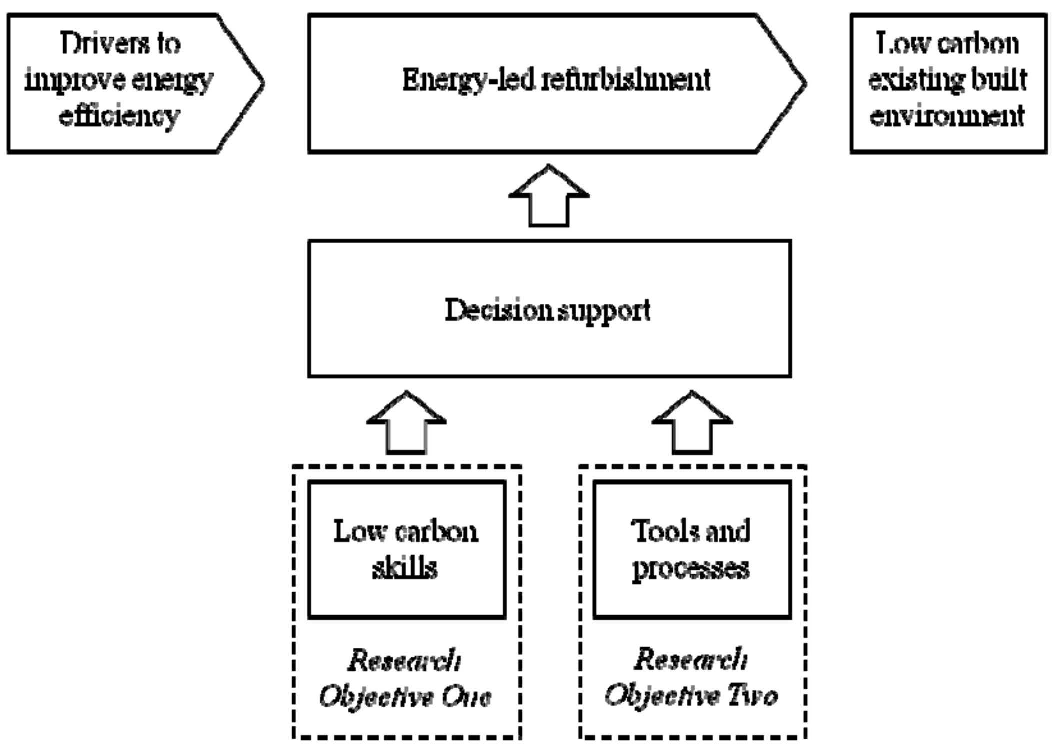

Figure 1 – Contextual Arrangement of Research Objectives

Following a literature review in Chapter 2, Chapter 3 of this thesis presents the first study, which addresses research objective one; the examination of professional competence within the low carbon construction field. Chapter 4 fulfils research objective two in part, through a second study. This presents a methodology for the energy-led refurbishment of an existing, non-domestic property, and the decision support mechanisms required to facilitate it. This may be delivered through computer software directed at facilities managers within large organisations who are responsible for the energy performance of a non-domestic property portfolio. Chapter 5 fulfils the remainder of research objective two in a third and final study. This addresses the development of a single module of the decision support methodology presented in chapter 4. The module specifically aids the assessment of individual energy performance improvement measures against a completely unique set of weighted assessment criteria (developed within the third study). Conclusions are given in Chapter 6.

Chapter 2: Literature Review

This chapter reviews the literature on refurbishment of non-domestic buildings within the context of sustainability policy and national, European and global concerns.

2.1 Sustainability

The term sustainability is complex to define. Its use and relevance has been evident within a wide range of academic research fields for several decades, although its definition remains indefinite. Several sources debate the definition of both sustainability and sustainable development on a global scale, each detail the need for such definition to lie in the practical and useful application of sustainability principles. Kemp and Martens (2007) specify the principle of protecting the current, positive aspects of human activity as sustainability and the principle of continuous improvement of human activity indefinitely as sustainable development. Glaiv and Lukman (2007) align with this theory of sustainable development as a "process or evolution", which implies that it is a constant activity that will evolve in nature simultaneously to the human race, and therefore questions whether sustainable development can be ultimately and successfully achieved. Brown et al (1987) emphasise the importance of the inclusion of contextual, spatial and time scales to ensure the accurate definition of sustainability, but identify the major goal of sustainability as the existence of a world. One of the most frequently cited definitions of sustainability states "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p15)

There are a multitude of global issues that can be addressed within the sustainability mantle, of which three distinct, yet interconnected, factors sit. These factors are most commonly referred to as economical, environmental and social. These respectively address: economic growth within society, the protection of "natural biological processes and continued productivity and functioning of eco-systems" (Brown et al, 1987, pp713-719), and the "continued satisfaction of basic human needs" (Brown et al, 1987, pp713-719). The simultaneous consideration and fulfilment of these three components equates to sustainable living. The practical application of these in a global context requires the consideration of complex sub-issues within each factor.

The risk of climate change as a result of human activity can be linked to sustainability and sustainable development. The Intergovernmental Panel on Climate Change (IPCC), "assesses the most recent scientific, technical and socio-economic information produced worldwide, relevant to the understanding of climate change" (IPCC, 2013, p1), and has made such links between climate change and sustainable development, in a measured manner (Najam et al, 2003). The impact of future climate change consequences often create connotations associated with the environmental perspective of sustainable development. However, this narrow view of climate change and the need for a broader outlook upon sustainable development is acknowledged in the existing literature (Beg et al, 2002; Munasinghe, 2000; Swart et al, 2003; Willbanks, 2003).

This outlook would consider the negative impact of climate change upon the ecological environment, that in turn has a consequential affect upon the economical environment, not purely in terms of continuous economic growth, but in the economic penalty that is predicted if climate change risk not mitigated quickly and effectively (Stern, 2007), and furthermore, the sociological impact, particularly upon developing countries, most vulnerable to climate change consequences (Munasinghe, 2000).

The complexity of simultaneously addressing the three branches of sustainable development in line with climate change risk mitigation, is amplified through the need to protect and maintain growth and improvement in each branch of sustainability. (OECD, 2001) describes the importance of the three factors in consideration of political activities. The global dissemination of sustainable development principles and practice lies in successful policy design and propagation.

2.2 Global Policy

Globally, developed and developing countries are committing themselves to reducing greenhouse gas (GHG) emissions. The need to reduce emissions is central to mitigating global warming and subsequently climate change risk. The identification of the global warming phenomenon has been linked in scientific literature (National Research Council, 2010) to increased GHG emission levels as a result of human activity, specifically traced back to the industrial revolution. Emission reduction targets, and the various mechanisms required to achieve these targets, have arisen from various influences. This includes, most notably, the United Nations Framework Convention on Climate Change (UNFCCC), an international treaty, of which the members meet annually to address actions towards tackling climate change. Pertinent global agreements have arisen from such meetings and include the Bali Road Map, Copenhagen Accord, and Cancun Agreements. The overarching agreement is the Kyoto Protocol, viewed as a historical first step towards global climate change policy, it is an international agreement that sets emission reduction targets for the period of 2008-2012. However, it was quickly condemned to fail in achieving its desired scenario, where risk of human-induced climate change is reduced to an acceptable level. Mckibben and Wilcoxen (2002) link the Kyoto Protocol's ineffectiveness to the years of negotiation it underwent within the UNFCCC platform, as well as the departure of the USA from the signatories, and as a result, calls the Protocol's financial viability into question. Nordhaus and Boyer (1999) concur with this view, identifying the balance between environmental and financial benefits as a key issue for success. Bohringer (2004) conclude that the USA departure in fact "led to a complete dismantling of the Kyoto Protocol" (Bohringer, 2004, pp. 597 – 617). Victor (2004) believe an overhaul of the strategy was required to "achieve real action" (Victor, 2004, p24). The five year structuring of the Protocol provides an opportunity for re-evaluation and response to such criticisms, through an amended post-2012 agreement. Streimikiene (2009) state its "given rise to a large number of international climate policy architectures" (Steimikiene, 2009, pp. 129 – 141), and proposes that a successful agreement would have to consider all aspects of sustainable development in tackling climate change, with the inclusion of developed and developing countries. EEPS (2009) highlight the key issue to lie in determining an approach that commits developing countries to tackle the emissions for which they are responsible whilst avoiding a negative impact upon their economic growth, required to take them out of poverty and therefore fulfil socio-economic facets of sustainable development.

Some carbon emission reduction commitments, that countries have agreed to set, are conditional on an overall international agreement being reached. The countries that consider themselves to be in direct competition with one another over manufacturing of goods, such as the United States of America and China, feel that it is unfair for one to commit to such reduction targets and not the other and so political barriers arise. Chichilinsky (2009) predicts a pessimistic prospect in relation to the USA and China agreeing upon emission limits, highlighting that they are in fact two of the largest contributors to worldwide emissions, therefore stressing the severity of the situation if they do not arrive at some agreement. There are some countries that are on track to achieve the targets that they have agreed to, such as the United Kingdom and Germany, but it is these smaller European countries that are the smallest polluters of the global environment.

It is still clear regardless of the success in setting or achieving emission reduction targets worldwide, that sustainability has become a major issue to be addressed at the many summits and talks held between world leaders every year, for example, the UNFCCC COP meetings, G8 Summits and the World Energy Leaders' Summits. The topic of sustainability is therefore becoming increasingly important on the world leaders' agenda and engages both developed and developing nations together in discussions about feasible solutions to climate change.

2.3 European Policy

The reaction of the European community towards the desired goals of international talks and initiatives to tackling climate change, and the implementation of sustainable development principles, has been overall positive. Lorenzoni et al (2006) states "The European Union (EU) politically has been a fervent supporter and promoter of the Protocol and the UK has taken up a leading role on the issue" (Lorenzoni et al, 2006, pp. 73 – 95). As a result the European Climate Change Programme (ECCP) was created to provide a platform for the introduction of European Directives developed to tackle climate change. The European Community has committed itself to the overarching target of reducing emissions by 80% by 2050 versus 1990 baseline levels (European Union, 2002). There is also an intermediate emissions reduction target of 20% by 2020, although this would be superseded by a 30% target for 2020 if particular conditions are met to validate this commitment. It is the initiatives and directives that align with the ECCP that will be implemented across the EU member states to achieve this target. For example the European Energy Action Plan (EurActive, 2010), the EU Emissions Trading Scheme (European Commission, 2010), the promotion of renewable energy directive (European Union, 2001), energy performance in buildings directive, (European Union, 2002), the promotion of combined heat and electricity generation directive

(European Union, 2004), eco-design directive (European Union, 2005), and end-use efficiency and energy services directive (European Union, 2006) etc.

2.4 UK Policy

The UK Government's vision for tackling climate change aligns closely with the EU vision, and as a member state, seeks to take an active, exemplar role within the climate change debate. DETR (2000) describes how the UK Climate Change programme has gone beyond what was required from the Kyoto Protocol, and set comparably more ambitious domestic targets. Rudd (2009) affirms that the EU, and consequently its member states, is taking the lead in tackling climate change and should continue to do so "...both in the setting of targets and establishing policy tools..." (Rudd, 2009, p.1).

The UK government intends to achieve the ambitious domestic, emission reduction targets through close involvement with the EU and the application of their policies within a UK context. The UK 2008 Climate Change Act, "World's first long term legally binding framework to tackle the dangers of climate change" (DECC, 2008a), includes the overarching target of an 80% emissions reduction by 2050 (against 1990 levels), as well as a 34% emissions reduction by 2020. The latter target is set an additional 14% above the EU's specified 20% reduction commitment for 2020, even if the EU's conditional 30% by 2020 target is validated, then the UK will strive to achieve an additional 4% reduction.

From the UK Climate Change Act (Parliament, UK., 2008) arose important initiatives to address climate change, ultimately the ambitious carbon reduction targets were most notable, but also a Carbon Budgeting System (DECC, 2008b), the formation of a Committee on Climate Change (CCC) (CCC, 2010), additional carbon reduction proposals such as the Carbon Reduction Commitment Energy Efficiency Scheme (CRC) (DECC, 2010), measures on bio fuels etc. The Act commits the UK Government to produce five-yearly reports upon the current state of the UK's climate change efforts and the development of a programme designed to tackle climate change risk to the UK. In addition to this the UK Government has been given further powers allowing the formation of a Community Energy Savings Programme and to influence and encourage the country's private sector to reduce emissions.

The CRC Energy Efficiency Scheme launched in 2010 is a trading scheme designed to encourage large organisations that consume a significant amount of energy and consequently contribute to a large proportion of the UK's emission levels, to assess, manage and improve their energy efficiency. DECC (2010) describe the scheme as "central to the UK's strategy for improving energy efficiency and reducing carbon emissions" (DECC, 2010, p.1). However, the scheme has been widely criticised since its release. The reason for such criticism lies with the performance league table the scheme proposes as well as the complexity and cost for the participants. As a result of a Government consultation, the CRCEE Scheme will be revised and released in June 2013, and therefore will address concerns of both the public and private sector participants. Chief Executive of the Committee on Climate Change, David Kennedy states "The CRC scheme has the potential to make an important contribution towards meeting carbon budgets. However, current proposals risk making the scheme unnecessarily complex. We are therefore proposing that Government modifies its design to make participation in the scheme easier..." (CCC, 2010, p.2).

2.5 New Build Construction and Sustainability

There are two major branches of the construction industry specific to property; new build construction and repair, maintenance and refurbishment. The new build construction sector has been the target of many low/zero carbon Government policies. Currently, in the UK, all newly built domestic properties must be zero carbon from 2016 onwards (DCLG, 2009a). The Code for Sustainable Homes, introduced in 2006, is a standard for sustainable residential property (voluntary in the private sector) that is set above the current minimum requirements of the building regulations (DCLG, 2009a), and supports the domestic sector in achieving the 2016 target. The new build, non-domestic sector has been set a similar target, in that all newly built non-domestic properties must be zero carbon from 2019 onwards (DCLG, 2009b). The definition of zero carbon, at its simplest equates to a building with net zero carbon emissions over one year. In newly built domestic property this will include "emissions from space heating, ventilation, hot water and fixed lighting, expected energy use from appliances, and exports and imports from the development (and directly connected energy installations) to and from centralised energy networks." (BSRIA, 2009a, p.1) The domestic zero carbon definition has undergone amendment since its initial designation in 2006, in line with the release of the Code for Sustainable Homes, it was aligned with the attainment of level 6 within the Code. However, the difficulty in achieving this level for every site and the expensive nature of doing so, led to the Government's 2008 consultation on the definition of zero carbon (DCLG 2009a). As a result of this consultation, the definition consists of a three-tiered hierarchy to be met, and includes energy efficiency (addressing the standards of the building fabric and mechanical/electrical systems, and appliances where supplied by the developer), carbon compliance (the use of on or near site energy generation) and allowable solutions (essentially carbon off-setting through off site energy generation or Community Energy Funds paid into by developers) (DCLG, 2009a). BSRIA (2009a) raises questions surrounding credibility of the zero carbon definition, with reference specifically made to the third tier, allowable solutions, and whether these will actually off-set carbon to net zero in real terms. Furthermore, how this definition will translate into future building regulations is still unknown to some extent (UKGBC, 2008). Saunderson et al (2008) emphasises the need for the UK Government to avoid application of zero carbon 'too literally', and there is an opportunity to achieve both carbon and social integration benefits through "linking new build developments intrinsically with the existing built environment" (Saunderson et al, 2008, p.7) to reduce emission levels. Ultimately, the definition of zero carbon homes is well established, even if questions over its effectiveness remain. Conversely, the definition of zero carbon non-domestic property remains ambiguous. It is acknowledged that such a definition needs further examination and should be built upon the domestic equivalent (UKGBC, 2008; DCLG, 2009b; UKGBC, 2010). Upon the successful proposal of the Code for Sustainable Homes, the case was made for a Code for Sustainable (Non-domestic) Buildings. The UKGBC assembled a task group in 2009 to examine the need and potential format of a non-domestic code. The primary outcome suggested that there was a need for such a code that would address both new and existing property, that it should aid industry to understand sustainability policy not contribute to existing confusion, address zero carbon targets for the sector, and proposed a novel building 'health check' or MOT. "The Code for Sustainable Buildings should establish one clear policy and regulatory trajectory towards a sustainable built environment..." (UKGBC, 2009, p.2). However, the code has remained as a proposal to date.

The identification of a need for low/zero carbon buildings is evident in Government targets, policies, and consultations. The ambiguity that exists specifically within the non-domestic sector regarding first, the definition of zero carbon, and second, an appropriate trajectory for achieving zero carbon, is primarily due to the complexities that lie within non-domestic property. This complexity translates into the design, construction and commissioning of energy efficient non-domestic buildings. Bordass and Leaman (2005) highlight that although a well established methodology for new build delivery exists in the form of the RIBA (Royal Institute of British Architects) Plan of Work, key construction professionals as well as clients do not “engage closely with the performance of the buildings they have created.” (Bordass and Leaman, 2005, pp. 347 – 352). As a result, persistent issues arise in building performance post-handover, even in the simplest of building designs. Way and Bordass (2005) identify that sustainability performance criteria, as it becomes increasingly stringent going forward, will place greater emphasis upon “predictability of the end product”(Way and Bordass, 2005, pp. 353 – 360). If this predictability is not yet being achieved, as was found in a ground-breaking series of post-occupancy studies entitled ‘Probe’ (Bordass et al, 2001), then it will only become a bigger issue as progressively innovative design standards are expected by clients procuring new build property (Way and Bordass, 2005). Bordass and Leaman (2005) identify effective feedback throughout the procurement of a property as a mechanism for improving both quality and sustainability. BSRIA (2009b) presents the Soft Landings framework, this aims to achieve better buildings through elimination of gaps that currently exist between client and designer expectations and the actual performance of the building delivered, with a particular emphasis upon energy performance, through additional support and feedback throughout the entire build process, not just at handover/post-handover. The Soft Landings framework can be used within the new build construction process as well as refurbishment of existing property.

2.6 Sustainability in the Existing Built Environment

As discussed, the Government have set definitive targets for the new build construction sector. However, it is estimated that less than 1% of the existing building stock will be replaced annually going forward (BSRIA, 2009a). Furthermore, approximately 60% of the current building stock will still exist in 2050 (Carbon Trust, 2010), and existing buildings therefore pose a considerable challenge in meeting the overarching 2050 emissions target. Wood and Muncaster (2012) states that "Even if all new buildings were to be constructed to be low (or even zero) carbon designs, the size and rate of the development programme required would be inadequate to avoid the projected, terminal global warming." (Wood and Muncaster, 2012, pp. 219 – 231). As a result, a sustainable future is therefore unattainable without consideration of the existing built environment (Wood, 2005; Mansfield, 2009). The emissions associated with the operation of existing buildings is notable, the multiple energy applications within this sector account for approximately 40% of the UK carbon emissions (Carbon Trust, 2010).

Wood (2005) notes the consideration of the embodied energy already associated with the existing built environment alongside the reduction in operational energy consumption. Embodied energy can be defined as the "sum of all energy required to extract, process, deliver and install the materials needed to construct a building" (Jackson, 2005, pp. 47 – 52). Consideration of embodied energy can be extended beyond this definition, to apply to the entire lifecycle of a building, up to end of life, and therefore including any refurbishment works across the operational lifetime of a property, as these too, contribute to the total embodied energy. The embodied energy associated with an existing building could be measured through examination of the materials and construction techniques used at the time of construction. This form of embodied energy is considered as 'spent' or already used/generated, and is often referred to as 'sunk energy and carbon' (Menzies, 2011, p.5). It is therefore not as crucial as measuring the embodied energy associated with a new building, yet to be constructed, in meeting carbon reduction targets. However, the measurement of an existing building's embodied energy is useful in a presenting the case for retaining and improving existing buildings over demolition and new build construction. The embodied energy that is already attributed to an existing building combined with that attributed to refurbishment works, is likely to be less than the embodied energy attributed to demolition of the existing building and construction of a new property (Menzies, 2011).

The existing UK domestic building stock undergoes considerable examination regularly, with data regarding condition, value and energy collected through various mechanisms, such as the English Housing Survey in England, UK (Ravetz, 2008).

Comparatively, the understanding of the existing, non-domestic building stock is limited. Kohler and Hassler (2002) propose a primary reason being political interests lying in the understanding of social housing. Whilst Ravetz (2008) suggests the contentious nature of Government involvement in the private sector as reasoning for little attention towards the non-domestic built environment. Furthermore, the complexity of the non-domestic building stock creates numerous data points to be included within a systematic survey of the stock to achieve a representative sample, and therefore would result in an expensive and time consuming process (UKGBC, 2007). The physicality, operation and ownership hierarchies of the non-domestic building stock are heterogeneous in nature, all of which contribute to its complexity. Although the stock can be quite broadly sub-divided into private and public sector facilities, a vast range of construction forms, sizes, functions and ages are present (Carbon Trust, 2009). As part of a project to develop a national, non-domestic building stock database which would provide a better picture of energy use in non-domestic buildings, Steadman et al (2000a, b) surveyed four towns in England, recording a range of building characteristics. This work confirmed the complexity of building forms in the non-domestic sector. Even within these categories, considerable differences in asset energy performance; building fabric, mechanical and electrical systems, and controls, as well as operational energy performance; small power and equipment, and energy management strategies exist.

The solution to reducing the energy consumed within the existing non-domestic building stock involves, first, establishing an understanding of its energy performance, and second, portfolio-wide improvement with the primary driver of improving energy performance and consequently reducing associated carbon emission levels.

2.7 Global Building Assessment Methodologies

The existing literature presents numerous reviews and proposals of methodologies and criteria for the appraisal of sustainable/energy performance of new and existing buildings (Birtles and Grigg, 1997; Cohen et al, 2001; Ellison and Sayce, 2007; Lutzkendorf and Lorenz, 2006; McDougall et al, 2002). However, several of the 'Green Building Councils' representative of different countries around the world, have their own sustainability assessment methods/tools/certification schemes that are widely known. These began with the development of BREEAM (Building Research Establishment Environmental Assessment Method) in 1990 in the UK, followed by LEED (Leadership in Energy and Environmental Design) in 1998 in the USA. The former are possibly two of the most widely adopted methods globally, although other methods include: Green Star (Australia), DGNB (Germany), Estidama (Middle East), CASBEE (Japan), HK-BEAM (China). Although similar, they are not directly comparable, primarily due to the fact that they have been designed to suit the climatic conditions and cultural priorities of the country in which it has been developed (Haapio and Viitaniemi, 2008; BSRIA, 2011). Essentially, the core of these methods is some set of criteria by which to score proposals for a building, potentially at any stage in its lifecycle, although some methods are limited to new build construction or refurbishment works. The outcome of this method is an indication of how sustainable/green/environmental the building's performance is. Cole (2005) notes the opportunity these methods provide as a forum for sustainable building performance. However, the multiple methods competing within the same market could lead to confusion rather than an open debate forum and cause consumers to be unsure of the optimum method for their situation (Cole, 2006). Haapio and Viitaniemi (2008) share this view, with concern upon the clarity of the 'where', 'when' and 'who' of each assessment method, consequently leading to barriers in the uptake of such methods. Cole (2006) highlights an additional issue with numerous assessment methods, in the level of learning that construction professionals will need to undertake to become and remain knowledgeable of multiple methodologies, although this may be lessened due to the number of similarities between all of them. Cole (2005) predicts continued revision to the assessment methods going forward, and as a result increased complexity. BSRIA (2011) questions whether this continuous refinement to produce progressively more demanding rating methodologies is a positive trajectory or if it will in fact lead to unnecessary complexity and cost.

2.8 European/UK Building Assessment Methodologies

The release of the EU Energy Performance of Buildings Directive (EPBD) in 2002 (Council Directive 2002/91/EC) introduced the requirement of increasingly stringent energy performance within building regulations as well as energy performance certification for member states. The EPC (Energy Performance Certificate), as of 2008 in the UK, is required when a (domestic/non-domestic) property (whole/ part of a building) is constructed, sold or let (DCLG, 2013). The EPC essentially measures the asset energy performance of a property, an energy rating is presented that is based upon potential performance of the asset's building fabric and services (heating, cooling, ventilation and lighting). The EPC rating is provided along with a recommendation report, with potential measures that could improve the energy efficiency of the property if implemented. An accredited energy assessor must carry out the EPC using an approved simulation software tool that complies with the National Calculation Methodology (NCM), broadly, either the Simplified Building Energy Model (SBEM) produced by the Government or a Dynamic Simulation Model (DSM) (DCLG, 2013). Although a standard methodology and software tool is used in the creation of an EPC, the accuracy of the EPC is reliant upon the assessor's service provision. The level of detailed data/information the assessor gathers from a property will impact the accuracy of the EPC, as default values/systems are present within the methodology the surveyor could theoretically select these where data/information was not obtainable. Dixon et al (2008) document some of the initial issues and predictions associated with EPCs and the commercial property market, a key short term prediction being 'price-chipping' against rental/capital value of a property where a potential occupier could utilise the EPC recommendations report to demand price reductions.

In summary, the saturation of the EPC market with numerous companies offering energy assessor services, and the resultant competitive nature of EPC assessment pricing, has largely led to the 'pricing-out' of high quality assessors. Consequently, many of the current EPCs, valid for up to ten years, could be built upon inaccurate/incomplete data, as the EPC has quickly become viewed as a licence to transact by many in the property sector rather than a fair representation of a building's energy performance.

The DEC (Display Energy Certificate), released in the UK in 2008, is required when a property is occupied by a public authority and visited by the public, and is over 500m^2 TUFA (Total Usable Floor Area) (DCLG, 2011). The DEC assesses the actual energy consumed through building operation over one year. Similarly to the EPC, an advisory report is provided along with the operational performance rating, presenting recommendations for improvement in energy efficiency. The combined EPC and DEC ratings represent the asset and operational energy performance of a property respectively, and it is therefore beneficial to hold both to provide a full picture of overall energy performance. It was highly anticipated that the roll out of mandatory DECs for all non-domestic property, within the public and private sector, would arise from the UK Energy Act 2011. This did not occur and resulted in disappointment for key players in the property sector backing such movement towards mandatory DECs (BBP, 2012). Bruhns et al (2011) undertook an investigation into DEC benchmarks and found that these were largely accurate, and therefore supports the roll out of mandatory DECs across the non-domestic building stock. The UK's Green Building Council are major advocates of mandatory DECs due to the "...lack of good data on energy use...on which to base energy reduction strategies and investment decisions" (UKGBC, 2011, p.5). However, UKGBC (2011) recognise the barrier arising from the complexities of the landlord and tenant relationship regarding energy consumption, particularly in buildings with multiple tenants. As a result, UKGBC (2011) recommend the use of DECs to capture tenant energy consumption and landlord DECs (alternatively known as LES – Landlord Energy Statement) together to provide a clear representation of the operational energy consumption within a multi-tenanted property.

In order to understand the energy performance of an existing, non-domestic property, both the asset and operational performance of the building is required, and the EPC together with the DEC (in some form), is one consistent approach to measuring this performance across the existing building stock.

2.9 Building Performance Improvement

It is through such assessment methods and energy performance surveys of existing property that a baseline energy performance and associated carbon emissions can be established. It is necessary to understand this baseline performance in order to identify opportunities and measure improvement post-refurbishment. This baseline also acts as an indicator of refurbishment activity, for example, Carbon Trust (2010) identifies the relatively constant level of carbon emissions associated with non-domestic property over the last twenty years as a key indicator of a dearth in refurbishment activity in this sector.

It is estimated that buildings are accountable for approximately 46% of total UK energy consumption, and of this, non-domestic property equates to approximately 17% (Pout, MacKenzie and Bettle, 2002). There are different approaches to understanding this total energy consumption and carbon emissions at individual property level. Liddiard, (2012) examine energy end-use in non-domestic buildings through the relationship between space usage/function and energy consumption levels. They conclude that in retail property, the majority of electrical energy is consumed in sales activity space, with other high energy consuming functions identified as storage, office and circulation. In offices, the majority of electrical energy is consumed in office work space, followed by reception, storage, circulation and meeting spaces. Alternatively, energy and/or carbon emission levels associated with key building end-uses (heating, lighting, cooling, ventilation, catering, hot water, equipment and other) is used (Pout, MacKenzie and Bettle, 2002; Carbon Trust, 2009; Perez-Lombard, Ortiz and Pout, 2008). Pout, MacKenzie and Bettle (2002) identify heating to attribute to greater than half of overall energy use in the majority of non-domestic buildings, with lighting as the second largest energy consumer.

Different fuel types used in the operation of buildings equate to different carbon emission levels. Energy consumption and carbon emission levels should be considered simultaneously, not substituted for one another in decision making. The metric that takes precedence for reduction will be dependent upon the decision maker, although it should be noted that the UK reduction targets relate to carbon emission levels, compared to other western European countries whose targets are concerned with energy consumption reductions (European University Institute, 2012). Bordass et al (2001) highlights the carbon intensive nature of electricity compared to gas per delivered unit. Pout, MacKenzie and Bettle (2002) also identify that delivered energy emission factors cause electrical energy consumption to be notably more carbon intensive than gas energy consumption, although note that gas supplied energy typically accounts for a greater percentage of energy end-use in commercial and public sector buildings.

2.10 Barriers to Building Refurbishment

Although a robust (albeit generally high level) understanding of how energy is consumed within the non-domestic sector is evident within the literature, how this data is interpreted can lead to complexities in decision making. Furthermore, additional barriers to refurbishment and decision-making within this process are known, and must be overcome if the required energy and carbon emission reductions are to be achieved within the non-domestic sector.

BBP (2010) identified five key barriers to refurbishment of non-domestic property for carbon reduction, as: commercial (the landlord and tenant divide), roles and processes (lack of clarity, methodologies and evaluation criteria), financial (shortage of capital finance, and unattractive payback periods), technology (in terms of available technologies and their performance, limitations associated with existing property, and industry professionals' skills shortages), and policy (lack of emphasis and support for improvement of existing property). LCICG (2012) similarly highlighted commercial, financial and regulatory obstacles to innovation in non-domestic property, as well as the fragmented supply chain, conservative nature and lack of necessary skills associated with the building sector. European University Institute (2012) also looked to professional skills as a barrier to energy-led refurbishment, stating the "...process involves so many small actors that often do not have the appropriate skills and/or information to take these decisions rationally." (European University Institute, 2012, p.5) and that education of professionals in the building sector is essential if they are to act as advisors to property decision makers. Kohler et al (2009) identify a transition in building demand within Europe, from the construction of new property to the maintenance and refurbishment of existing property that will oblige property professionals to shift their attention. The need for professional competency in this field presents a significant barrier, as the nature of refurbishment is complex and must be guided by industry professionals.

Once the decision to undertake refurbishment of a property has been made, how the optimum refurbishment strategy is designed must be considered, and the existing literature examines this. CALEB (2008) identifies an inordinate focus upon highly complex refurbishment improvement options as a key barrier to improving performance, and states that readily available solutions (e.g. fabric thermal performance improvements) are suitable in doing so but are not being implemented as decision makers are distracted with higher risk options. Carbon Trust (2010) concurs with this in part, as they put forward a staged approach to building performance improvement, progressing from simple, cost-effective measures to a more expensive, integrated approach leading to 2050. Bettle, Pout and Hitchin (2006) suggests prioritisation of measures from a financial perspective also, questioning whether it is more effective to implement fabric measures to reduce demand of heating systems and consequently fossil fuel consumption or improve the efficiency of electrical systems to reduce property reliance upon electricity. However, if this were to be viewed from a carbon perspective, then perhaps the inverse would be suggested. Roberts (2008) suggests when building fabric is improved that it is the optimum time for HVAC system replacement. This infers a whole building approach to refurbishment, which is essential when improving an existing property’s energy performance, as changes to fabric could cause a change in the demand of building services and vice versa. This holistic view of building performance is beneficial in ensuring that the impact of individual improvement measures is considered comprehensively, and is an approach that is already evident in the domestic sector (Fyhn and Solli, 2012).

However, it may not be as simple as Roberts (2008) suggests, as buildings undergo regular repair and maintenance works that involve replacement cycles of key building systems. Brand (1994) presents a model of key building systems’ lifecycles, with the structural frame remaining until end of building life, external fabric systems changing every 30-50 years, building services systems at a minimum of every 15 years, use of space at monthly/yearly intervals and equipment changes as often as minutes, hours or days. A truly whole building approach would need to consider these concurrent works in line with the refurbishment improvements.

European University Institute (2012) highlights the nature of refurbishment for energy performance improvement in terms of the numerous improvement options available which can vary so widely in terms of cost, predicted savings and technical performance. It is the multiple attribute decision making process involved in this form of refurbishment that poses a significant challenge. The existing literature presents numerous decision support models and tools for the design, construction and refurbishment of buildings and these are examined in detail within Chapter 4 of this thesis. Although the literature presents a variety of solutions to decision-making, it widely agrees upon the complex nature of refurbishment for energy performance improvement, and wider sustainable benefits. Mickaityte et al (2008) describes refurbishment of this nature as "very sophisticated" as the process must satisfy multiple factors. Babangida et al (2012) concur, highlighting refurbishment's "multi-faceted" form, necessitating "collaborative efforts to overcome physical challenges" (Babangida et al, 2012, pp.1091-1105).

2.11 Refurbishment of Hard to Treat, Non-Domestic Buildings

From a strategic perspective of the existing building stock, it is sensible to first address those properties that present cost effective opportunities for improving energy performance and associated carbon emissions. However, if carbon reduction targets are to be met then it is not sufficient to undertake refurbishment of these opportunities alone, the scale of the problem means that even those properties considered hard to treat must too be improved as far as reasonably possible (European University Institute, 2012). Roaf et al (2008) defines hard to treat by different construction forms, one of which is solid wall construction. This construction type is associated with pre-1919, traditional properties, these equate to 20% of the entire building stock in Scotland (Historic Scotland, 2012) indicating the significance of traditional property in the UK built environment.

Hard to treat terminology is often associated with domestic property and much of the literature is directed towards the domestic sector (Loveday et al, 2011; Lewis, 2010; Beaumont, 2007, Vadodaria et al, 2010; Roaf et al, 2008). The hard to treat, solid wall construction form is evident in both the domestic and non-domestic stock. The solid wall non-domestic property is typically the conversion of a large historical, domestic property, as well as purpose built, office locations. The literature providing guidance on solid wall domestic property is transferable to a point from a technical perspective, as the built form is consistent across the two sectors, although the occupancy type and patterns varies between the two and must be considered when evaluating the energy performance of a solid wall, traditional non-domestic building. This non-domestic property type can be found in major city centres across the UK, as office premises occupied by both public sector organisations and service sector businesses, providing them with a presence in the city centre. Traditionally, city centre office locations have been desirable due to the obvious benefits associated with accessibility for staff and clients as well as nearby support services (Scottish Government, 1998). Changing working requirements associated with telecommunications and desirable open plan environments gave rise to out of town office locations, such as business parks.

Although the rise of 'virtual working', through increasingly efficient telecommunications and computing devices mean that working from home is a viable alternative (Hill, Ferris and Martinson, 2003), potentially negating the need for vast out of town office spaces, and a return to smaller inner city 'base' locations for staff, such as 'hot desking' facilities (Cascio, 2000). It is evident from the existing literature, that although working practices may change over time, the inner city office location (and consequently the historical non-domestic property) remains relevant to date. As occupiers, large businesses and organisations are required to respond to increasingly prevalent legislative drivers, as well as drivers associated with their core operations, for sustainable performance, the energy efficiency of the portfolio in which they operate becomes highly relevant.

The traditional view of business strategy lies in the continued generation of profit to satisfy shareholders. However, this approach to business is changing to integrate the principles of sustainable development, McKinsey (2011) presents a global survey of company executives which found the participants to view the implementation of sustainability in business as no longer a process by which to satisfy reputational criteria but actually improved their organisation's short and long term value. Kerr (2008) explains that many large organisations are in a position to adopt social entrepreneurism, in which the subject of sustainability falls, and that the transition is unavoidable. A prominent driver has been the identification of climate change as a strategic issue in business management and its consequential impact upon a business' competitiveness (Okereke and Russel, 2010). Interestingly, regulatory drivers have already encouraged some businesses to review their sustainable performance, as those taking the initiative to invest in low carbon approaches early view new regulations as supportive and welcome their establishment (Okereke and Russel, 2010). It can therefore be suggested that many businesses do not view climate change and their resulting energy management approach as a process carried out to satisfy regulation but one that is inherent to their overall business strategy. It is in fact an economic opportunity, whether that be in the form of penalty avoidance or reduction in overhead costs, particularly with the uncertainty associated with energy prices, with rises predicted as high as 60% between

2009 and 2016 (Harvey, 2013). Studies have shown that the majority of professionals working within small, medium and large businesses believe that energy management strategy is very important to their business and will be increasingly so (British Standards Institution, 2009). A key element of energy management strategy is a company's property management team and how it is organised to achieve results. Many businesses now employ a dedicated energy manager who is set annual energy reduction targets, either as a contractual requirement or within a bonus incentive scheme.

The sustainable performance of hard to treat, traditional, city centre offices is not only relevant to the occupiers and their business operations but also to the heritage of the existing stock. The conservation of traditional property aligns with the core principles of sustainable development, as does their energy-led refurbishment. In simultaneously satisfying both requirements, technical and ethical barriers, in addition to those already identified, must be addressed.

Adaptation of traditional buildings can be viewed as sustainable in that it they remain a valuable and relevant part of today's society, by ensuring their survival. The historic built environment brings great benefits to society; social, educational, economic and environmental. Historic Scotland (2002) identifies the historic built environment as key contributor to quality of life and provider of a sense of national identity. Palmer (2008) discusses the positive impact the historic environment has upon a community, also highlighting the sense of identity and meaning it holds, creating a unique environment. Beyond community level value, Palmer (1999) identifies a correlation between the built heritage and a sense of national identity, in an increasingly globalised society.

Historic buildings are often the result of a great deal of high quality design and construction, proven by the centuries that they stand for (Feilden, 2012). Many are admired as the culmination of excellent craftsmanship or the clever use of vernacular materials to create exquisite structures representative of their time. These buildings provide inspiration for modern architecture and encourage creative solutions to combining old with new in the same setting. "...redevelopments can draw inspiration from our past in creation of our future surroundings and can provide points of reference and cultural continuity" (Scottish Government, 2007). Our historic building stock can therefore educate built environment professionals.

The economic benefits provided by the built heritage arise from tourism. However it is not only the historic buildings and structures that have been converted into tourist attractions but it is the atmosphere within towns or cities that is created by the historic built environment. This generates a significant income as well as providing additional employment for the local area. Scotland, for example, is known internationally as a country with a strong built heritage, the Scottish Government (2007) examines how Scotland's architecture policy reinforces the economic benefits associated with our built heritage, "...a real economic driver, attracting inward investment, helping communities to regenerate and playing a vital part in our tourist industry" (Scottish Government, 2007, p.88).

Changeworks (2008) notes the significant embodied energy associated with traditional properties. Matsumoto (1999) argues that when an old inefficient property is replaced with a new, efficient version, the embodied energy associated with the demolition and new construction will be offset within sufficient time through energy savings of the new building. However, Kennedy (2010) suggests the improvement of existing inefficient properties as a sensible alternative, as the true embodied energy level associated with these buildings is still not fully comprehended.

In overcoming the technical barriers to improving traditional property, it is necessary to first understand the holistic behaviour of this property type compared to that of modern construction. May and Rye (2012) identify the broad differences in traditional and modern building behaviour in both their pre and post refurbishment state. May and Rye (2012) conclude a dearth in energy in buildings research within this specific property type, and the importance in fulfilling this deficiency due to the significant differences from other property types. Traditional buildings interact with their environment in a different manner from modern construction equivalents. Traditional properties, in the context of this research, align with the definitions presented in Urquhart (2007a) and Drewe (2007), in that they typically pre-date 1919, have mass masonry (solid) walls, little or no insulation built into the existing fabric, originally single glazed windows and high air infiltration levels. The building fabric readily allows the absorption and evaporation of moisture; conversely, modern construction forms look to eliminate the transfer of moisture across the building fabric and utilises a series of impermeable, sealed materials, to do so.

These barriers can be overcome through careful consideration of refurbishment improvement measures, utilising the range published guidance that addresses specific measures largely produced by organisations that safeguard the historic built environment. English Heritage (2012) states that they support the Government's intentions to reduce the energy consumption associated with the built environment so long as it is approached in a manner that does not damage heritage buildings. Stubbs (2004) recognises this alignment of historic building adaptation with the principles of sustainability, specifically referencing energy conservation and the re-use of existing buildings.

2.12 Conclusion

A review of the literature has revealed the increasing emphasis being placed upon carbon emission reductions globally through policy and binding targets that countries are committing to. The non-domestic property sector presents notable opportunity for carbon emission reductions through improved energy efficiency, with great emphasis being placed upon new build construction to date. However, the significance and challenge associated with the existing building stock is emerging and must be addressed through refurbishment. The refurbishment of existing non-domestic buildings faces many barriers, including an ill-defined process with a deficiency in low carbon skills to guide building owners and occupiers in this complex transition.

The aim of the work described in this thesis is therefore to develop an approach to the energy-led refurbishment of existing, non-domestic buildings, addressing decision support and the professional competence required to deliver it. The following chapters detail three studies examining both the 'energy in buildings' professional competency and decision support mechanisms for energy-led refurbishment.

Chapter 3: Energy in Buildings - Professional Competencies

3.1 Introduction

The non-domestic building sector contributes significantly to the UK's net carbon emissions. Although this sector is diverse, a percentage can be classed as professional buildings, those properties in which white-collar businesses function, where the building portfolio is inherent to business operation (Janda and Parag, 2013, p.1206). These are most typically office locations, many of which hold great potential for energy performance improvement. This capability for improvement is combined with a multi-faceted driver for change, examples include: carbon reduction legislation, corporate realisation of the economic opportunity associated with energy efficiency, and a change in perception towards the relevance of environmental issues in business. The opportunity to improve the energy performance of existing office buildings is therefore present. However, the practicality of fulfilling this opportunity is highly complex due to numerous factors: financial, technical and social in nature, that need to be considered simultaneously. Furthermore a particular level of professional competence is required to support this complex process of energy-led improvement of an existing building; termed as energy-led refurbishment within this thesis.

Built environment professionals must recognise the changing requirements of non-domestic building owners and occupiers towards energy-led refurbishment and adapt their level of competence in this field to respond effectively. This deficiency could be remedied through the establishment of a recognisable, specialised branch of existing professionals, equipped to deliver energy-led refurbishment, although, Janda and Parag (2013, p.1206) query whether our increasing understanding and knowledge of climate change is significant enough to support the proposition of an entirely new professional.

The objective of this chapter is to understand the effectiveness of existing institution-defined competencies for built environment professionals' in equipping them to deliver a successful energy-led refurbishment. It proposes an optimum competency specification for this type of work. The methodology, results, associated discussions and conclusions will be presented here.

3.2 Professional Competence Methodology

A desk study was carried out to examine the professional competency sets as defined by the institutions of the traditional built environment professions in the UK. The competency sets defined by the BIFM (British Institute of Facilities Managers) (BIFM, 2010), RICS (Royal Institute of Chartered Surveyors) (RICS, 2006a; RICS 2006b; RICS 2006c), RIBA (Royal Institute of British Architects) (RIBA, 2010), and CIBSE (Chartered Institute of Building Services Engineers) (CIBSE, 2009), were surveyed to determine the core skills of architects, building surveyors, building services engineers, facilities managers, project managers and quantity surveyors.

A set of structured interviews with a small but representative group of experienced professionals in building surveying, facilities management, project management and quantity surveying as well as construction industry clients (non-domestic building users) from facilities management and energy management backgrounds were held in 2011. See Table 1 for interview participants. Open-ended questions were developed for the construction professional and client interviews, see Appendix A for these. The majority of interviews were held in the workplaces of the participants, the others being carried out over the phone. The interviews were recorded and transcribed following the interview to allow for reflection of the results and key points to be highlighted.

All of the professionals involved were highly experienced in their field. As shown in the interview format presented in Appendix A, the interviews began with a series of questions regarding the participants' background to affirm their level of expertise.

Participant No.	Discipline	Job Title	Domain
1	Building Surveying	Senior Building Surveyor	Construction Professional
2	Facilities Management	Facilities Management Consultant (with Building Services Engineer Background)	Construction Professional
3	Quantity Surveying	Senior Cost Consultant	Construction Professional
4	Project Management	Associate Director of Project Management	Construction Professional
5	Facilities Management	Head of Facilities Management	Construction Client
6	Energy Management	Energy Manager	Construction Client
7	Energy Management	Energy Manager	Construction Client

Table 1 – Interview Participants

3.3 Professional Competence Results and Discussions

Relevant discussion themes relating to professional competence in the energy performance of the built environment (specifically energy-led refurbishment of commercial property) that arose from the interview results are presented and an optimum competency specification is defined.

3.3.1 Construction Professionals' Views on Refurbishment

The initial questions posed to the professionals aimed to capture the respondents' views regarding the definition of building refurbishment, based upon their experience. This provided an insight into the industry view of the term refurbishment, and furthermore, energy-led refurbishment. The interviewees generally agreed that the refurbishment process is one that can vary widely and that every project is different. Some minor works to a property, purely superficial or cosmetic, such as re-decoration works may be classed as refurbishment. Conversely, refurbishment could be a term used to classify works to change the function of the whole or part of an existing building. Their views confirm that within industry the spectrum of works that can be labelled as refurbishment is wide although most can simply be defined as some physical change within an existing building. It was concluded that refurbishment projects form part of all participants' roles, to some extent, but those roles would usually include some level of new build development as well, with the exception of the building surveyor, whose role focused entirely upon existing buildings.

When asked specifically about energy-led refurbishment, all of the respondents agreed that this would involve refurbishment of an existing building with the sole purpose of improving the energy performance of the property. Some highlighted that they would associate the term with the fulfilment of government sustainable initiatives or policies, whilst others identified a reduction in operational costs of the building. One interviewee discussed how improvements to the building fabric as well as controls and services, i.e. an entire overhaul of the building's performance, correlated better with the term energy-led refurbishment for them.

3.3.2 Construction Professionals' Views on Professional Education and Training

The original education and training undertaken by the participants as well as any subsequent 'energy in buildings'-related education and training was examined within the interview. The aim of which was to determine whether the participants perceived their original education to have sufficiently equipped them with the competencies required to deliver the key responsibilities of their current role and whether they felt any need to become more knowledgeable of sustainability issues within their sector.

All of the interviewees felt that their original education did equip them with the core academic skills and knowledge they require for their day to day work. However, their qualifications - possibly over ten years old - did lack an emphasis upon 'energy in buildings'. Participant One highlighted a notable change in newer professionals to the industry, who had recently completed their academic training, and that many appear to have a keen interest in sustainable construction in general and that their education did address this area to a greater extent than the participant's own, although he could not confirm whether their enthusiasm for the subject area successfully translated into competence.

Participant Four stated that sustainability was one area of focus within their assessment of professional competence with the RICS, but they were not questioned to a level of detail comparable to their core competencies assessment; a depth of knowledge they felt would be required within their day to day work. General questions were raised regarding high level sustainability matters, but they were not required to be aware of specific energy performance improvement issues within new build or refurbishment sectors in the construction industry.

Those participants responsible for building design felt that they were under pressure to be aware of new technologies and materials as well as the relevant government policies and initiatives. Whereas those responsible for management of the design process felt they did not need to become as knowledgeable, but to simply have a level of awareness required to valuably participate in design team discussions. They felt that the main pressure was coming from their clients, with the need to advise them of sustainability issues. All of the professionals expressed that they were keen to undertake some re-training in the area of low carbon building design and operation, and stated that it would be beneficial if there were more Continuous Professional Development (CPD) events in this subject. Some of the professionals did identify that the main barrier to undertaking re-training is not obtaining support from their company but in finding the time to attend due to the pressures of their role and the time they allocate to professional development in their core competencies.

3.3.3 Construction Professionals' Views on Professional Governing Bodies

The participants felt that their professional bodies had changed to focus more heavily upon sustainability and its related issues, over the last two years; they had seen this through an increased number of seminars and events being held around the subject. Participant Two, from an engineering background, reported that they felt CIBSE were pushing a new qualification forward entitled the 'Low Carbon Consultant' (CIBSE, 2007) which he was particularly interested in undertaking, and thought it would be a credible path to specialising in low carbon design and operation of buildings. Whereas the remaining professionals felt that their governing bodies were providing more guidance and events and seminars in the area but don't envisage the core competencies of their professions to include any more detailed sustainability skills than they already include, which at present they view as an "outline overview attitude" (Participant Four, 2009).

3.3.4 Construction Professionals' Views on their Own Organisations

All interviewees were aware of their companies' environmental policies and mission statements. Participant One remarked on the significant amount of information they could find on the company's intranet, with news of projects, policies and technologies, and although the information was brief, it brought key issues to their attention. Participant Three commented on their company's forward thinking approach towards sustainability in construction and recognised the great commercial opportunity to increase their business and become leaders in this specific field. However, the participant also felt that the company itself lacked application of the same sustainable practices within their own building portfolio, and in order to be true leaders in the market, they needed to address this discrepancy.

The matter of whether employers would actually advise their staff to actively encourage clients to consider energy issues was also discussed. Those professionals involved in advising clients upon technical aspects of design and specification reported that their employers would encourage the consideration of energy performance improvement as a potential cost saving. Whereas those within a management role felt that the company would never influence the client's requirements as they may have various constraints or separate energy related projects operating within their organisation already.

Participant Two highlighted that there are several dedicated experts in low carbon construction/sustainable construction within their organisation, a specialisation that arose through a personal interest in the sector. These experts tend to form a comparatively small percentage of the organisation, acting as a specialist team to deal with specific projects. However, the participant felt that their expertise was not successfully disseminated across all disciplines within the company, although they could go to them to discuss issues or ask advice.

3.3.5 Construction Professionals' Views on Client Attitudes towards Energy

Participant One stated that over the last five years their private sector client had actively run investigations into energy saving opportunities within lighting, cooling and controls etc. However, they identified a notable, diminishing interest in these investigative projects corresponding to the recent recession impacting the industry.

Participant Four described their experiences with public sector clients, looking to refurbish existing properties. The interviewee stated "you have to link it [energy performance] to cost to force change" (Participant Four, 2009). This refers to the need to drive forward the execution of energy performance improvement initiatives using financial incentives or penalties. They explained how many of their public sector clients must achieve certain performance indicators to secure funding for a project, for example, attainment of a BREEAM excellent rating as minimum (BRE, 2009). The participant admittedly stated that they did not believe BREEAM to be a mechanism for addressing energy performance comprehensively but was beneficial in that it forces the client and design team's attention towards sustainability issues in construction.

Some interviewees noted the impact of the CRC (Carbon Reduction Commitment) Scheme (DECC, 2010) – a UK based mandatory emissions trading scheme for high energy users – since its introduction in 2010. Some of the participants' clients must comply with this scheme, and one discussed how the building owners they had spoken to were either wary of the reputational and financial impact upon their organisation, whilst others view it as an opportunity to demonstrate how energy conscious they are.

3.3.6 Construction professionals' views on the importance of 'energy in buildings'

All of the professionals concurred that energy performance of the building comes approximately third behind health and safety and operational performance. However Participant Three did consider energy performance to form a major part of the operational considerations. In terms of the importance of energy performance of a building within a refurbishment scheme, the participants all agreed that capital cost comes first. Although Participant One stated that they try to communicate the benefits of lower operational costs due to energy saving interventions in the design, and it was a matter of convincing clients to look beyond capital cost.

3.3.7 Construction professionals' views on decision making in refurbishment

The decision making process within building refurbishment can impact upon the potential energy performance of the property. The interviews identified a link between the client type and the level of client involvement in decision making in refurbishment. The professionals explained that some clients are happy to rely more heavily upon the consultants' knowledge and to provide just the basic requirements for intervention such as function and staff seating capacities etc. Others desire a greater level of involvement in options appraisal and selection. Often, larger clients have internal property managers and designers who compile design guides that external professionals must follow. Participant One stated this approach can be restrictive, although had found increasing flexibility in recent years to incorporate energy performance improvements, although a thorough business case was required to support such recommendations before final sign off.

In regard to the refurbishment process itself, the participants confirmed that they did not follow a standard process, checklist or structured approach, Participant Four stated "it [refurbishment] is rather 'off the cuff', success is reliant upon consultants' experience, great if you have the right expertise, not great if you don't" (Participant Four, 2009). Some participants stated that the process would most often begin with a general condition survey to highlight key elements that required bringing up to building standards quality and beyond that, the client's required standards, ensuring that the property will function within its required capacity until it is no longer needed, typically twenty to thirty years. The option appraisal process would either involve a design team 'brainstorm' session or, where applicable, referral to the client's design guide for intervention selection.

3.3.8 Client views on their organisation's attitude towards energy in buildings

All interviewees agreed that they had witnessed a change in their companies' attitudes, some noting such change dating back to the late nineties. Participant Five stated the main driver behind this change was their own clients and their requirement to see evidence of effective and efficient working practices. Participant Six noted three influential pressures upon them to become more focused upon sustainability and consequently energy performance: first, their corporate responsibility reporting, quoting "...to demonstrate good stewardship of our resources to potential clients." (Participant Six, 2009). They identified this as the key driver, followed closely by cost reduction, as reduced expenditure on energy translates into investment in their key business functions. Finally, policy compliance, specifically the CRC Scheme (DECC, 2010). The company's initial concerns surrounded the reputational aspect of the scheme – a publicly available league table of particular companies and their associated energy consumption levels – as the company was determined to be within the upper quartile of the rankings, alongside competitors within their industry. However, further changes to the scheme has caused the financial risk to the company to increase, and it now becomes a primary consideration.

All interview participants' organisations take a proactive approach to improvement works within their property portfolio. Participant Six explained that their company has an internal team of designers who create design guides for external consultants to follow, and that these guides incorporate energy performance considerations, addressing every building element. They admitted that their company's approach towards their building portfolio wasn't perhaps leading edge in addressing energy performance, but that they seek to take responsibility for what they consume and aim to reduce that as far as possible.

Participant Six described their proactive strategy towards building improvement is delivered in the form of a continuous upgrade investment programme, run annually. This programme involves an initial condition survey by external professionals against set questions across the UK stock, this is collated into a report and key areas of work are identified, design consultants then base design for these works upon the design guides developed by the client's designers, which have in built energy performance initiatives, and the package is delivered for costing and programming, covered by one external consultancy.

Participant Five described how they have company guidelines regarding their strategy for improvement of their portfolio and this includes an energy performance charter which must be met. To support the guidelines, the organisation has an internal, Europe-wide forum where they communicate best practice improvements to sites and learn and share ideas. In contrast Participant Seven explained that their company-wide low carbon strategy specifically addresses the energy management of the building portfolio in which they operate.

All of the participants remarked that they all have internal energy performance targets that work in line with their businesses. Participant Six described their very carefully designed sustainability framework in which the highest responsibility lies with a non-executive director on the board of their organisation, to whom all sustainability issues have to be reported to. They explained that energy performance targets form part of this framework, and currently they have an energy consumption reduction target (benchmarked against 2008 levels) to be achieved by the end of 2012. This is a target that applies across their international portfolio and they are already 75-80% on their way to achieving it based upon the initiatives undertaken in the UK alone. The company are currently reviewing their target structure for the period following 2012 and have decided to implement targets based upon specific metrics rather than a flat reduction target. They want to challenge themselves and ensure significant results are achieved across the entire, international portfolio.

In terms of how high energy sits on their building performance agenda, the participants agreed that it did sit increasingly higher on their agenda. Participant Six described the main driver behind their business' new building selection is the location and how they can locate the right staff for their business, then secondly would be the building quality. Once they have that building they will look at how energy efficiently it performs and if it is not up to their company standards then they will include energy interventions within the fit out of the building. These interventions tend to include upgrade of the fabric and a heavy focus on controls but would be unlikely to include any major changes to the type of key plant items within that building. The interviewee did highlight the fact that the last time their organisation procured a property was probably in 2008 and they cannot see them procuring any new properties in the near future, rather the opposite, they intend to down size the number of buildings in which they operate.

Also, landlords are now offering more energy efficient buildings which they find very helpful and attractive compared to what used to be on offer in the market, “there is a huge difference in recent years”.

3.3.9 Client sourcing of expertise – Whom do you consult?

All explained that their organisations use both internal and external construction consultants, depending on the complexity and scale of the project at hand. Participant Six’s company use an internal, technical compliance team to prepare and ensure compliance with their own design guides and the energy standards. They have a framework of external consultants who carry out and manage the design in accordance with these internally set standards. All of the participants stated that they have contractual relationships with external consultants and those contracts include energy performance related clauses. The most specific are with the repair and maintenance engineers, and the participant explained that the engineer must deliver year on year energy consumption reductions, the progress of which are discussed at monthly contract framework meetings. Participant Five explained that they need to see evidence of the experience of these external professionals in energy performance improvements and how they have been innovative in past, similar projects. They explained that clients are frustrated by the same initiatives and ideas/approaches to improvements in their properties coming from different consultants who are afraid to take risks with newer technologies/ideas. They look for openness and an ability to provide non-standard solutions, achieving the same conditions in their properties but without being restricted to standard, constant volume systems. They stated “We expect innovation led by industry experts” (Participant Five, 2009).

3.3.10 The optimum construction professional to lead energy performance improvements in existing buildings

The interviewees were asked, based on their experience, whom they would consider to be the optimum professional to lead an energy-led refurbishment project. The participants each referred to one or more of the established construction professions, citing their reasoning for their selection due to the competencies of the profession, some going on to discuss the opportunity for the creation of a new professional through the combination of particular competencies of existing professions or the specialisation of existing professions, combining their traditional competencies with new in doing so. This specific aspect of the interviews leads to the creation of a competency matrix, one that defines the skills of an individual capable of leading an energy-focused refurbishment project.

With the construction professionals and industry clients interviewed, each stated some combination of a building services engineer with either a project manager or building surveyor's selected skills. The common message was that they believe the energy performance improvement of an existing property to be a highly technical process, in which the greatest return on investment can be achieved through intervention in building controls and plant. The building services engineer was therefore identified as most capable to deliver the technical aspect of the improvement process. Furthermore, Participant Four noted their awareness of building regulations, how to ensure the plant delivers to meet these, how to improve upon the standards stipulated in the regulations and an understanding of how the regulations will change in the future. However, all of the participants went on to describe the barriers to this professional being the leader in this area based upon their traditional competencies and their own experience of working with this professional. Some stated that the building services engineer's work is often isolated from the other professionals on a design team, and although they have an intimate knowledge of building performance, their ability to articulate an innovative, strategic approach to energy improvement was questioned. Participant One stated an appropriate leader would be one that combined the skills of the building services professional with a professional with an understanding of the fabric and user needs, such as an architect or building surveyor. Participants Four and Six stated that in the past, when they have approached a building services engineer with questions outside their remit, then they are often "met with a blank look" (Participant Six, 2009). This issue of professionals being defined rigidly by their competency set could be one barrier towards existing professionals branching out into specialisation in energy in buildings. Participant Four stated that a project manager facilitates all of the expertise to deliver the optimum solution but would not class the project manager as a leader, and suggested the building surveyor as a strong leader due to their combined project management and general technical competencies but admitted they would require further training and development to be capable of leading a specialised energy project.

The discussions held with the participants identified management and technical competencies similar to those held by building services engineers, building surveyors and project managers. Following review of the transcripts and professional governing bodies' competency sets, a competency matrix was developed, as shown in Table 2. This presents the competencies required of a professional capable of leading an energy-led refurbishment of an existing, non-domestic building, with the intention of being a completely new professional, although various existing professionals' skill sets could be adapted to meet this matrix.

3.3.11 Barriers to a new professional

Participant Four did state their apprehension to the development of a new professional, as they were unsure of how the structure of the design team would then work, it may need to be altered to include a new professional and wondered how a client would accommodate an additional set of fees on projects where an entire design team is required. The professional did acknowledge that perhaps in situations where the client is looking to focus solely upon the energy performance of their portfolio then perhaps it would be feasible to bring in this new professional to lead mechanical and electrical professionals. However where the project consists of a major refurbishment combined with new build as well, as many of their projects have, then the client may struggle to justify an additional set of fees for this new professional. The participant provided an example of where many of their clients are required, by their organisation, to achieve a minimum BREEAM rating (BRE, 2009), thus forcing them to consult a BREEAM advisor. However, due to the low fees available for this advisor, the individual is not used to their full potential, they are brought in for an initial workshop which often turns into a checkbox exercise, when they could be assessing and contributing to the design. This professional explained that in order to get the client to pay an additional set of fees on larger projects, they would need to be forced to bring that professional on board by having to achieve a particular credit or rating which the professional would ensure.

Participant Two also remarked that the new professional would have to be accredited in some way to prove to the client that they are worth employing. As there are so many individuals specialising in this area under a variety of titles, clients need to be assured of this professional's credibility.

3.3.12 Sourcing of low carbon expertise

The professionals interviewed, when asked of their own education and training, stated the subject of sustainability in construction was addressed, but their qualifications, some dating over ten years old, did not equip them to comfortably lead an energy focused project at this stage in their career without the need for further training. Participant One noted the level of low carbon construction knowledge displayed by new graduates entering the industry at this time. University qualified graduates, combined with an increasing focus upon the introduction of low carbon and sustainable construction within degree programmes, presents a source of expertise for the industry. However, recent trends in the industry may present barriers to the utilisation of this source to the level required at this stage in the wider low carbon agenda. The construction industry employs a significant number of people, particularly in the UK, with construction workers and professionals accounting for at least 7.5% of UK employment (ConstructionSkills, 2010), although, the recession hitting the global economy post-2007 caused the loss of a large number of construction employees and consequently skills loss. Approximately 300,000 people were lost from the industry between 2008 and 2011 (ConstructionSkills, 2009). Furthermore, 2015 employment levels in the sector will remain 3.5% lower than levels in 2007, when they were at their peak (ConstructionSkills, 2011). Consequently young graduates' confidence in the construction industry as a secure career path, following the commitment of three years or more at university, at this time could be wavering due to the public reporting of the sector as an indicator of economic growth.

Routes to specialisation in low carbon construction are increasingly available through higher education and post graduate degree programmes. The lack of opportunities for construction graduates within industry currently could present the decision to undertake an additional qualification as an attractive alternative. Building upon their foundation of sustainable construction knowledge gained in their undergraduate courses by studying a specialist carbon management post graduate qualification or similar, could provide the industry with a crucial resource of low carbon specialists. The difficulty in relying upon this resource is the high demand for this specialist type from other sectors with similarly ageing demographic as construction, looking to recruit young professionals. In particular, the energy sector are actively looking to attract university degree qualified people, through various mechanisms, evident in their target to increase the number of qualified people in the sector by 28% by 2020 (UKCES, 2012).

It would therefore be impractical to rely solely upon the inflow of higher education graduates to fill the knowledge gap for the entire industry, especially when worker flows into the sector are supplied primarily by those moving from other industries and not those in full time education. Easton (2011) interestingly comments that “re-skilling and mobilisation is required, similar in scale to adopting a wartime footing” (Easton, 2011, p.4).

Of those graduates who do choose to enter the industry with expertise in low carbon construction, the question is of their level of influence and whether they will be given the opportunity to disseminate their expertise. Typically, it could take ten years for a new graduate to reach a position where they can utilise their skills in this area. It is the professionals who are forty years or older, currently working in the industry who are responsible for the management of design, construction and operation of building projects (Easton, 2011). It is this group of professionals that need to be targeted for low carbon skills training.

One way in which to introduce new skills and improve competence in a new area is through Continuous Professional Development (CPD) mechanisms. Professional governing bodies set out their CPD expectations of members, although these can vary between the various bodies. An effective source of low carbon expertise could arise if the appropriate governing bodies were to define a low carbon curriculum delivered through CPD training. The CIBSE Low Carbon Consultant accreditation has attracted the attention of engineers looking to specialise in this field, and is noted by some of the interview participants. All of the professional bodies could design a similar accreditation across all of the traditional disciplines, one that requires a certain number of CPD hours around a low carbon curriculum. This could lead to a recognised level of low carbon competency across the industry, something that clients would desire, as one of our interviewees stated.

Further to the determination of an industry recognised accreditation, one that is adapted to the skills required of each discipline, is the examination of the necessary skills at each level of the industry. As discussed, the impact of junior professionals upon the dissemination of low carbon expertise is limited; they may not be involved in high level decision making. Instead their value lies in the practical delivery of low carbon building performance at project level. The RIBA (2009) defines low carbon skills through a competency set specifically for architects, and prescribes three levels of competence. Although the levels of competence, in this case, are used to aid the professional to determine their need for additional training, it presents the feasibility of defining levels of competence within low carbon skills. This could be used to define levels of competence for differing levels of seniority in the construction industry.

3.4 Optimum Built Environment Professional Competencies

From consideration of professional governing bodies' competency sets and the outcome of the interviews held with built environment professionals and clients, a competency matrix was developed, see Table 2. This matrix aims to define the core skills that a construction professional must possess in order to successfully promote and lead an energy-led refurbishment of a non-domestic property. Table 2 also presents the established built environment professions against the optimum competency set, showing which skills the professionals are currently required to possess in accordance with their governing bodies' guidance.

This competency set could be viewed as the skills encompassed by a new low carbon professional, or as the development of a specialised branch of one of the existing professionals; the matrix format aids identification of the potentially most appropriate professionals to specialise in the low carbon branch of construction. This is not the first time that competency sets offered by built environment professionals have been critically examined in response to externally imposed changes. For example, the development of project management into a clearly defined, accredited profession within the construction industry, codified a role that was previously considered as an additional competency of other construction professions (Watson et al, 2011). Additionally, the accreditation of architects in building conservation is now established, and offers an alternative route to competence within their discipline (English Heritage, 2013).

The small, yet representative, sample of interviewees showed that clients want to make their building estate more energy efficient but may not be receiving the guidance they require from industry. They want innovative, bespoke solutions that work for their buildings but, to offer this, professionals need to be knowledgeable about technology and have the ability to lead the complex refurbishment process. Current professionals admit they do not know enough about energy in buildings. It can therefore be suggested that either a new profession is needed or the competencies of existing professions must be overhauled.

The optimum competency set can be sub-divided into three areas of expertise: management, technical and financial. The individual competencies within these three aspects are presented.

Table 2 – Optimum Competency Matrix

ESTABLISHED BUILT ENVIRONMENT PROFESSIONALS	OPTIMUM COMPETENCY SET																
	MANAGEMENT								**TECHNICAL**							**FINANCIAL**	
	Contract Practice	Collaborative Supply Chain Development	Energy-led Project Appraisal	Leadership	Programme and Planning	Project Administration	Risk Management	Sustainability Knowledge Management	Building Pathology	Construction Technology+--	General Building Services Understanding	Hard to Treat Solutions	Whole Building – Holistic Approach	Inspection	Legal and Regulatory Compliance	Design Economics and Cost Planning	Procurement and Tendering
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	1	2
Architect	**MC**			SC	SC	SC	SC	SC		**MC**	SC	SC			**MC**	SC	**MC**
Building Services Engineer	SC			**MC**	SC	SC	SC	SC		SC	**MC**				SC	SC	SC
Building Surveyor	**MC**		SC		SC	SC	**MC**	**MC**	**MC**	**MC**		SC		**MC**	**MC**	**MC**	SC
Facilities Manager	**MC**	SC	SC	**MC**	SC	SC	**MC**	**MC**		SC	**MC**				**MC**	**MC**	**MC**
Project Manager	**MC**			**MC**	**MC**	**MC**	**MC**			**MC**					SC		**MC**
Quantity Surveyor	**MC**				**MC**	SC	**MC**	**MC**		**MC**	SC				SC	**MC**	**MC**

Key:
MC - Main competency
SC - Sub-competency

3.4.1 Management Competency One – Contract Practice

An awareness of the various forms of contract used in construction projects as well as an understanding of contract law is required by any construction professional. However this is a particularly crucial part of energy-led refurbishment as clients may choose to include energy performance targets/related clauses within contracts between them and their consultants and their contractors, something the project leader would have to be capable of advising a client upon.

3.4.2 Management Competency Two - Collaborative Supply Chain Development

In order to ensure an innovative design team are appointed within the refurbishment project the project leader must have sufficient networking capabilities to build relationships with specialists who are knowledgeable within energy in buildings. The project leader must facilitate and lead a working relationship between the consultants that encourages collaboration and innovative solutions to be brought forward to the design.

3.4.3 Management Competency Three – Energy-led Project Appraisal

This competency addresses the analysis of client requirements for the project. The project leader must establish a brief with the client and define the project parameters. In order to maximise the opportunity for the implementation of energy-led intervention within the design, the leader must first gain a thorough understanding of the client's organisation and how they approach adaptation within their property portfolio. They must determine whether the client is required to meet any externally set carbon reduction targets or initiatives and ensure that the energy-led design integrates these requirements. The leader must also establish whether the client's organisation has internally set carbon reduction initiatives, and/or sustainability/energy advocates that they will need to report to and satisfy. The emphasis of this competency lies upon the individual's ability to maintain focus on the operational outcomes of the design, and the impact of the design upon the building user’s satisfaction throughout the project duration.

3.4.4 Management Competency Four - Leadership

This competency is core to the role, the individual must be aware of leadership techniques and how to motivate and manage people effectively in order to achieve optimum results. This competency is crucial in an energy-led refurbishment as the project leader will need to encourage innovative solutions that will work within the complexities of an existing building.

3.4.5 Management Competency Five - Programme and Planning

This is a competency relevant to all construction projects, of which any project leader would have to be capable.

3.4.6 Management Competency Six - Project Administration

This is competency that is core to project managers in any sector as it is crucial to running and reporting on a project efficiently.

3.4.7 Management Competency Seven - Risk Management

This competency covers the management of risk on a construction project. This is particularly relevant to energy-led refurbishment as many of the interventions implemented will not be as well established as other interventions, for example innovative methods of energy supply or new building materials. The project leader would need to be knowledgeable of risk management techniques as well as emerging technologies to be able to safely manage the risk of their implementation within the project.

3.4.8 Management Competency Eight - Sustainability Knowledge Management

A full understanding of the wider subject of sustainability and how it relates to the built environment is crucial to allow the professional to communicate the relevance of energy performance improvement in buildings. A key area for continuous learning, due to increasingly available information on the subject.

3.4.9 Technical Competency One - Building Pathology

A thorough knowledge of the building fabric is crucial in the energy-led refurbishment of a property as it can have a major impact upon the energy performance of the property. The project leader must understand defects in the building fabric and how these must be addressed. The professional must also be aware of how different fabric interventions can impact the way in which the building functions in terms of air movement, disposing of moisture and dealing with temperature variations. The project leader must be able to identify where particular interventions implemented within a refurbishment project could impact on building performance in the future, i.e. future-proofing considerations.

Technical competency one combined with the following technical competencies addresses the knowledge and understanding of energy performance from a building physics perspective. These encompass the key technical skills required to evaluate asset and operational energy performance.

3.4.10 Technical Competency Two - Construction Technology

A full understanding of the most common as well as emerging construction technologies is essential.

3.4.11 Technical Competency Three - General Understanding of Building Services

The professional must have a solid understanding of the most common mechanical and electrical elements of a non-domestic property. They must understand how these can be made more energy efficient as well as be aware of alternative energy sources through renewable technologies. They must be able to communicate with the building services engineers effectively and understand their technical language to be able to understand the issues that may arise within the energy-led refurbishment of an existing building’s services.

3.4.12 Technical Competency Four - Hard to Treat Property

These competencies are specifically designed for the improvement of existing buildings, within this sector are properties classed as hard-to-treat due primarily to their construction techniques. This professional would need to have a level of awareness of the common issues that can arise when treating this building type. One example is historic buildings of traditional construction. These form many of the key office locations in many major city centres, providing large organisations with a highly visible presence. Historic buildings are often classed as hard to treat in terms of energy performance improvement as they tend to perform in a different manner to those of modern construction. They require practical solutions that are both technically and socially acceptable.

3.4.13 Technical Competency Five – Whole Building - Holistic Approach

The professional must have a holistic view of the property undergoing refurbishment, they must ensure that interventions are compatible with one another and within the building itself. The energy demand of the property must be addressed and reduced as far as practically possible to eradicate energy wastage. Then the potential for energy supply solutions must be assessed.

3.4.14 Technical Competency Six - Inspection

In order to understand the current state of the property pre-refurbishment a thorough inspection must be undertaken, the project leader must be aware of the elements that will form the inspection to ensure that a clear picture of the current energy performance of the property is captured. The leader should have the technical capability to carry out an inspection themselves or where specialists are required, be able to guide them to focus not only upon the core performance requirements of the building but those elements that impact its energy performance. The professional must be aware of the various mechanisms for collecting energy performance data from an existing building and how to analyse it to determine the baseline energy consumption.

3.4.15 Technical Competency Seven - Legal and Regulatory Compliance

This competency requires an in depth knowledge of legal/regulatory compliance within the construction industry. This would apply to all construction professionals. The professional should be aware of energy performance related building regulations and how these will change in the future and should assist clients to understand what is required of their property. Furthermore, the professional must be aware of and be able to communicate the significance of the various energy performance related policies and initiatives that will affect them and enable the client to meet them through refurbishment of their property.

3.4.16 Financial Competency One - Design Economics and Cost Planning

This competency ensures that the individual has an awareness of how different interventions and construction processes impact upon the capital cost of the project as well as the operational cost of running the building. The individual must have an understanding of whole life costing so that they can communicate the benefit of various energy related interventions to the client from a WLC stand point. This is a crucial aspect of energy-led projects as the value of implementing energy performance improvement interventions is in the reduced operational costs of the building.

3.4.17 Financial Competency Two - Procurement and Tendering

This competency ensures that the professional has a sound knowledge of the different procurement routes and approaches to tendering to enable them to communicate the advantages and disadvantages of each to the client.

3.5 Assessment of Existing Professions' Competence

The matrix presented in Table 2 represents how existing competency sets as defined by professional governing bodies meet the optimum competency set determined in this study. The sourcing of competency sets as defined by the RICS; the building surveyor, quantity surveyor and project manager were easily accessible, comparable and clearly defined. The remaining professions reviewed competency sets were less accessible and presented broad competencies that made it comparatively more complicated to extract which skills the professional did or did not hold.

3.5.1 Skills matrix assessment

The matrix shown in Table 2, identifies which of the seventeen optimum competencies, form 'main competencies' and 'sub-competencies' of the traditional professionals' skill sets. 'Main competencies' are defined as those that appear within the governing bodies' guidance literature as the key, overarching skills, and the 'sub-competencies' are simply those that fall within the domain of these skills. For example, RICS (2006a) identifies 'Analysis of Client Requirements' as a potential Building Surveyor competency, and addresses the determination of a client brief at project inception. Although it does not place the same level of emphasis upon energy performance as 'Management Competency Three – Energy-led Project Appraisal', as detailed in 3.4.3 of this chapter, energy efficiency does form part of the required knowledge for the 'Analysis of Client Requirements' competency. The Building Surveyor therefore holds a sub-competency of 'Management Competency Three - Energy-led Project Appraisal', as is indicated in the Table 2 matrix.

The matrix in Table 2 permits quick identification of optimum competencies that are not fully addressed by the existing professions. 'Management Competency Two – Collaborative Supply Chain Development' and 'Technical Competency Five – Whole Building (Holistic) Approach' are shown to be included in few or none of the traditional professionals' skill sets. These are interlinked as they centre upon the need for experts collaborating and approaching building performance issues from a holistic perspective, as is necessary in successful energy-led building refurbishment. These are possibly the most complicated skills to implement as it is not simply something that is taught, it is in fact a behavioural change that is required.

There have been efforts within the wider construction industry to encourage collaborative relationships in line with the lean principles advocated in the Latham (1994) and Egan (1998) reports. The Lean Construction Institute (LCI) was launched in the UK in 2005 and promotes the learning and implementation of lean principles, one of which being supply chain collaboration. McMeeken (2008) cites a quote from the LCI founder, stating "Lean is alive and well but it is developing slowly. Only about 15% of companies are achieving what Egan recommended" (McMeeken, 2008, p.1). One of the most notable attempts towards collaborative working in the construction industry is the Partnering approach to project delivery, although it faces its own barriers. Bresnen and Marshall (1999) indicate that prescribed, collaborative techniques and procedures may not result in successful partnering relationships, but that cultural change is required too, although they go on to state that identifying cultural change is the simultaneous identification of "a wide range of very difficult issues, problems and dilemmas" (Bresnen and Marshall, 1999, p.466). The need to accelerate successful collaborative relationships within the construction industry is highlighted by Janda and Parag (2013), as they identify the overwhelming challenge associated with the transformation of our existing building stock's energy performance to meet required reduction targets with a "fragmented construction industry" (Janda and Parag, 2013, p.1206).

The matrix also permits quick identification of those traditional professions whose skill sets best align with the optimum set. The Building Surveying and Facilities Manager professions perform well, and hold not only the most competencies overall, with a spread across the financial, management and technical categories, but also the most 'main competencies'. Although, the Building Surveyor was presented as a potential professional for specialisation within the interviews held, neither the Building Surveyor nor Facilities Manager traditionally form part of the design team. Instead, they may be brought in as consultants at project inception to carry out inspections/ advise on energy systems/ maintenance etc. Participant Four stated the Building Surveyor would typically be used to carry out the initial survey and report of the condition of an existing building undergoing refurbishment, with little or no further involvement during later project stages. The question therefore arises, if these professionals were to specialise in energy in addition to their current skills sets, would they be utilised effectively and permitted to in fact lead an entire refurbishment process.

The interviews held also identified the Building Services Engineer as a potential candidate for specialisation within energy in buildings. Conversely, Table 2 shows the profession to fulfil a total of eleven optimum competencies, following the Building Surveyor, Facilities Manager and Architect, with only two of these being considered as 'main competencies'. This is surprising and raises the question of the relative importance of the optimum competencies in delivering a successful energy-led refurbishment project. Easton (2011) illustrates this, providing the example, "the ability to make a case with a client is arguably more important than technical competence...and technical competence is crucial" (Easton, 2011, p5).

3.5.2 Integration of sustainability and consequently energy knowledge

The competency of sustainability arises in many permutations throughout the traditional professions' competency sets and all professions appear to have synonymous yet rather broad definitions when it comes specifically to the contribution of that competency to the work activities of the professional. Sustainability knowledge is evidently a logical first step in the integration of energy expertise into existing competency sets as it provides the contextual grounding from which to build energy in buildings understanding. Dixon et al (2008) highlight the efforts of UK taskforces and governing bodies in promoting the inclusion of sustainability into accreditation requirements, although conclude that a lack of practical knowledge within the area remains amongst global RICS members. This is supported in the comments made by the participants of this study, where they explained that sustainability formed a proportion of the focus during their assessment of professional competence, and as a result provided them a 'high level awareness' at best. Participant One stated "Sustainability in general was addressed by the APC but at insufficient depth for the projects that I am now working on", furthermore, Participant Four stated "I envisage no change to my core competencies from what I currently perceive as an outline overview of sustainability". The question therefore arises, if the incorporation of sustainability into competency sets has already been carried out by global governing bodies but this has not disseminated sustainability practice within the professions they oversee then perhaps a different approach is required.

Instead of appending an additional competency of sustainability, and therefore energy performance, perhaps the review of existing competencies and the integration of the sustainability principles into these as an underlying theme would be a more successful approach. A sustainable building, one that operates efficiently and effectively, meeting the performance requirements it was designed to achieve, is increasingly viewed as a quality building. BRE (2007) defines quality as the "technical excellence" of a property, a definition that encompasses a sustainably constructed building that is "fit for purpose, adaptable and durable" and therefore uses energy efficiently (BRE, 2007, p.5). If sustainable practice is therefore best practice it should be incorporated into all existing competency sets as it then becomes relevant to every construction professional.

The specificity of energy performance is only apparent in the CIBSE Building Services Engineer, RICS Building Surveyor and BIFM Facilities Manager competency sets. However, only the BIFM identify a competency dedicated to energy performance, whilst the remainder, include energy performance as a sub-skill within more generic competencies. In the case of the Building Surveying pathway, energy is detailed only within the 'Analysis of Client Requirements' competency. The interviews revealed the Building Surveyor as a potential professional suitable for specialisation, although the Building Surveyor admitted that they would require additional training in the technical aspects of building energy performance. It therefore appears that the Building Surveyor holds the professional competencies in awareness and advising of energy performance and wider sustainability at project inception when developing a project brief, but it is questionable whether energy sufficiently underpins their technical competencies such as 'Building Pathology' and 'Construction Technology'. The CIBSE Building Services Engineer competency specification mentions energy performance within the 'Demonstrate a personal commitment to professional standards, recognising obligations to society, the profession and the environment' requirement. Surprisingly energy is not mentioned elsewhere, although where it is, comparative to the Building Surveying specification, there is greater emphasis upon actively promoting and engaging in the reduction of energy demand of the proposed or actual building in question. The language is much stronger and connotes a more practical stance.

3.6 Conclusion

This chapter has considered the appropriateness of professionals' competencies for energy-led refurbishment. According to the DBIS and DECC (2010) 'The transition to low carbon and resource efficient buildings...will create new and evolving demands for skills and knowledge'. This view is supported by the industry clients interviewed in this study. For the growing field of energy-led refurbishment of existing property, it appears there are already sporadic pockets of expertise within the existing professional disciplines. However, industry clients desire competencies that are not currently being offered by any particular professional group practising in the UK. This deficiency can be remedied through additional training of all existing professionals to improve the general knowledge of the industry as a whole. Alternatively, the creation of a new professional could be a viable approach, to lead the transition in low carbon skills. According to Abbott (1988), there is an opportunity for new professional(s), primarily arising as a result of increasing understanding of a subject leading to the identification of new problems, in this case, greater understanding of sustainability by all stakeholders and how it relates to the construction industry, therefore causing identification of new issues, requiring a dedicated expert to overcome them. An expert could arise through the creation of an entirely new profession, the competencies for which have been presented in this study, similarly to the creation of the dedicated Project Management role in construction in the last 40 years (Watson et al, 2011). Alternatively, an expert could arise through the specialisation within an existing discipline, as has occurred within the Architecture and Building Surveying disciplines, with specialisation in building conservation (English Heritage, 2013). Both approaches face barriers that must be overcome to facilitate successful transition to a low carbon built environment. Despite how this transition is remedied, an additional consideration within the energy performance improvement of existing buildings is the approach undertaken by such professionals.

The next chapter examines this approach, before presenting an optimum decision support process for energy-led refurbishment of existing, non-domestic properties.

Chapter 4: Decision Support Tools

4.1 Introduction

As already noted, the successful retrofit of an existing, non-domestic property must overcome a range of barriers, both financial and non-financial and decision makers therefore require support. The objective of this chapter, is to review and appraise decision support tools (DSTs) for building retrofit, as detailed within the existing academic literature. This leads to a proposed optimal DST that builds upon the positive attributes of current DSTs. This DST is then further developed within Chapter 5 this thesis.

4.2 The Case for Decision Support

Although the sustainability agenda has been present and relevant in the built environment, for at least ten years with the introduction of the Energy Performance of Buildings (EPBD) Directive in 2002 (European Union, 2002), the effective and successful application of its principles in existing property is still an emerging area that requires investigation to support the industry in this current transition. One key development in the last decade has been the emphasis upon refurbishment of existing property in the non-domestic sector with the sole intention of improving energy performance, as well as other sustainability performance metrics, that were once viewed as an addendum to the refurbishment process.
In undertaking the refurbishment of existing, non-domestic property a range of barriers must be overcome, the Better Buildings Partnership (2010) identify the five key barriers to be: commercial (the landlord and tenant divide), roles and processes (lack of clarity, methodologies and evaluation criteria), financial (shortage of capital finance, and unattractive payback periods), technology (in terms of available technologies and their performance, limitations associated with existing property, and industry professionals' skills shortages), and policy (lack of emphasis and support for improvement of existing property). It is evidently a highly complex activity but one that must be addressed if we are to, not only, meet our emission reduction targets, but also future-proof our existing non-domestic building stock.

Organisations operating within non-domestic property portfolios are becoming increasingly interested in their energy performance and consequently their 'carbon footprint'. This is a result of a multi-faceted driver for change, in the form of: carbon reduction legislation and policy, corporate realisation of the commercial opportunity associated with; a reduction in building operational costs, avoidance of financial penalties and a potential reduction in building obsolescence risk, and a need to fulfil Corporate Social Responsibility (CSR) commitments. At present, many organisations are undertaking a graduated approach to the integration of energy management principles into their corporate strategy (BBP, 2013), beginning with determination of the baseline energy performance of the portfolio in which they operate. This involves the capture of energy performance data through a variety of mechanisms, ranging from legally required energy performance certification to the installation of automatic meters to record granular data that, combined with software packages, facilitate analysis of the collected data. This is evidently the first step in improving energy performance, and therefore is logically an area that has already undergone and continues to undergo a notable level of research in academia and industry. The subsequent step is to utilise this information to identify opportunities for improvement, termed in this thesis as energy-led refurbishment.

The approach to energy-led refurbishment requires definition, a recognised methodology that will structure this complex activity, and ultimately overcome the barrier associated with 'roles and processes'. It is within such a methodology that decision support sits to aid property professionals through the various steps required to achieve the desired outcome, of a building operating at its optimum efficiency.

A DST designed specifically for the purpose of energy-led refurbishment would encompass a clear strategy for execution and support the user in doing so. It would provide a single point of contact for the collection, analysis and storage of energy data, whole-building improvement option appraisal and, furthermore, continuous improvement.

4.3 Attributes of Current DSTs

Ten DSTs have been identified from the available literature on building refurbishment. The attributes of these vary widely, but all bring some useful characteristics forward which a typical property manager of non-domestic buildings may find valuable. In most cases the authors give examples of the tools in use but in the interests of brevity these are not discussed here. Therefore, after a brief description of each tool, Table 3 assesses them against desirable criteria that the optimum DST for energy-led, non-domestic refurbishment, would encompass.

4.3.1 EPIQR (Droutsa, Flourentzos and Wittchen, 2000)

This tool is directed towards domestic property owners who want to improve the overall performance of their property, but is mentioned here because of its influence on other DSTs for the non-domestic sector. The system aids the user assessment of the current building condition by breaking down the building into fifty separate elements. The user then assigns a deterioration code to each element. The system also provides an indoor environment quality (IEQ) questionnaire which the user can circulate to the building occupants, to identify particular issues that may otherwise be omitted in the user's building assessment.

The energy performance of the building is determined through energy bills and calculations are carried out to determine the heating and cooling requirements. The system provides an 'active energy flowchart' by which the user can visualise the heat gains and losses of the building and test what effect different interventions will have upon these. These interventions appear to be limited to increasing fabric insulation, changing the ventilation rate and alterations to the existing glazing.

There is also an energy calculation module, where the user can view specific building installations and how alterations to these could provide energy savings. These also appear to be limited and only address boilers, pipe insulation, thermostatic valves, lighting and solar collectors. The information this module provides can be combined with the deterioration assessment, IEQ questionnaire results and respective life span of the elements to make an informed decision about the optimum interventions.

The system can very quickly generate an estimated refurbishment cost based upon the building assessment input. The results of the building assessment are presented graphically, where the user can view the various works required to bring each element back to an acceptable performance level. The user can view either the deterioration levels or the cost to refurbish each element. The user can deselect particular actions and view the resultant impact upon the overall refurbishment cost.

The overall focus of this system appears to be the identification of an estimated cost to bring building elements up to the highest standard possible. The system does consider energy performance but it appears that the energy performance assessment of the original building could be more accurately executed. The energy related interventions are limited to the specific items within the energy module as well as the building fabric improvements.

4.3.2 TOBUS (Flourentzou et al, 2002)

TOBUS appears to be based upon the same principles as EPIQR DST but is suited to non-domestic property refurbishment. The system aids the user to assess the current state of the building in the same manner as EPIQR, by breaking down the building into fifty elements and supporting the user to select a deterioration code for each. The energy performance of the building pre-refurbishment is determined through energy bills and the heating/cooling consumption levels are calculated. The system provides the user with a 'normalised consumption per unit floor area'.

TOBUS uses the same 'active energy flowchart' as EPIQR by which the user can visualise the heat gains and losses of the building and test what effect different interventions will have upon these.

An IEQ questionnaire is circulated around the building occupants and the results are then represented graphically, as well as the creation of complaints and building syndrome indexes.

The system presents the results of the building assessment graphically with the cost and deterioration levels for each of the elements, which the user can deselect as required to view the impact upon the overall cost. The DST does have a 'scenario creator' which allows the user to determine the level of intervention for several elements as well as some energy performance improvements if so desired. The system also has the capacity to save the various refurbishment scenarios for later review.

TOBUS has additional energy modules to EPIQR which are better suited to its non-domestic purpose, including lighting and daylight assessments, office equipment and elevators.

The system provides the user with a global refurbishment estimate initially based upon the basic building information, but there is a function that allows the user to enter additional data to increase the accuracy of the cost, including project complexities, VAT and a percentage for contingencies. The 'detailed scenario builder' within the DST allows the user to review all costs and quantities of the interventions. Three cost reports are created by the system for the user to review.

4.3.3 XENIOS (Balaras and Dascalaki, 2004)

This DST is intended for use in the hotel sector and aids the user to carry out an environmental impact assessment of their property. The system helps the user to break down the building into macro-elements and elements, to each of which a deterioration code is assigned.

The results of the assessment are presented graphically detailing cost and deterioration level for each element, which the user can adjust to view the impact upon overall cost.
The energy performance of the building pre-refurbishment is determined through standard heating and cooling calculations utilising user collected information. The system uses the energy consumption levels estimated by the system, to calculate the associated air pollutants, including NO, CO, CH_4, non-methane volatile organic compounds and SO_2.
In addition to the actions to deal with deterioration of the macro-elements there are nine energy related and four water related environmental refurbishment actions. The pre-defined energy related interventions are solar collectors for sanitary hot water, solar collectors for swimming pool heating, solar cooling, chiller cooling with seawater, installation of zoning and controls in elevator systems, use of energy efficient office equipment, improving lighting energy efficiency, daylighting and room key card control. The pre-defined water waste reducing measures are desalination of seawater, brackish water desalination, conservation of sanitary water in hotel rooms (with one year payback and with two year payback). An installation cost and payback period is included for all of these environmental interventions.

4.3.4 BEMS Data Based DST (Doukas et al, 2009)

This DST is to be used specifically with buildings that have a Building Energy Management System (BEMS). It utilises the BEMS collected data about the building's energy usage to assess the energy performance of the building. The BEMS data is combined with relevant external parameters to create building indexes. These are then compared to standard indexes of energy performance, by the system, to benchmark how well the building is performing.

The system contains a proposals database which provides interventions for particular building functions, e.g. heating, cooling etc. The DST selects interventions to be prioritised following the comparison between the building indexes and the standard, best practice, indexes. Those with the greatest difference between the two indexes are addressed and interventions to close the gap between them are presented for further evaluation.

These priority interventions are then assessed against financial criteria of net present value, payback period, and the internal rate of return. In addition, the potential carbon flow of the intervention is evaluated. This determines the potential increase in financial benefits through the implementation of 'greenhouse-gas reducing' technologies.

Following the two step evaluation process a final list of proposed interventions is provided, categorised within each of the building functions. These are displayed in descending order of profitability.

An interesting feature of this system is the 'Proposal Implementation Check', where continuous improvement is carried out, as the system records what interventions have been implemented and updates the database of experience it contains.

This system is based heavily upon measured figures rather than subjective user survey results and therefore is likely to provide significant energy savings if the intervention proposals are implemented. However, the interventions are only assessed against potential energy savings and cost. Qualitative criteria, which may be viewed as important when assessing the suitability of interventions, are excluded.

4.3.5 GA (Genetic Algorithm)-based DST (Castro-Lacouture et al, 2009)

This system is targeted towards domestic property managers or owners and aims to help the user to improve the overall quality and performance of their building. It assists the user to assess the current building state with an online questionnaire. The system uses six broad criteria by which it assesses building performance: safety, usage, convenience, comfort, utility and health, each of which is further sub-divided. The DST has a prescribed threshold score which indicates a benchmark of assessed building performance, based on scores calculated for each criterion. If the building's total performance score is below the threshold then refurbishment is recommended. If so, the DST will then guide the user through the refurbishment options.

When determining a refurbishment intervention scenario, the user has to choose between 'budget priority' and 'quality priority'. For budget priority the user sets their desired budget and the system generates interventions that gain the optimum level of quality achievable within that budget. For quality priority an expected benchmark of quality is prescribed by the user and the system will present the interventions at the lowest cost within that benchmark level. The user can alter their budget as required to clearly see what they can achieve within their set budget.

The system's cost system uses the net present value (NPV) to reflect the life cycle cost of each action to gain some context around the costs produced. The NPV includes the initial action cost, the annual energy saving income of each action, the annual refurbishment action cost, the expected lifespan of the action, the action residual value and the discount rate.

The system provides a list of actions under each assessment criterion, depending upon the condition score assigned to the element during the building audit. The DST recommends an intervention action for that level of deterioration and calculates the additional score that this action will bring to that element if implemented. An additional score is given for the 'sustainability' of the intervention action, therefore the more sustainable options the user implements, the higher a quality score their building will have achieved post-refurbishment. The cost per metre squared is also included against each intervention action.

The DST does not seek to reduce energy consumption levels or the associated carbon emissions directly. However, the additional score provided by utilising more sustainable versions of the interventions does provide the user with the option to undertake a more sustainable refurbishment. It is possible that the interventions will therefore provide energy savings, however the system does not appear to aid the user to calculate their energy performance pre or post refurbishment or provide the potential energy savings of the various interventions. The energy savings are considered in terms of the cost savings they could bring but energy consumption itself does not form one of the six building and intervention assessment criteria.

4.3.6 Hybrid Decision Support System (Gao et al, 2010)

This decision support system is centred on sustainable building development. The focus of this tool is to aid the user to improve the overall sustainability of their non-domestic property using five criteria -Sustainable Site, Energy Efficiency, Water Efficiency, Materials and Resources and Indoor Environment Quality. The system tries to assist those organisations who want to improve the sustainability of their building stock by providing them some direction through the numerous options open to them.

The system helps the user to assess the current building state, against the five criteria, with what appears to be a user-friendly interface. The system then recommends the most appropriate intervention actions based upon the assessment results. A hybrid algorithm is employed which efficiently searches and analyses the suitable interventions before recommendation to the user. This algorithm allows the system to strike a balance between the user's available budget and the sustainability scores allocated to each intervention option. The more interventions implemented by the user, the higher the building's overall sustainability score becomes.

The refurbishment budget can be set by the user and adjusted as required. The system will only present intervention options that arrive within the budget and where they do arrive within budget, the options with the highest sustainability scores are put forward.

The system does not appear to provide actual figures for the pre and post refurbishment carbon emissions and energy consumption, nor the potential savings that the interventions could create. However, when the system was applied to a case study office building, results of an independent energy simulation tool showed that significant savings were made in both energy consumption and associated CO_2 emissions. The results of this secondary tool also showed that the user may reach a refurbishment solution that provides a building without the highest possible energy saving but one that is overall more sustainable.

4.3.7 Knapsack Model (Alanne, 2004)

This method aims to overcome the three common challenges that design teams face when undertaking a refurbishment project - (i) achieving agreement between designers whilst considering each team members' opinions and experience, (ii) achieving sustainability in design and satisfying the often conflicting criteria that define sustainability, and (iii) dealing with the increasing number of technologies and products on the market to ensure that the optimum systems have been selected. The user's team will work with the designers to develop refurbishment intervention options and use a multiple criteria approach to assess the individual interventions and determine their utility scores (i.e. how well they satisfy the criteria). The paper details some of the methods that are available to the user to develop criteria and assign weights to them. The results of this analysis carried out by the user then acts as an input to the knapsack model.

The knapsack model maximises the utility of the interventions by bringing them together into a refurbishment scenario, where the sum of the utilities is created. The knapsack model subjects the interventions to certain constraints relevant to the project to ensure that the interventions that form the outcome of the model are feasible. The system does not aid assessment of the current building state and it appears that the user must also determine the range of possible interventions and their assessment criteria. The apparent purpose of the knapsack model is to aid assessment of large amounts of information in a short amount of time and consider conflicting constraints, which will impact upon the combination of interventions.

4.3.8 Multi-variant Design and Multiple Criteria Analysis (Kaklauskas et al, 2005)

Kaklauskas et al created a method of multi-variant design and multiple criteria analysis of a building refurbishment project, broken down into twelve steps. The first six stages are where the individual building element interventions are analysed. The paper provides formulae that aid the user to determine the significance, priority and utility of each element intervention. This helps the user to gather a significant amount of information about their element interventions, which acts as an input to the next six stages of the process.

In stages seven to twelve, multi-variant design and multiple criteria analysis of the entire building's refurbishment scenario is carried out. This brings together the individual element interventions from the first six stages to form a feasible refurbishment scenario. Any unfeasible interventions are removed/ rejected and the optimum interventions are grouped in line with their assigned priority levels. A summarised decision making table of all the refurbishment scenarios is created along with the relevant information.

The method does not aid the user to assess the current building state, and the user must be aware of what elements require action and what they need to do to those to bring them up to the required performance levels.

The interventions are assessed against multiple criteria including both quantitative and qualitative items. This can create misleading results depending on how well the assessment is carried out and the balance between the quantitative and qualitative information due to the subjectivity of the qualitative values. However, when undertaking a refurbishment, especially in a non-domestic building where the occupants may not be involved in the design process, the opinion of the occupants and consideration of the impact on them (whether it be due to the duration of works or reduction on working space or changes in IEQ) is critical for a successful refurbishment. This method is one of few that consider the qualitative aspects within the refurbishment assessment.

One of the interesting features of the system is that it details a table where multiple buildings to undergo refurbishment are listed along with their elements for refurbishment and the relevant quantitative and qualitative information. This is the only system of those reviewed here that appears to include analysis of multiple buildings at once, and this would be a very useful feature for property managers who are responsible for a large building stock.

4.3.9 Knowledge and Device Based DST (Zavadskas et al, 2006)

The DST consists of decision support, knowledge and device sub-systems which are combined to assess the refurbishment scenario. The decision support sub-system contains three major tables which hold the required information. Firstly, the initial data tables detail the building's characteristics, condition information, desired budget etc, all input by the user. The system does not appear to aid the user to collect this information about their property. Secondly, tables detailing the refurbishment intervention options are already contained within the system and the user has not had to provide these. Thirdly, the tables of multi-variant design are where the potential combination of interventions is determined.
The criteria by which the interventions are assessed are provided by the system along with typical weights and qualitative values, however the user can adjust these based upon their design team's recommendations.

Within the decision support sub-system the database management system manages the large amount of information relating to the refurbishment and has the capacity to allow several users to operate the system at once. This is a useful feature for large non-domestic building stocks where there may be multiple property managers requiring access to the system.

The interventions can be assessed and their potential for energy savings and improvement in building quality within the allocated cost constraints can be assessed.

The knowledge sub-system creates the intervention lists and assessment criteria, as well as their weights and values. The system also goes a step further and provides suggestions of suitable suppliers for the works based on the level of investment the user is willing to commit to each intervention, the cost of alternative actions, assessment results of the interventions and the reliability of the supplier from past experience. An email template is also composed for the user to issue to the supplier(s) to negotiate the arrangements for the works. This brings the consideration of practicality of the interventions to the forefront of the user's mind, and is a rare feature in the DSTs reviewed.

The device sub-system is where the internal condition of the property is recorded, i.e. indoor environment quality, and passed onto the decision support and knowledge sub-systems for consideration.

4.3.10 Two-factor Method (Kazakevicius et al, 2007)

This method of refurbishment analysis aims to simplify the selection of interventions by separating them into three groups: those that improve energy performance, those that improve building performance and those that achieve both. Firstly, the method helps the user to set an investment ceiling and, if the costs to refurbish are above the investment ceiling then the user is advised that refurbishment will not be cost effective and to consider sale or demolition. Secondly, the interventions are allocated to the three groups for assessment, with formulae provided for each group to determine the level of investment for each. The cost efficiency of the interventions is assessed. Energy efficiency related interventions are assessed using 'Cost of Conserved Energy' (CCE) and a CCE limit is set. If the amount of investment on the energy interventions arrives too closely to this limit then it is recommended that the user reconsiders the level of energy interventions. The same is carried out for the building improvement measures which have no impact upon energy performance. The method suggests that the level of investment for these is assessed using "the Net Present Value (NPV) of regular payments for 'Maintenance, Repair and Rehabilitation' (MRandR) over a period not exceeding the lifetime of the proposed measures..." (Kazakevicius et al, 2007, pp. 192 – 201).

The method allows the user to look at energy performance and building improvement measures from a financial point of view. The user can determine what payback they will gain from implementing energy interventions (such as reduced energy bills) and what payback they will gain from building renovation interventions (such as reduced maintenance costs, increase in property market value or additional/improved facilities).
The system does not aid the user to assess the current building state but directs their thinking into separating the energy improvements and building renovation improvements. The summarised table that this method creates allows the user to view the interventions within their groups and the corresponding costs, energy savings, payback and lifespan of the element.

The user has to identify the interventions and this method aims to help the user assess the attributes of these in a simplified manner when compared to the sometimes complex method of multiple criteria assessment.

4.4 Discussion of Current DSTs

All of the DSTs reviewed present positive attributes that would aid a property or facility manager to make improvements to an existing building. However, Table 3 shows that there is no single DST that completely fulfils the needs of the target user. This section discusses the pertinent points arising from the literature review.

Table 3 – Existing DST Comparison Summary (Strachan and Banfill, 2012)

Decision Support Tools Reviewed	Decision Support Criteria: 1.Carbon Emissions Savings				2.Energy Consumption Savings				3.Cost					4. Building Assessment		5.Refurbishment Interventions			6.User Acceptability			7.Data Quality						8.Usefulness				
	1.1 Help to calculate carbon emissions associated with building pre-refurbishment.	1.2 Provides estimation of carbon emission savings associated with refurbishment interventions.	1.3 Helps to calculate/provides carbon emissions associated with building post-refurbishment.	1.4 Is it likely the DST will aid emissions savings	2.1 Help to calculate energy consumption of building pre-refurbishment.	2.2 Provides potential energy consumption savings associated with refurbishment interventions.	2.3 Help to calculate/provides energy consumption of building post-refurbishment.	2.4 Is it likely the DST will aid energy consumption savings.	3.1 Provides the cost of the overall refurbishment scheme.	3.2 Provides the cost of individual refurbishment interventions.	3.3 Provides financial payback/ROI of the refurbishment scheme.	3.4 Provides a mechanism for setting a budget.	3.5 Provides a mechanism for adjusting costs.	4.1 DST aids pre-refurbishment building state.	4.2 Considers energy performance as a main focus when assessing the pre-refurbishment building state.	5.1 DST provides the refurbishment interventions.	5.2 Refurbishment interventions undergo multi-criteria assessment.	5.3 Energy performance is a main intervention assessment criteria.	6.1 Occupant views considered during refurbishment intervention suitability assessment	6.2 Level of intrusiveness is included during refurbishment intervention acceptability assessment.	6.3 Occupant opinions re. indoor environment quality have been considered during refurbishment intervention acceptability assessment.	7.1 Cost data reliably sourced.	7.2 All associated refurbishment costs are included (external factors).	7.3 DST contains international cost data.	7.4 Current building state data is accurately obtained	7.5 Refurbishment interventions are reliably sourced.	7.6 Refurbishment intervention assessment criteria are reliably sourced	8.1 User interface is suited to non-computer experts.	8.2 DST can be accessed remotely.	8.3 Mechanism for continuous improvement/review of building performance in the future	8.4 Assesses non-domestic buildings.	8.5 Assesses multiple buildings.
EPIQR (Droutsa, Flourentzos & Wittchen, 2000)	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	D	Y	Y	M	Y	N	M	N	M	Y	M	N	Y	M	D	D	Y	D	N	N	D
TOBUS (Flourentzou et al, 2002)	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	D	Y	Y	M	Y	N	M	N	M	Y	D	Y	N	M	D	D	Y	D	N	Y	D
XENIOS (Balaras & Dascalaki, 2004)	Y	D	Y	Y	Y	Y	Y	Y	Y	Y	Y	D	Y	Y	Y	Y	N	Y	N	N	N	D	N	N	M	D	D	Y	D	N	Y	D
BEMS Data Based DST (Doukas et al, 2009)	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	D	Y	Y	Y	Y	N	Y	N	N	N	D	D	D	Y	M	M	Y	Y	Y	Y	D
GA-Based DST (Castro-Lacouture et al, 2009)	N	M	N	M	N	M	N	M	Y	Y	Y	Y	Y	Y	N	Y	N	N	N	N	N	M	D	N	M	D	Y	Y	Y	N	N	D
Hybrid Decision Support System (Gao et al, 2010)	N	M	N	Y	N	M	N	Y	Y	Y	N	Y	Y	Y	M	Y	N	M	N	N	M	M	N	D	M	D	D	Y	M	N	Y	D
Knapsack Model (Alanne, 2004)	N	N	N	M	N	N	N	M	Y	Y	D	Y	Y	N	N	N	Y	M	M	M	M	M	M	M	M	M	M	Y	D	N	Y	D
Multivariant Design and Multiple Criteria Analysis (Kaklauskas et al, 2005)	N	N	N	M	N	N	N	M	Y	Y	M	Y	Y	N	N	N	Y	M	M	M	M	M	M	M	M	M	M	Y	D	N	Y	Y
Knowledge and Device Based DST (Zavadskas et al, 2006)	N	M	N	M	N	M	N	M	Y	Y	Y	Y	Y	D	M	Y	Y	M	N	N	M	D	M	D	M	D	D	Y	N	N	Y	D
Two-factor Method (Kazakevicius et al, 2007)	N	D	N	Y	N	D	N	Y	Y	Y	Y	Y	Y	N	N	D	D	Y	N	N	N	D	D	D	M	D	D	Y	N	N	N	D

Key

Yes (DST fulfills this criterion) Y **Maybe (DST fulfills this criterion to some extent) M**

No (DST does not fulfill this criterion) N **Do Not Know (Insufficient information in paper to assess this criterion) D**

4.4.1 Carbon Emission Savings

Six out of the ten DSTs would be likely to yield carbon emission savings if used during the refurbishment decision making process. This has been concluded from the interventions proposed by the DSTs as well as the results of case studies presented in the DST literature. This is a positive outcome of the review, although only one of the DSTs showed that it would provide actual carbon emission savings figures. The display of pre and post refurbishment carbon emission figures is a useful feature of a DST, in addition to energy consumption (kWh) figures, as different users will have different reporting preferences. With many government policies and targets referencing greenhouse gas emission reductions, large organisations and consequently high energy users are looking to identify the emissions they are responsible for, as a result of their property portfolios but also wider sustainability issues, such as travel and waste. It would therefore be useful for the DST to support the user to identify the proportion of their organisation's carbon footprint that buildings account for.

4.4.2 Energy Consumption Savings

In order to maintain the energy consumption savings that could be achieved, the property manager needs to ensure good energy management is practised across the building stock. The building users need to be informed of how they use energy and what the consequences of their behaviour are upon consumption levels. "Successful energy management must combine an effective strategy with the right practical interventions. It begins with the key decision makers, and then involves every employee on a day-to-day basis." (Carbon Trust, 2010, p.4).

Good energy management could help to maintain energy savings and avoid energy wastage. Occupants are often referred to as the primary problem in buildings when it comes to energy efficient performance, yet consideration of occupancy issues are at times dismissed as 'soft' or 'fluffy' in industry. A DST could provide a FM/PM with the technical interventions that are required to improve the baseline building performance, but it must go beyond this to emphasise the importance of energy management if true savings are to be achieved and maintained over time. The drive for behavioural transition in an organisation must come from the organisation itself in the form of cultural change. However, a DST could supply the user with the information they need to educate their employees about how the building works. The DST could present good energy management as the primary level of intervention that would detail actions to minimise wasted energy created through inefficient use of small power and equipment, lighting and HVAC controls. The Carbon Trust provides both strategic and practical level energy management plans which could be incorporated into a DST to provide the user with the management information required to run an efficient building, with specific references to the interventions analysed or proposed by the system.

Furthermore, energy management principles can be incorporated post-refurbishment in the form of an action plan specific to the management of the 'new' building environment created due to the refurbishment interventions applied to the existing building state. It is the final stages of a project, new build or refurbishment, where so little attention is directed towards post occupancy performance. Once handover is complete then it is up to the property manager to determine how they will run the building. Initiatives such as 'Soft Landings' "closes the loop between design, construction, operation, feedback and into design again." (BSRIA, 2009, p.5). 'Soft Landings' advises that an aftercare team is situated in the building with the occupants after handover and provides an aftercare checklist which includes meeting with the occupants to discuss what has been done to the building and what changes they can expect in their daily use of the property, technical guidance for the facilities management team and informal walkabouts to note any occupancy related observations. Aftercare in this programme extends to three years after handover has occurred. The DST could promote seamless transition between the pre and post refurbished building state, by generating an energy management action plan that details how the chosen interventions have caused changes to the optimum approach to building use. It could also supply a post-refurbishment occupancy questionnaire to feed into the plan, to determine how successful occupants feel the refurbishment has been and if they have any queries about how to use any controls or equipment. XENIOS (Balaras and Dascalaki, 2004) is the only DST reviewed which makes reference to occupancy behaviour and energy management issues. This article provides a link to the XENIOS website where hotel manager and guest guides are available, detailing how to maximise the sustainable performance of the property. Although this guidance will be generic to most hotels it goes a step further than the remaining nine DSTs, which do not appear to provide any energy management guidance.

Some of the DSTs reviewed present energy related building interventions that could either reduce energy demand or provide a renewable energy supply. However, none of the DSTs mention the importance of separating the two forms of intervention, through the selection of demand interventions before considering supply technologies.

The EU is pushing for the widespread use of renewable energy sources due to their clear benefits of financial savings, energy security, environmental protection and the creation of new jobs. It proposes a new Directive on renewable energy, setting an ambitious target to reach a 20% share of energy from renewable sources by 2020 (European Union, 2001). However, the Tarbase research project (Tarbase, 2010) highlights the difficulties of justifying renewable energy supply technologies, "Most options are currently difficult (or impossible) to justify economically and will not produce carbon savings on the same scale as measures relating to small power, lighting and HVAC." (Tarbase, 2010, p.95). While large organisations may be drawn towards the 'renewables' trend and appreciate the public relations benefits they bring, electrical and thermal energy use in non-domestic buildings have to be tackled from the demand-side prior to supply-side options. Essentially energy demand must be addressed as a priority, to avoid supplying to wasteful energy consumers.

4.4.3 Cost Function

DSTs cost functionality is central to their validity. A FM/PM user will require a reliable cost for the refurbishment works, as it may form the basis of their business case to justify expenditure and release funding for such works within their organisation. In addition, the procurement approach could demand a level of certainty from the capital cost and payback generated by the DST, where an ESCO (Energy Contracting) model is to be used. All of the DSTs reviewed address cost as a priority, some providing the user with significant cost information and analytical functionality, including budget setting capabilities, to arrive at the optimum refurbishment scheme from a financial perspective. The use of a DST could allow rapid refurbishment intervention option appraisal, to create the most cost effective scenarios that simultaneously satisfy non-financial performance criteria as far as possible within a set investment ceiling.

A key factor that impacts cost reliability is the capacity of a DST to firstly, define the limitations of the cost it generates, whether it includes: materials, labour, professional fees, legislative approval fees, preliminaries, contingencies, financial impact on refurbishment of an occupied building (moving furniture/staff), out of hours working, working with noise restrictions etc. Secondly, is to then go on to include these factors within the final cost output, as these are all supplementary costs that a FM/PM would have to account for if they were to undertake the works. Upon review of the DSTs in this study, the majority did not include these items within the final cost output, or if they did, it was not apparent. The exclusion of such items would lead the user to question a DSTs appropriateness for the granular nature of individual intervention option appraisal. Instead, many of the reviewed DSTs cost modules would perhaps be better suited to provide a high level cost estimate for refurbishment. An estimate required by a user who is still to take the decision whether or not to refurbish, rather than a user who wants to actively improve their portfolio and requires a relatively accurate cost to take forward as a budget.

It must be stated that many of these reviewed systems are still prototypes and their cost modules may undergo development to accommodate these more specific cost analysis factors. As well as this, many of the DSTs contain flexible cost modules which could be adjusted to suit the user’s needs. However, this requires a greater level of user input – perhaps undesirable where a user is to justify the cost of employing a DST and the associated training.

The majority of the DSTs reviewed did include the presentation of financial payback information for refurbishment scenarios. This is incredibly important information to display as many organisations that are starting to look at their energy performance, will set relatively strict parameters regarding the maximum payback period they are willing to commit to. This is due to numerous factors, but one key issue to consider is the current average length of commercial leases of less than five years in the UK, as tenants are cautious to commit to long term leases due to the current financial climate. Consequently, let buildings become a major issue when assessing feasible intervention options. It would be a useful function for a DST to therefore allow the user to filter intervention options based upon payback periods. Furthermore, this would meet the current needs of FM/PMs to determine where the highest consumers are within their portfolio and then how they can achieve savings within these properties through ‘easy wins’ –short payback measures.

4.4.4 Present Building Condition

Not all the DSTs support the user to assess the current condition of their property, some require the user to determine the current state independently and use it as an input for the DST. The current condition information must be collected accurately, to allow a thorough picture of the building to be recorded. The DSTs which do assist in recording the current condition could be viewed as limiting the amount of information collected, as they use a specific list of questions, providing multiple choice answers and a series of images to select from.

BEMS Data Based DST (Doukas et al, 2009) uses Building Energy Management System (BEMS) data combined with standard building information to analyse the current energy performance of the building. This appears to be a more accurate way of assessing the current building condition as it utilises actual operational data, with the potential to analyse half hourly consumption performance and identify the building functions attributed to the highest consumption levels.

In order to gain a true representation of the current building condition, the DST should be able to combine BEMS data (if available) with user input on standard building information (preferably the results of a professional survey, procured by the user) and provide an indoor environment quality (IEQ) questionnaire to be issued to the occupants to gather their views on the building's present state.

The collection of building condition data that is not directly linked to energy consumption should be included in the pre assessment, most likely within a professional survey, as the any outstanding repair and maintenance issues should be remedied prior to or concurrently to energy performance improvement measures as the condition of the existing fabric, controls and services could impact upon the success of the improvement measure.

4.4.5 Refurbishment Interventions

Practicality determines the physical feasibility of the refurbishment options and is therefore critical when assessing refurbishment scenarios. Douglas (2006) highlights the importance of feasibility and the three factors that contribute to form refurbishment feasibility, "Viability, (economic feasibility), practicality (physical feasibility) and utility (functional feasibility)" (Douglas, 2006, p.38).

A DST that does provide intervention options should take into consideration the practicality or 'buildability' of the proposed options. It is unclear from the papers reviewed whether or not the interventions they provide have undergone some assessment of their appropriateness for the particular building in question.

Every property is different, particularly existing non-domestic property that may have already undergone refurbishment schemes or changes in use etc, therefore an intervention suitable for one property may not be suitable for another, whether that is due to access for installation, compatibility of materials, available space etc. The DST must consider these practical issues by taking into consideration the building's location, surroundings, type of site, fabric, services, controls, occupancy, function, dimensions etc and then assess how suitable or compatible each intervention will be for that property. The DST could assess the interventions against 'practicality' criteria and eliminate those options that would be unsuitable. Alternatively, it could provide the interventions with corresponding information about their 'buildability' attributes, allowing the user to decide what is feasible. Of course the latter option would require the user to be familiar with construction technology.

One example of where little detail regarding an intervention's practicality is in XENIOS (Balaras and Dascalaki, 2004) where the user can adjust the thickness of the wall insulation and see the direct impact upon energy savings. It does not state what type of material is used, whether it is installed internally, externally or in the wall cavity (if present), whether there is access to carry out the works etc. These are only a few of the factors that need to be considered before a wall is insulated. The only aspect where practicality is considered in the DSTs reviewed, is where additional costs are added using a 'complexity coefficient' which includes; access, size of operation and working conditions. However these do not appear to be used to assess the appropriateness of the proposed interventions.

Where the DST does not provide the interventions, but only an assessment of their suitability and compatibility with other interventions, then the criteria could include practicality issues.

The inclusion of external factors is also key in influencing the suitability of an intervention. The DSTs analysed do not consider legislative or other external factors which may influence the suitability of some interventions. These external factors include certain approvals that any building design needs to undergo prior to commencement of the works, such as building warrants, planning permissions and where appropriate conservation area and listed building consent.

It may be possible to design a DST that incorporates these requirements into the assessment of interventions. It is unlikely that the interventions, proposed by current DSTs, would be deemed unsuitable by building control or planning authorities but it is when these interventions are combined with a specific building type, in a certain location, that disagreements may arise.

Existing standardised building control checklists could be incorporated into a DST to maximise the interventions' potential acceptability. Alternatively, this information could be provided to the user for consideration of the interventions, and to allow for any alterations to be made prior to a scheme being submitted to the appropriate authorities.

4.4.6 User Acceptability

The DSTs generally do not consider occupant's views of the state of the building before refurbishment nor in relation to the proposed interventions. As discussed in section 4.3.2, the occupants of the building determine how efficiently that building will operate, and if the DST supported the user to include the views of the occupants then this could help to streamline the entire project process. By ensuring that they feel informed and that they have a channel for communication, they will feel more motivated to use the building to its maximum potential post-refurbishment.

4.4.7 Data Quality

It is unclear from the DSTs reviewed whether data used was of substantial quality as the source was not provided. Even for DSTs that provide the source of their cost data, conversely, the source of their decision making criteria or building assessment criteria was unclear.

4.4.8 Continuous Improvement

A mechanism for continuous improvement within the DST's would improve its relevance to property professionals today. Property managers would benefit from the ability to review what interventions have been applied to their building(s). A DST could act as a provision for storage of performance data, and therefore storage of a performance baseline for future intervention.

A module for review within the DST would aid the user to analyse the portfolio in terms of previous interventions and their associated success factors (whether they were met and why). This would support decision making for future building works, allowing for previous lessons learned to be disseminated to new projects.

The 'BEMS Data Based DST' presents a means for review and appears to be the only DST of those reviewed to do so. It updates its internal databases with the works carried out and the new building energy performance. "...new data recorded from the operation of the building with the new equipment installed can set new standard values...so that a continuous process for constant improvement in energy efficiency can occur." (Doukas, 2009, pp. 290 – 298).

4.4.9 Concluding Discussion Comments

The ten DSTs reviewed would certainly support the user in assessing the performance of their property and potential interventions within a certain budget. However, the majority struggled to provide sufficient detail regarding carbon emission savings and energy performance, and did not appear to consult the building users' views pre or post refurbishment. One key point that has arisen from this review is the lack of attention towards post-occupancy evaluation, i.e. how successful the refurbishment has been in terms of user acceptability as well as energy performance, and furthermore the determination of an updated baseline from which to measure future improvement. This is important as it provides a basis for future intervention, ensuring that the building continues to operate as efficiently as possible. Through examination of the attributes of the current DSTs and the requirements of current property/facilities managers of non-domestic building stock, a proposal for an optimum DST template is described in 4.4.

Since the writing of this initial review (Strachan and Banfill, 2012), there have been developments in the literature relating to decision support/ decision making tools, systems and methodologies for existing building improvement. In the most recent examination of the literature (see below), there is a notable number of publications looking to build upon previous DSTs through improvement in cost functionalities and increasing specificity towards energy performance improvement of existing office buildings. Furthermore, new DSTs that specifically support property managers already working within efficiently performing property to carry out works that lead to zero carbon and positive-energy buildings have been developed. The development of such DSTs in recent years following the initial review aptly illustrates the changing needs of the property manager, and reaffirms their need for support in energy-led refurbishment.

- Economically Optimal Evaluation (Kumbaroglu and Madlener, 2012)

  The DST addresses future rises in energy prices within the decision-making process, and through a 'techno-economic' assessment methodology, identifies the optimum timing of refurbishment decisions.
- Key Factors Methodology (Costa et al, 2012)

  The proposed DST centres upon the optimisation of operational energy performance processes, and provides virtual testing of different building operation solutions.
- Retrofit Analysis under Uncertainty (Heo et al, 2011)

  The decision support methodology centres upon large scale refurbishment undertakings, and the risk associated with such refurbishment options.
- Decoupled Whole-Building Simulation (Rysanek and Choudhary, 2012)

  The authors present a DST that not dissimilarly to other DSTs, focuses upon the financial aspects of refurbishment for improved energy performance. Interestingly, this DST includes behavioural measures as a refurbishment option.
- Multi-objective Optimisation Model (Asadi et al, 2012)

  A multi-objective DST that determines the optimal cost, energy reductions and thermal comfort associated with refurbishment options within domestic property.

- Office Building Multivariate Analysis (Djuric and Novakovic, 2012)

  The paper presents an approach to the utilisation of building data to further improve energy efficient office buildings. It is an example of advancement in recent years of the increasingly high expectations of existing properties' energy performance towards zero carbon classification.

Despite these developments in the DST literature, the conclusions drawn from the initial review remain valid in leading to the requirement of the optimum DST described next.

4.5 Optimum DST Model

Consideration of the desirable attributes combined with key observations resulting from the literature review in Chapter 2, specifically sections 2.9 and 2.10, leads to the following seven step process for the 'optimum' DST.

4.5.1 DST Target User

This DST is targeted at property managers who are responsible for the energy performance of a non-domestic building or building portfolio. It could theoretically support decision making at every level of the non-domestic property ownership hierarchy. However, the proposed granularity of the DST functionality may not be as relevant to investors and fund managers within the property market. It has therefore been specifically designed to aid property managers who are concerned with asset level issues, some operating within owner-occupier and others within tenant organisations. The DST is most feasibly implemented where in the case of a tenant organisation, the landlord and tenant have established an agreement that permits energy performance improvement, most typically through a memorandum of understanding or green lease. The pressure upon property managers to review their building portfolio, and related energy consumption is passed from board room level as it becomes increasingly 'green', due to businesses considering the benefits of sustainable retrofit of their facilities; these improve indoor environmental quality, demonstrate corporate environmental commitment, reduce operational costs, improve productivity and enhance public relations (Lockwood, 2008). Studies have shown that the majority of professionals working within small, medium and large businesses believe that energy management strategy is very important to their business and will be increasingly so (British Standards Institution, 2009). A key element of energy management strategy is a company's property management team and how it is organised to achieve results. Many businesses now place the responsibility of energy management with their property managers, or alternatively employ a dedicated energy manager, who is responsible for collecting energy performance data, carrying out benchmarking, executing improvement project and reporting results. Consequently, their performance is measured through annual emission reduction targets, either as a contractual requirement or within a bonus incentivised scheme. This pressure to achieve year on year reductions in energy consumption/carbon emission levels, combined with the overwhelming range of intervention options for existing buildings can make it difficult to make informed decisions when selecting an optimum energy performance improvement package. This proposed DST looks to support this professional in carrying out these emerging energy management responsibilities.

4.5.2 Optimum DST Model – Step One: Building(s) Assessment

The primary purpose of step one in the process is to gain a holistic view of performance and record it in a database. In order to achieve this, several pieces of information must be collected from the property. The DST would support the user in gathering this information, by guiding them through the collection process and a user friendly interface would facilitate input and analysis of the data. The user would be expected to have a particular level of technical capability (based on the target user detailed in 4.4.1). However, this step could be outsourced to a professional surveyor where this is not the case.

The collection process would begin with the identification of the building's key features to determine a profile of the property. This would include information regarding location, orientation, age, construction form, HVAC systems, function, floor area(s), occupant type, number, hours and working patterns.

The system then helps the user to further investigate the building's state, assessing the condition of fabric, service and control elements that if in poor condition could impact energy performance. For example, the thermal performance of an external wall could be detrimentally affected by an external leaf that is in poor condition, such as a brick wall that requires re-pointing or a cladding system with a damaged or missing tile etc.

The energy performance analysis of the property includes the energy consumption/demand levels through a survey proforma and/or Building Management System data (where available). The system supports collection of the available energy data at the time of DST use, and encourages the user to implement measures in the future to aid the collection of increasingly granular data and therefore supports a graduated approach to energy performance improvement. For example, the introduction of AMRs. Further to the energy usage data, is the logging of building elements that would impact performance within the system: the thermal efficiency of the current fabric state, the efficiency of key building service items and the type, efficiency and suitability of current energy controls, fuel types, number, type and organisation of meters/management systems. Once a view of energy consumption has been established, the associated carbon emissions are also presented to provide the user with the different performance metrics that they may be required to report upon.

Operational efficiency of the building as a result of the wider organisation’s culture and behaviour is captured in step one. This will supplement the asset energy performance already established. It is concerned with the assessment of internal heat gains as well as the plug load associated with the building operation. Excessive and unnecessary heat gains mean that users will demand additional cooling, consequently creating a higher electrical demand. The small power and IT equipment will also put an increased electrical load on the building if it is inefficient or used inefficiently. The DST uses a standardised questionnaire or checklist to determine what small power and IT equipment is currently within the property. This can be used to check whether the current equipment is appropriate for the occupiers’ needs, as these are constantly changing in line with increasing occurrences of remote working and travel, and whether it is the most efficient version available, taking into consideration its age. A common issue identified by many large organisations is the misalignment between the occupants’ requirements and the provisions made by their IT colleagues. The IT department will often over-specify the amount of equipment and may not take into consideration energy efficiency as a priority over other performance metrics.

The DST presents a consistent focus upon occupancy related issues throughout the seven steps, and the occupancy information collected at the beginning of step one will facilitate the comparison between occupancy characteristics and the results of the small power and

IT equipment audit, highlighting areas of misalignment and recommending areas for investigation as well as appropriate changes.

The same audit is carried out by the user regarding lighting, to determine the amount and type of lighting currently in place, how efficiently it is running, how it is controlled and whether it is suitable for the tasks being undertaken. If the user has employed a professional surveyor to carry out the initial building survey then they could also ask them to carry out a daylight assessment of the building to determine areas where the daylight levels are sufficient without the use of artificial lighting. The results of this survey can provide the figures required to act as evidence for occupants, that demonstrates why they may not need to use artificial lighting at all times. It is facts derived from such figures that may encourage cultural change within the organisation.

It is ultimately the occupants that will determine the success of a refurbished property and it is therefore important that their views upon the current state of the building are gathered pre-refurbishment to highlight any areas for improvement that the property manager may not be aware of. The DST provides a standardised Indoor Environmental Quality (IEQ) questionnaire for distribution to and completion by occupants.

A secondary and separate questionnaire determines the current attitudes and behaviours of the occupants towards energy usage, if they are aware of their current energy usage and what impact it may have upon the organisation and the environment, if they are aware of how to change their behaviour and if they are aware of how to change but don't feel motivated to do so, along with the reasons why etc.

Cultural change is important when assessing the energy performance of a building, as a change in the way the occupants use the building and its contents can provide significant energy demand savings (Hong and Lin, 2013). This is possibly one of the most difficult obstacles when trying to improve a building's energy performance. Even if the appropriate equipment and controls are provided the users need to be aware and motivated to take advantage of these.

4.5.3 Optimum DST Model – Step Two: Energy Demand Interventions

This step addresses the outcome of step one through the proposal of energy performance improvement measures (EPIMs) to reduce the building's energy demand. Farmer (2010) concludes that it is the speed and order in which interventions in our non-domestic building stock are implemented that will determine whether Government carbon reduction targets are achieved, with emphasis upon the separation of cost-efficient and cost inefficient interventions. The DST reflects this methodology through the adoption of a tiered approach to EPIM adoption. This permits the user to select interventions that are suited to their current capabilities and to return to the DST once they have the resources to undertake a more complex intervention strategy. The DST presents three levels of intervention:

- Level 1 - Changes in occupancy culture and behaviour towards energy consumption
- Level 2 - Changes in lighting, small power and IT equipment to energy efficient alternatives where appropriate
- Level 3 - Changes to building fabric, services equipment and controls

The user can select the level of intervention they want to undertake, up to all three levels if so desired. A range of EPIM options are provided by a knowledge database within the DST. The EPIMs proposed by the system are assessed against a set of multiple criteria, with assigned weightings of relative importance within the decision. The assessment criteria contain both qualitative and quantitative items, and these are detailed further within Chapter 5 of this thesis. The user can adjust the weightings to suit their particular requirements, although the system provides a recommended set based upon the knowledge of a carefully selected low carbon expert group. Central to the success of step two of the DST is its capability to ensure compatibility between the EPIMs put forward, thus avoiding the proposal of an impractical solution.

4.5.4 Optimum DST Model – Step Three: Simulated Building(s) Performance Post Energy Demand Interventions

The benefit of using DST software within energy-led refurbishment is the ability to theoretically model the potential performance of the property following EPIM implementation prior to carrying out the works, through an appropriate back-end modelling software. The outcome of this simulation provides a foundation for the modelling of energy supply interventions as well. The separation of energy demand and supply analysis is important to provide the user with a true representation of the energy demand of the property that is required for it to operate efficiently and effectively. The eradication of any energy inefficiencies prior to consideration of energy supply technologies is a logical approach that will avoid unnecessary expenditure to supply to a wasteful building.

4.5.5 Optimum DST Model – Step Four: Energy Supply Interventions

The system assesses the energy supply interventions against multiple criteria in the same manner as the energy demand interventions, using both quantitative and qualitative criteria. This module of the system presents the most suitable low carbon/renewable energy sources for the building as well as relevant, practical information about the management requirements of installing and running such systems.

The system can also provide a deeper level of intervention where renewable technologies are considered for the energy supply of multiple buildings within the organisation's building stock.

The user has the option to deselect all energy supply interventions if they feel they are not appropriate.

4.5.6 Optimum DST Model – Step Five: Simulated Building(s) Performance Post Energy Demand and Supply Interventions

The building is re-simulated combining the original state of the building plus the energy demand and supply interventions to determine the new performance. The system provides the energy consumption and carbon emissions savings, the overall cost to achieve the new building performance, the cost savings achieved through reduced energy bills and the payback of the individual interventions. Additional analysis of all EPIMs against the detailed assessment criteria set can also be accessed at this point.

4.5.7 Optimum DST Model – Step Six: Energy Management Action Plan

The DST generates an energy management action plan based upon the interventions selected. This advises the user on how to effectively implement these measures and manage what is essentially a new version of their existing building to maintain efficient performance over time. Post-refurbishment the user is instructed to re-circulate the IEQ questionnaire to all occupants to determine how the refurbishment actions have changed their working environment. The results of which will be logged within the system to allow generation of a report to draw comparisons between pre and post refurbishment performance from an occupancy perspective. This can then act as a tool for the property manager to encourage engagement from occupants to consider their energy usage within the building. The system encourages the ongoing consultation of occupants to ensure long term change in behaviour.

4.5.8 Optimum DST Model – Step Seven: Continuous Improvement

This module of the DST provides a mechanism for review of the different refurbishment scenarios developed by the user through the tool as well as acting as a database to record what actions have been carried out on which properties. This review mechanism allows different property managers perhaps working within the same organisation responsible for different regions to share data, knowledge and experiences regarding energy performance. The DST aids the user to continually review their property portfolio to determine when opportunities for new intervention measures arise. This is particularly pertinent as property managers are being set increasingly stringent year on year energy reduction targets, and the subject of energy performance therefore becomes an area for continuous improvement within their business.

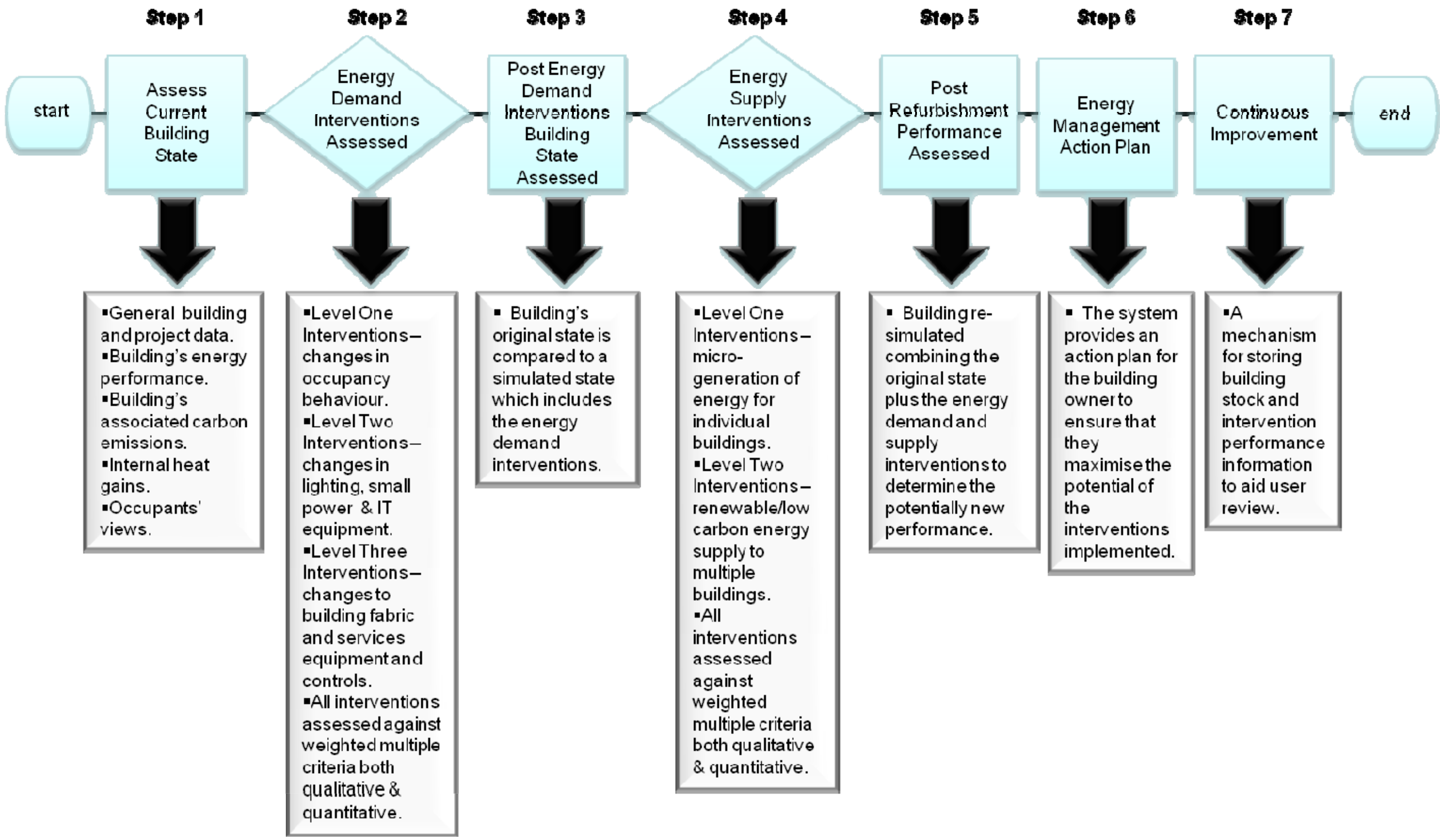

Figure 2 – Optimum DST Process (Strachan and Banfill, 2012)

4.6 DST Case Study

4.6.1 Case Study Overview

The optimum DST process was designed based upon a review of existing DST literature combined with a knowledge of Property Managers emerging requirements in the energy performance improvement of existing buildings.

To permit validation of the DST process designed within this chapter, a case study of an energy-led refurbishment of a hard to treat, office building has been selected and is presented here. This case study allows identification of similarities and opportunities between the DST and refurbished property, through the theoretical application of the DST process to a real energy-led refurbishment project. Information was extracted from the case study building through a formal interview of the appropriate professional responsible for the building's performance within the organisation, and examination of the organisation’s externally and internally available literature.

4.6.2 Case Study Subject

The DST in its current form is generic to all non-domestic building types and could be applied to any non-domestic property portfolio. A specific portfolio type was then selected for the case study, one classed as hard to treat (due to both technical and legislative reasons). This is the Historic Scotland (HS) building portfolio, and the case study examines the organisation's approach to energy-led refurbishment and how it was applied to the HS headquarters office building, Longmore House in Edinburgh, Scotland. HS is an executive agency of the Scottish Government, responsible for the protection and management of the historic built environment.

Longmore House

Originally constructed in 1880 as the Royal Edinburgh Hospital for Incurables before conversion into an office in 1994. This conversion included the addition of a significant extension to the rear of the property. It currently houses approximately 350 staff.

The property has a classical architectural style and was listed as a category B property in 1991.

Property is estimated to contribute to 5% of HS' total emissions.

Improvement measures undertaken to date:

1. Insulation of roof space
2. Repair and draught-proofing of existing windows
3. AMR (Automatic Meter Reading) technology installation
4. Chemical cleaning/flushing of boilers and radiators
5. Water heating upgrades
6. Replacement of halogen light fittings
7. Re-lamping halogen with LEDs
8. Improved lighting controls
9. Replacement of IT equipment
10. Rationalise printers

Figure 3 - Case Study Building Summary

4.6.3 Case Study Discussion

The improvement of Longmore House's energy performance is an ongoing process, described as "piecemeal" in nature by the interview participant (Participant 1). The term piecemeal fits the current approach to the process of energy-led refurbishment quite aptly. This could primarily be attributed to the new nature of this specific form of refurbishment. The new nature of this area is evident in that: construction professionals do not feel equipped to address it using their current skills base (as identified within Chapter 3 of this thesis), it is an activity that was once not considered as a credible sole driver of a building's refurbishment and arguably is now, dedicated roles are being created or redefined within existing organisations to specifically manage their carbon/energy performance, and finally, new legislation is being designed to specifically trigger building owners/occupiers to undertake energy performance improvement of existing property.

This piecemeal approach relates to decision-making at the building level due to the element of trial and error required when determining suitable improvement measures. This trial and error often occurs due to the multiple criteria that need to be considered/fulfilled when selecting a specific improvement measure, particularly in a hard to treat property. Although the approach to energy-led refurbishment is described as piecemeal in nature at the building level, at a strategic level, HS have a clearly defined methodology for reducing the carbon footprint of the organisation. This is in the form of an internal Carbon Management Plan (CMP), disseminated throughout the organisation. The plan features a hierarchical approach to reducing carbon and consequently energy consumption. This hierarchy presents three levels of intervention (Historic Scotland, 2011, p.8):

1. Reduce energy and fuel consumption, by targeting highest using sites and operations, through improved monitoring and staff awareness
2. Adapt our buildings, to improve energy efficiency through insulation, improved lighting, heating systems, controls etc
3. Diversify our energy supply by installing renewables at appropriate sites.

This hierarchy is reflective of the optimum DST presented in section 4.4 of this chapter. The implementation of such a hierarchical strategy across the entire HS estate and operations validates first, the DST's separation of energy demand reduction and energy supply intervention option appraisal, and second, the graduated approach to energy demand intervention. The DST Step 2 module presents three levels of intervention, to permit the user to gradually implement increasingly major works in terms of both cost and inconvenience/disruption to building operation. Participant 1 describes this tiered approach as appearing logical, yet is not always followed by those looking to improve their carbon footprint, "It's just a really pragmatic approach, using common sense, so many people jump on the bling [renewable technologies]" (Participant 1, 2012).

When discussing tier one of the HS hierarchical approach to carbon reduction, Participant 1 highlights the competing priorities that pose a barrier towards behavioural change within their portfolio towards energy consumption. “For example, the retail teams will want shop doors open because that’s how you get customers in, so we [Climate Change Team] are responding with alternative simple solutions, such as signage, projecting lighting towards pathways etc, so that we can close the doors and reduce heat loss. It seems basic but it doesn’t enter the thought process of other people because it isn’t their focus, they’re interested in meeting their own targets, in terms of sales etc” (Participant 1, 2012). The level 1 intervention described in the DST Step 2 module ‘Changes in occupancy culture and behaviour towards energy consumption’ could provide large organisations such as HS with literature/recommendations appropriate for dissemination to staff that is specific to the nature of their property portfolio. Upon running the DST Step 1 module, the output of which is a thorough building performance assessment, the DST Step 2 module would then present intelligent occupancy behavioural changes, for example, where the property in question displayed significant levels of heat loss through the existing fabric, the literature would emphasise the importance of closing external doors when not in use, closing internal doors to unconditioned areas, closing internal shutters (if present) overnight to conserve the internal building temperature etc.

This graduated approach to energy performance improvement that is witnessed in this case study, beginning with establishment of reduction targets, followed by a focus upon the collection of performance data to inform a valid baseline from which to assess the impact of improvements, is supported by the DST. It is crucial that the DST is capable of supporting the varying levels of expertise and intervention required by the user. The tiered approach to intervention assessment within the DST demonstrates this.

The approach to delivery of tier two of the HS hierarchy is tied directly to budget planning and forecasting future funding requests for such works. A five year projection is presented within the CMP and details portfolio-wide refurbishment recommendations, the capital cost, associated financial and carbon emission savings, payback, implementation programme and the outcome of the recommendation’s implementation with regards to the overarching emission reduction target. The improvement options’ appropriateness for the individual properties within the portfolio is an additional performance metric that is relevant at a more granular level of option appraisal. The CMP refers to the pertinence of such assessment of appropriateness, and although it does not appear to address the same extent of assessment criteria as the DST Step 2 module, relevance of such evaluation is validated through its mention within the CMP and subsequently supported through interviews with key members of the Climate Change Team. The CMP emphasises the need for a balanced consideration of both the "wider aspects of construction, conservation and regulatory constraints...with the carbon benefits" (Historic Scotland, 2011, p.18). Similarly, the views of participants from the CCT align with this, Participant One "...the best payback and what was appropriate for the building itself..." (Participant One, 2012).

This illustrates the multiple attribute decision making process that is undertaken when selecting a performance improvement measure for an existing property, particularly one classed as hard to treat due to parallel technical, legislative and social factors resulting from the traditional and historic nature of the building. The DST Step Two 'Energy Demand Intervention' module facilitates this complex multiple attribute decision making process and provides a unique set of weighted assessment criteria specific to the energy performance improvement of an existing office building of traditional, mass masonry construction. These assessment criteria and their determination are detailed further within Chapter 5 of this thesis. In short, they consider the impact of an improvement measure at every stage in the measure's lifecycle, from installation, operation to disposal, and address every aspect of performance, from aesthetics, potential changes to existing fabric behaviour, capital cost and payback, to ease of installation. The DST analysis of improvement options leads to the generation of a 'suitability score' for each individual improvement measure, indicating the level of appropriateness of each and permitting direct comparison of all options.

A key function of the DST is that it creates a centralised point for building energy performance, assessment, improvement and review. Due to the rapid introduction of internal reduction targets, internal energy/carbon managers responsible for performance management and improvement, and penalties arising from legislation, the undertaking of a thorough performance review can be easily overlooked. It is necessary to regularly re-evaluate baseline performance and report on both improvement and decline in performance, re-adjusting the approach to intervention as required. HS releases quarterly energy reports (QER) for each region of their portfolio internally to demonstrate the energy and subsequent carbon emissions associated with individual properties. The consumption levels for the reporting quarter are compared against those for the same quarter of the previous year, permitting a fairer analysis of performance. The reports highlight those properties where consumption levels have evidently increased and instruct investigation and potentially intervention where required. Furthermore the report identifies the sourcing of the data, from estimated consumptions to AMRs. The reports also appear to be one mechanism for the active encouragement of those responsible for each property or site to present recommendations to the central Climate Change team based on their intimate knowledge of the property. Participant One states the following of the QERs "...they've been going now for 6 months, so it's all still really new. Some regions have taken it really well and grabbed it and gone for it, they've set up energy focus groups that meet every month and look specifically at their energy use, and try to get the figures down. I want to see those energy focus groups extended over all the regions, and supported by a network of green champions, which not only look at energy use but start to look at wider issues" (Participant One, 2012).

This review of performance aligns with the Step 7 module of the DST 'Continuous Improvement', although reporting is the first step in undertaking continuous improvement of a portfolio, the full implementation of analysis of reported results and the impact of such analysis outcomes, upon the continued approach to energy performance management and improvement must be followed through effectively. The relationship between the DST Step 7 'Continuous Improvement' module and the Steps 1 ('Current Building State') and 2 ('Energy Demand Intervention') ensures a direct link between the outcome of an energy-led refurbishment, with the continuous improvement of the portfolio going forward. Furthermore, the performance metrics reported upon can initially be limited to purely energy consumption and carbon emission levels, a logical starting point. However, to obtain a holistic view of portfolio energy performance, building occupants' views must be considered in conjunction with this, especially pertinent in non-domestic building portfolios, where occupancy comfort, satisfaction and productivity are key performance indicators. Occupant satisfaction is particularly important in an estate like HS, as traditional properties are often create connotations of uncomfortable environments within the public forum, and in line with the protection and conservation of the historic built environment, of which HS strive for, it would be beneficial for the organisation to carry out a thorough analysis of energy-led refurbishment upon occupancy comfort once the reporting mechanisms for energy and carbon emissions are established. Participant One did acknowledge that they were still to carry out a formal POE of the case study property, but an informal walkround of the treated areas was carried out to gather initial verbal feedback from the occupants. The CMP references the impact of energy improvements on staff cultural change, and emphasises the importance of sustainable behaviour, so POE should be formally carried out. "[staff awareness and behavioural change] has the potential to contribute the most significant benefits across the Estate by engaging staff at all levels and business areas to change the culture of HS to a low carbon organisation." (Historic Scotland, 2011, p.51).

The measures implemented within the energy-led refurbishment of Longmore House form a list of portfolio-wide improvements. These have been assessed at high level within the CMP, with a focus upon programming over the next five years in line with the availability of project funding. Logically, the measures, often termed as ‘easy-wins’, those that are relatively simple to implement, low inconvenience and minimal cost for the greatest gain in terms of energy/carbon reduction, are programmed for immediate HS implementation. This approach to the selection of portfolio-wide improvements, (as opposed to the selection of individual improvements for individual properties) has benefits both financial and practical in nature, although may not be suitable for all property portfolios. The HS estate consists of a wide variety of building types, ranging from basic site huts to scheduled monuments. The heterogeneous nature of the HS property portfolio could make it difficult to address improvement measures on a portfolio-wide scale. However, there are commonalities within their building stock, in the form of energy inefficiencies, most notably heat loss and air infiltration. The measures for improvement can therefore address these through fabric and heating system repair, upgrade and replacement across the portfolio. The CMP addresses these improvements at high level, leaving a level of decision making remaining at building level regarding the specific type of measure, how it will be installed appropriately for the building in question in terms of construction detailing, consideration of conservation requirements and impact on occupants. The DST currently supports high level and building level option appraisal through the Step 2 ‘Energy Demand Intervention’ module and the weighted assessment criteria set, bespoke to traditional, non-domestic property. A modification to the DST could therefore be the function to identify appropriate portfolio-wide measures.

Whether these improvement measures already implemented have been successful in achieving carbon reductions is still an ongoing process of data collection and analysis. The impact of some interventions can take several weeks to become evident in the gas and/or electricity consumption levels of a property. However, initial analysis, specific to the Longmore House refurbishment, and utilising degree days was carried out by the Carbon Manager, and has demonstrated savings in energy consumption against the 2008/09 baseline. The benefit of the DST does not just lie in the achievement of reductions in the required metrics but the storage or data in one place and the analysis of these results, permitting lessons learned to inform future improvements. Due to the complexity and scale of the HS estate, a single point of contact, for energy performance data could be a useful tool.

4.6.4 Case Study Conclusions

The findings of the HS case study, examining not only the refurbishment of Longmore House, but also the wider, strategic approach to energy performance within a non-domestic property portfolio, have permitted the identification of parallels between the optimum DST proposed in section 4.4 and the HS approach to energy-led refurbishment. These are particularly apparent in:

- the need for a graduated, supportive approach to the entire energy-led refurbishment process due to the new nature of its implementation.
- the tiered format of energy performance improvement measures' proposition and assessment.
- the multiple criteria decision making process that is apparent in this form of refurbishment, particularly pertinent in hard to treat, non-domestic properties.
- the need to reinforce and support POE.
- the need for a DST to address entire portfolios, not individual buildings, which the optimum DST in this thesis does propose.

A notable improvement in the optimum DST functionality that has arisen from this case study, is the ability for the DST to identify improvement measures that are applicable across an entire portfolio. Although this may not be achievable for all improvement measures, where it is, then considerable cost savings could be identified as a result.

4.7 Conclusion

This chapter has reviewed the features of existing DSTs and synthesised them into an optimum DST, the appropriateness of which was then tested against what really happened in a single case study building. The next chapter develops step two of the optimum proposed DST – Energy Demand Interventions.

Chapter 5: Assessment of Energy Performance Improvement Measures

5.1 Introduction

Chapter 4 detailed the proposal of an optimum Decision Support Tool (DST) to support energy-led refurbishment of existing, non-domestic buildings. This seven stage DST (Figure 1) presents the second step as 'Energy Demand Interventions', and as explained in Chapter 4, this addresses the assessment of Energy Performance Improvement Measures (EPIM) and their suitability in reducing the energy consumption of an existing office building. The objective of this chapter is to develop step two beyond a conceptual process into a more practical model. The DST thus far has been a generic proposal for existing, office buildings. However, this chapter will show how the DST can be designed to apply to a specific building type, in the context of this study, an existing office building of traditional construction. This is defined by the following attributes:

1. The property is likely to pre-date 1919.
2. It will be of mass masonry (stone or brick) wall construction.
3. Originally single glazed windows.
4. Originally have no additional insulation materials built into the fabric.
5. It is likely to have high air infiltration levels.

Buildings of this construction type can often be found in the building portfolios of service sector and public sector organisations, providing them with a presence in many major city centres. This form of construction is often classed as hard to treat and it is for this reason that this study has chosen to address the selection of suitable EPIM's for an existing office building of traditional construction.

As discussed in chapter 4, the target user of the DST proposal is a professional responsible for the management of a business' non-domestic building portfolio. Many businesses require property managers to meet and sustain year on year reductions in energy consumption, either through a contractual requirement or a bonus incentivised scheme. This requirement applies pressure upon these professionals, combined with the overwhelming range of EPIM alternatives, can cause difficulty in informed decision making. It is a complex decision making process, that can be classed as Multiple Attribute Decision Making (MADM).

MADM can be characterised by alternatives, numerous attributes, attribute weights and incomparable units (Yoon and Hwang, 1995). In the context of this study, the alternatives are energy performance improvement measures (EPIM's). EPIM's have multiple attributes synonymous with assessment criteria; these are both qualitative and quantitative in nature therefore leading to incommensurable units of measurement. MADM involves evaluation of all available information and prioritisation of solutions. Prioritisation or ranking of the solutions requires some form of attribute weighting to allow scoring and comparison of alternatives. Decision-makers will have different views regarding the importance of a particular criterion, it is therefore necessary to use a recognised weighting methodology to determine the relative importance of each attribute/criterion. When a suitable expert participation group is applied to this methodology, a solid foundation is established to support a decision (Hamilton et al, 2007). The objective of this study is to define a set of assessment criteria against which to determine the suitability of an EPIM, and consequently aid decision making: these will subsequently be weighted in order of importance. The methodology, results and associated discussions of the DST step two development will be presented in this chapter.

5.2 Energy Demand Interventions Research Methodology

5.2.1 Introduction

The research methodology used to develop one module of the DST is described here. This is a two part, modified Delphi methodology. A Delphi survey process was undertaken to first determine the EPIM assessment criteria. This methodology enabled the collective input and agreement of an expert group upon assessment criteria that should be considered in energy demand intervention selection. The same Delphi expert group was then used to take part in a paired comparison survey to determine weightings of relative importance for the agreed EPIM assessment criteria.

5.2.2 Background to the Delphi Technique

Popularity of the Delphi technique dates back to the early 1960's, where it was primarily viewed as a mechanism for forecasting a future state (Gupta and Clarke, 1996). The technique has undergone many evolutions over time, to become a method that supports comprehensive decision making, planning and problem solving. It has been used in a wide range of sectors, examples include: construction (Hon et al, 2011; Manoliadis et al, 2006), education (Eskandan et al, 2007; Mamaqi et al, 2011), healthcare (Bond and Bond, 1982), information technology (Schmidt et al, 2001; Doke and Swanson, 1995), marketing (Jolson and Rossow, 1971; Lunsford and Fussell, 1993), and transport (Hojer, 1998; Sviden, 1988). However, the core principle of the Delphi remains; the obtaining of statistically valid consensus between a group of experts in a specific field, based upon their knowledge and experience, implemented through a series of iterative questionnaires, combined with controlled, anonymous feedback loops (Quade, 1970).

One of the salient advantages of implementing the Delphi technique is its ability to create an environment that permits independent thought of each expert. When this is combined with controlled feedback of other expert opinions, the individual is supported to reach a considered opinion in a measured manner (Dalkey and Helmer, 1963). Experts in a specific field will often have formed their own judgements about a subject relevant to their expertise and be inclined to defend that opinion and encourage others to conform when placed in a group scenario. Conversely, there will be experts who, when confronted within a group scenario, will feel pressurised to accept others' opinions or views on a subject. This is one element of the psychological occurrence "groupthink" which has been identified as one of the principal disadvantages of a group research method in existing literature (Janis, 1972); (McCauley, 1989); (Turner and Pratkanis, 1998). The Delphi approach provides the participants with anonymity to express their views, overcoming the direct confrontation associated with other qualitative, expert group research methods (Hsu and Sandford, 2007). Furthermore, the Delphi technique maintains the participants' focus upon the issue at the centre of the study, improving their problem solving skills and allows them to re-evaluate their preconceptions of a subject privately, in their own time (Hsu and Sandford, 2007).

The Delphi is typically delivered through a series of questionnaires. In each round, the facilitator will collect and feedback all of the participants' anonymous responses, to ensure all views are taken into consideration equally, and avoid emphasis on those who are domineering in the expression of their views (Rowe and Wright, 1999). The recommended number of questionnaire rounds varies in the existing literature. However, a series of three rounds is often recommended as a guide (Custer, Scarcella and Stewart, 1999).

The Delphi process is facilitated by the researcher remotely, and may be viewed as easier to manage than alternative group research methods. The participants can range geographically, as they are not required to meet in person, and the majority of communication is carried out electronically, via email or online survey tools. The process, is therefore, less reliant upon the researcher's skills in managing a group of varying characters and obtaining a balanced outcome. Instead, the researcher's skills centre upon nomination of an appropriate expert group and facilitating the group towards consensus without influencing the outcome and maintaining response levels across several iterations, a different challenge altogether. Existing literature does not prescribe a specific methodology for selection of appropriate Delphi participants. However, it is considered that an individual who is highly skilled, with specific, specialist expertise about a subject is an appropriate Delphi expert (Oh, 1974). In addition to this, the individual must have a reasonable approach, whereby they are open to revision of their views when presented with new information (Pill, 1971). The number of Delphi participants recommended in the existing literature varies from ten to fifty experts (Turoff, 1970).

An additional challenge associated with the nature of the Delphi technique is time (Hsu and Sandford, 2007). Time is required between each survey round to allow the facilitator to analyse and construct feedback of the expert views. Furthermore, the participants must be permitted sufficient time to allow them to consider the content of each survey round as well as the feedback of others' views before responding themselves.

5.2.3 Application of the Delphi Process

The overarching question posed to the Delphi expert group in this study was:

"What criteria should built environment professionals use to assess the suitability of an energy performance improvement measure for an existing building?"

Preceding this question, the participants were provided with a short explanation of the Delphi study's objective; to develop a set of weighted assessment criteria for a decision support tool, that will allow an individual working within an organisation – who is responsible for the management and improvement of that organisation's building stock – to make informed decisions about energy performance improvement measures applied to that stock. Specifically in office buildings classed as hard to treat, that are of traditional construction. A definition of this building type was also provided:

"Traditional construction within the context of this research refers to buildings that;
1. Are likely to pre-date 1919
2. Are of mass masonry (stone or brick) wall construction
3. Originally single glazed windows
4. Have no additional insulation materials built into the fabric
5. Are likely to have high air infiltration levels"

Once the Delphi experts had been selected, they were contacted via phone/email to explain the Delphi process. The participants were made aware of the numerous survey rounds, feedback and review of their responses and an approximation of time commitment. The process consisted of three rounds. In round one, a questionnaire was designed and delivered electronically via an online survey website. The questionnaire presented the participant with a selection of assessment criteria by which to determine the suitability of an energy performance improvement measure. This initial list of criteria was determined by the researcher based upon their literature review in Chapter 2, with particular reference to sections 2.5 – 2.10. The initial list provided the participants with a guide to begin development of a comprehensive set of criteria. The questionnaire consisted of seven questions, as shown in Table 4.

No	Question	Response Format
1	In your opinion, does the list contain sufficient criteria to assess the suitability of an Energy Performance Improvement Measure?	Yes/No
2	Are there any criteria that should be added to the above list?	Yes/No
3	If yes, then please describe what additional criteria should be added.	Comment box
4	If yes, then please explain why these additional criteria should be added.	Comment box
5	Are there any assessment criteria that should be omitted from the above list?	Yes/No
6	If yes, then please describe what criteria should be omitted.	Comment box
7	If yes, then please explain why these criteria should be omitted.	Comment box

Table 4 – Delphi Survey Questions

In round two, all thirteen experts completed the round one questionnaire, providing clear explanations for any changes they recommended. The round two questionnaire consisted of the same format as round one. However, the initial list of fifteen assessment criteria presented to the participants in round 1 was adjusted to represent the changes made by the group.

In round three, all thirteen experts completed the round two questionnaire, again providing clear explanations for any changes recommended. The results of round two were presented in a table in round three. This table format was required to meet participants' request, of a structured presentation of the assessment criteria in relevant categories to support decision making. This was a logical step in the development of the criteria set. Since the online web tool was incapable of presenting the results in the required table format, it was instead created in Microsoft Excel and emailed to each participant to review and comment. An expanded definition of each criterion was also issued to correspond with the table.

Once the assessment criteria were agreed and defined, they were weighted in terms of their relative importance. Rather than carrying out a further questionnaire, with the aim of achieving consensus between the participants, the weighting method of multiple criteria used was the paired comparison survey method.

5.2.4 Weighting Multiple Assessment Criteria

The collection of expert views regarding the weighting of multiple criteria has been viewed as a preferred method over purely analytical methods (Eckenrode, 1965). However, determination of criteria weights is a complex process due to the often conflicting nature of the criteria, and an appropriate method for elicitation of the expert weightings must be carefully selected. There are many weighting techniques available, and their attributes have been analysed and compared within existing literature (Bartlett, 1960; Eckenrode, 1965; Hobbs, 1980; Hajkowicz, McDonald and Smith, 2000).

- Fixed point scoring
- Rating
- Ordinal ranking
- Graphical weighting
- Paired comparison

The paired comparison method is relatively well known and has been implemented in this study, for the following reasons.

Hajkowicz, McDonald and Smith (2000) have found through practical application and review of weighting methodologies, that methods that require participants to distribute an allocated number of points across several items at once are not favoured. They surmise the cause to be the difficulty in considering numerous items whilst concurrently making substitutions of particular items' importance over others.

The paired comparison method resolves this difficulty of simultaneous assessment of all assessment criteria's importance at once, as it breaks down the decision problem into individual pairs of criteria to assess, therefore only two items need to be taken into consideration each time. This simplification of the decision problem provides clarification of the criteria set and forces the participants to consider each criterion and its meaning within the set, avoiding particular criteria from being overlooked. However, it is this detailed examination of every item that causes the paired comparison method to be undesirably lengthy. It asks a lot of the participants to complete a paired comparison survey due to the time commitment required.

The paired comparison method is simply to take pairs of criteria that permit the comparison of every individual criterion with every other criterion in a set (Hajkowicz, McDonald and Smith, 2000). The comparison is facilitated through a scale assigned to each pair, where the participant can indicate their perceived importance of one criterion against another. Saaty (1990) uses a nine point scale, in which one represents equal importance of the criteria in a pair, and nine represents one criterion being of the most importance in a pair. The scale can vary in its coding, Hamilton et al (2009) use a bipolar scale, still of nine points, but a centre point of equal importance is created as zero and negative one to negative four and plus one to plus four sit at either side of zero, producing a bipolar scale in contrast to the Satty (1990) unipolar scale.
The results of the Delphi methodology, i.e. the set of assessment criteria from questionnaire round three, formed the input to the weighting methodology. The same expert group used in determining the criteria were then employed to weight the criteria in terms of their relative importance using the paired comparison method. The experts agreed on a list of twenty two criteria, and this resulted in 231 pairs for the participants to consider. The number of pairs was calculated using Hobbs (1980):

$$o = \frac{m(m-1)}{2}$$

o = number of comparisons

m = number of criteria to be compared

Figure 4 – Paired Comparison Formula

A survey was created in Microsoft Excel, showing each pair with a nine point scale. The pairs were randomised to maintain participant engagement in the exercise, due to the significant length of the survey.

It was not possible to source a suitable online tool that could present the paired comparison in the required format. Furthermore, the 231 paired comparisons presented a significant amount of information for the participants to analyse in one sitting. Hard copies of the surveys and instructions were therefore issued to each participant via post for completion. The participants were provided with an adequate amount of time to complete and return their responses. However, due to the scale of the survey, two out of the original total thirteen experts failed to return their completed surveys, leaving 11 experts. Such a sample size is deemed appropriate based upon existing literature. Whilst there is no defined panel size specification for the Delphi methodology, Powell (2003) highlights the variance in the recommended Delphi panel size within existing studies, and Akins et al (2005) supports this, identifying Delphi studies that utilise panels of 10 to 100 (and above) experts.

The data that was returned underwent multiple sensitivity analysis methods as well as a reliability analysis, as described in 5.4. Once the weightings were finalised, they were issued to the eleven participants for comment. Of the experts who did respond to the finalised weightings, they noted their interest as well as their relevance to their professional work.

5.3 Energy Demand Interventions Results

5.3.1 Introduction

The results of the Delphi methodology, combined with the weighting methodology, to determine categorised, weighted assessment criteria by which to assess the suitability of an EPIM when applied to a traditionally constructed, office building will be presented here.

5.3.2 EPIM Assessment Criteria Categorised Results

The Delphi methodology, as described in 5.2, consists of iterative survey rounds to determine an agreed outcome from a group of experts in a relevant field, in this study, a set of assessment criteria. The Delphi process required three rounds to reach a level of consensus between the participants. The input and output for each round will be presented, along with the finalised assessment criteria set.

As detailed in 5.2, the participants were provided with a preliminary set of assessment criteria to begin the Delphi process. Table 5 presents these initial criteria.

No	Assessment Criteria
1	Capital cost
2	Financial payback
3	Additional maintenance costs
4	Reduced energy bills
5	Potential energy savings
6	Potential reduction in associated carbon emissions
7	Embodied energy of the EPIM
8	Embodied carbon of the EPIM
9	Ease of installation
10	Level of disruption to building occupants during works
11	Training building occupants in the use of new system(s) post refurbishment
12	Reliability
13	Impact on building's appearance
14	Level of improvement in building occupants' comfort
15	Requirement of planning and/or building control approvals

Table 5 – Delphi Round One Input

Table 5 shows fifteen criteria acting as the basis of the Delphi process. These were derived from the author's knowledge of the subject area, arising from experience working in the construction industry combined with research activities. Following the first survey round, see Appendix E for the participants' responses, twenty three assessment criteria were identified. Table 6 presents the results of the first round.

No	Assessment Criteria
1	Capital cost
2	Financial payback
3	Change to maintenance costs
4	Potential energy savings
5	Potential reduction in associated carbon emissions
6	Embodied energy of EPIM
7	Embodied carbon of EPIM
8	Ease of installation
9	Level of disruption to building occupants during works
10	Training building occupants in the use of new system(s) post refurbishment
11	Reliability
12	Impact on building's appearance
13	Level of improvement in building occupants' comfort
14	Requirement of Planning and/or Building Control Approvals (Incl. Listed Building Consent)
15	Impact on building's vapour permeability/'breathability'
16	Loss of original building fabric
17	Impact on existing building services
18	Impact on building's internal air movement/ventilation
19	Availability of EPIM
20	Ease of maintenance (availability of spares) of EPIM
21	Availability of grants, tax allowances and other financial incentives
22	Whole lifecycle cost of EPIM
23	Degradation of EPIM's performance

Table 6 – Delphi Round One Output

Table 6 shows the fourteen original assessment criteria, including the modification of two of the original criteria. 'Additional maintenance costs' has been altered to 'Change to maintenance costs', as it was explained that the installation of an EPIM would not necessarily increase the maintenance costs, but should still be considered in the decision, therefore 'Change to maintenance costs' was deemed a more appropriate term. 'Requirement of planning and/or building control approvals' now includes consideration of listed building consent, as this was indicated as important as the criteria have been designed to aid energy improvements in traditional buildings, a proportion of which are listed and may therefore present challenges in the installation of particular EPIM's. 'Reduced energy bills' has been removed from the list as it was decided that the 'Financial payback' criterion would encompass the benefit of reduced energy bills. Nine new criteria have been added to the set, numbers fifteen to twenty three in Table 6. The round one output acted as the round two survey input.

No	Assessment Criteria
1	Capital cost
2	Availability of grants, tax allowances and other financial incentives
3	Ease of installation
4	Loss of significant building fabric
5	Requirement of planning and/or building control approvals
6	Level of disruption to building occupants during works
7	Impact on building's appearance
8	Impact on building's internal layout/space
9	Potential energy/carbon savings
10	Financial payback
11	Change to maintenance costs
12	Ease of maintenance of EPIM
13	Reliability of EPIM's performance
14	Degradation of EPIM's performance
15	Training building occupants' in the use of new system(s)
16	Level of improvement in building occupants' comfort
17	Impact on existing building services
18	Impact on building's internal air movement/ventilation
19	Impact on building's vapour permeability/'breathability
20	Whole lifecycle cost of EPIM
21	Embodied energy/carbon of EPIM
22	Environmental impact of EPIM

Table 7 – Delphi Round Two Output

There are notable changes between the round one and two outputs (Table 7). The 'Loss of original building fabric' has been altered to the 'Loss of significant building fabric', this modification was agreed as it prevents the user being overly cautious and potentially rejecting a beneficial EPIM based on the loss of ordinary fabric. 'Potential energy/carbon savings' has combined two criteria that dealt with energy and carbon emission savings in the previous round. Similarly, 'Embodied energy/carbon of EPIM' has combined two criteria that previously addressed embodied energy and embodied carbon separately. 'Training building occupants' in the use of new system(s)' drops the 'post-refurbishment' statement from the previous round, as it was identified that training should be an ongoing process to ensure system operation remains efficient. There are two new assessment criteria in the set, 'Impact on building's internal layout/space' and 'Environmental impact of EPIM'.

The only change that has occurred in round three is the removal of 'Whole lifecycle cost' and the addition of 'Disposal cost of EPIM at end of useful life'. The question was raised of the definition of whole lifecycle costing in this context and it was decided, that due to the other financial criteria and the inclusion of a cost function within the DST, that it was not relevant in the set.

Table 8 shows the finalised set of twenty two assessment criteria. These have been presented in a format as requested by the Delphi participants (Table 9).

No	Assessment Criteria
1	Capital cost
2	Availability of grants, tax allowances and other financial incentives
3	Ease of installation
4	Loss of significant building fabric
5	Requirement of planning and/or building control approvals
6	Level of disruption to building occupants during works
7	Impact on building's appearance
8	Impact on building's internal layout/space
9	Potential energy/carbon savings
10	Financial payback
11	Change to maintenance costs
12	Ease of maintenance of EPIM
13	Reliability of EPIM's performance
14	Degradation of EPIM's performance
15	Training building occupants' in the use of new system(s)
16	Level of improvement in building occupants' comfort
17	Impact on existing building services
18	Impact on building's internal air movement/ventilation
19	Impact on building's vapour permeability/'breathability
20	Disposal cost of EPIM at end of useful life
21	Embodied energy/carbon of EPIM
22	Environmental impact of EPIM

Table 8 – Delphi Round Three Output

Energy Performance Improvement Measure (EPIM) Assessment Criteria (AC)					
AC result realised in the short term (beginning of EPIM's useful life)		**AC result realised in the long term (during – end of EPIM's useful life)**			
EPIM Installation		**EPIM Operation**		**EPIM Disposal**	
1	Capital cost	9	Potential energy/carbon savings	20	Disposal cost of EPIM at end of useful life
2	Availability of grants, tax allowances and other financial incentives	10	Financial payback		
3	Ease of installation of EPIM	11	Change to maintenance costs		
4	Loss of significant, original building fabric	12	Ease of maintenance of EPIM		
5	Requirement of planning and/or building control approvals	13	Reliability of EPIM's performance		
6	Level of disruption to building occupants during works	14	Degradation of EPIM's performance		
7	Impact on building's appearance	15	Training building occupants in the use of new system(s)		
8	Impact on building's internal space/layout	16	Level of improvement in building occupants' comfort		
		17	Impact on existing building services		
		18	Impact on building's internal air movement/ventilation		
		19	Impact on building's vapour permeability/breathability		
21	Embodied energy/carbon of EPIM				
22	Environmental impact of EPIM				

Table 9 – Categorised EPIM Assessment Criteria

EPIM AC	EPIM AC Definition
Capital cost	Initial cost incurred to purchase the EPIM, including all associated transport, labour and materials.
Availability of grants, tax allowances and other financial incentives	The availability of financial incentives for the implementation of particular EPIM's.
Ease of installation of EPIM	Also known as 'buildability'. The level of difficulty associated with the installation of an EPIM, including ease of transport to/movement on site.
Loss of significant original building fabric	Some EPIM's installation will have a low visual impact but may result in loss of significant, original building fabric.
Requirement of planning and/or building control approvals	The likelihood of requiring some form of formal approval for the installation of an EPIM, including Listed Building Consent where applicable.
Level of disruption to building occupants during works	The level of disruption caused by the installation of an EPIM on the building occupants' working environment, and consequently their productivity.
Impact on building's appearance	The impact the installation of an EPIM will have upon a building's appearance, both externally and internally.
Impact on building's internal space/layout	The installation of some EPIM's could impact upon the gross internal floor area or the internal layout of the building.
Potential energy/carbon savings	A quantitative measure of the energy savings and associated carbon emission savings of installing an EPIM.
Financial payback	A measure of the time required to recover the initial cost invested.
Change to maintenance costs	A potential increase or decrease in the building user's maintenance budget due to the installation of an EPIM.
Ease of maintenance of EPIM	The level of difficulty associated with the maintenance of an EPIM and any associated equipment or materials. Including the availability of spare parts over the lifetime of the EPIM.
Reliability of EPIM's performance	The reliability of an EPIM's performance. Risk of failure in meeting predicted energy savings, as well as any other performance criteria.
Degradation of EPIM's performance	The potential year on year reduction in the EPIM's ability to deliver energy savings.
Training building occupants in the use of new system(s) post refurbishment	The level of training and regular re-training required of building occupants to ensure the EPIM is operated at its maximum efficiency.
Level of improvement in building occupants' comfort	The level of improvement in indoor environmental quality due to EPIM installation, consequently improving the building occupants' comfort levels and potentially, worker productivity.
Impact on existing building services	The impact the EPIM's installation will have upon the existing building services (BS), including building fabric improvements, as these will change the internal environment and how it interacts with the BS. Some BS-related EPIM's can have a negative impact on the existing plant and its maintenance, this must be considered.
Impact on building's internal air movement/ventilation	The impact of the EPIM's installation on how the existing building deals with air movement. A negative impact could lead to serious air quality and condensation issues. Also, whether changes to the building's ventilation strategy need to be considered as a result of this EPIM.
Impact on building's vapour permeability/'breathability	A qualitative measure of the impact an EPIM's installation has on the building fabric and how it interacts with moisture. Whether or not that EPIM is compatible with the existing construction form.

EPIM AC	EPIM AC Definition
Disposal cost of EPIM at end of useful life	The financial cost of removing and disposing of the EPIM and any associated parts at the end of their useful life.
Embodied energy/carbon of EPIM	The total energy/carbon inputs required to manufacture an EPIM and its associated materials, from extraction of raw materials to reuse/recycle/disposal. This also covers the issue of EPIM availability, in terms of the energy/carbon cost of sourcing and transport.
Environmental impact of EPIM	The level of pollutants/environmental cost accumulated in the manufacture of an EPIM and its associated materials, from extraction of raw materials to reuse/recycle/disposal.

Table 10 – Assessment Criteria Definitions

Table 10 shows the definition of each criterion, these were written based upon the experts' responses and were issued to the participants for approval.

5.3.3 EPIM Assessment Criteria Weighted Results

A paired comparison methodology was used to determine weightings of relative importance for the twenty two assessment criteria. As detailed in 5.2, the same thirteen participants of the Delphi group were used to assign the weightings. The paired comparison survey consisted of 231 pairs of criteria to compare, and the experts' responses to each pair can be found in Appendix E. The results of the paired comparison surveys were marked to determine a total score for each criterion by each participant. The mean of the total scores across the expert group was calculated and then normalised to create weightings for each criterion to sum 100.

A sensitivity analysis was carried out upon the criteria weightings using three different methods: bipolar negative marking, bipolar sum of differences and unipolar analyses. These three scoring methods involve the allocation of numerical values to the nine point scale used in the paired comparison survey to represent the level of importance the participant assigned to a criterion. The results of each method will be presented and discussed before concluding with the preferred scoring method in which the finalised weightings are determined.

Table 11 and Figure 6 presents the weighting results of the bipolar negative marking analysis. In the bipolar method, the nine point scale is essentially allocated two poles with a central point of equal importance. The scale is assigned, from left to right, four to one, zero and negative one to negative four, as illustrated in Figure 4. The bipolar scale fits naturally with the nine point scale and corresponding written descriptions presented to the participants that allows either of the two criteria within a pair to be deemed much more, less or equal in importance to one another. In the negative marking method, the bipolar numbering of the scale is used as shown in Figure 4, and in the marking of each pair, a positive score is assigned to one criterion and a negative score is assigned to the remaining criterion - that perceived to be of lesser importance. This is with the exception of an indication of equal importance in which both criteria would be scored zero. As a result, the results show not only to what extent one criterion of the pair is more important but also to what extent, the remaining criterion is less important.

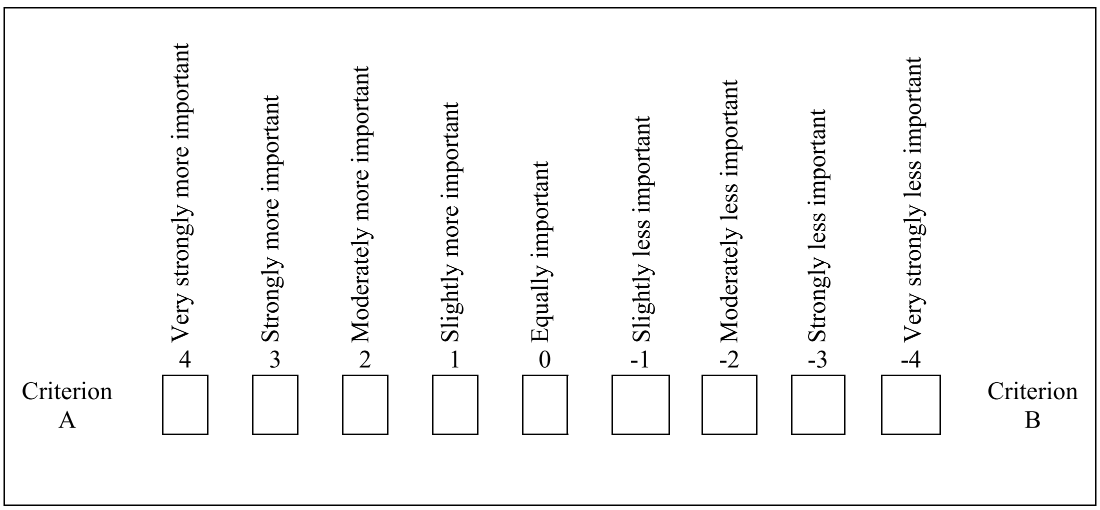

Figure 5 – Bipolar Scoring Scale Example

The weighting results of the bipolar sum of differences marking analysis are shown in Table 12 and Figure 7. This scoring method once more uses the bipolar scale as illustrated in Figure 4. However, the interpretation of the data differs in that the criterion of lesser importance within a pair is assigned a score of zero instead of a negative score as with the bipolar negative marking method. This allows clear identification of the more important criterion in a pair and avoids over inflation of the negative view of the criterion considered to be of lesser importance. The option of equal importance remains, in which case the criteria are each scored zero.

The unipolar method weightings are shown in Table 13 and Figure 8. This analysis uses a one to nine scale, essentially one pole of greater importance in each pair. Hamilton et al (2009) uses this as one of a variety of sensitivity analyses in their paired comparison study, one that uses the same written descriptions attached to a nine point scale with a central point of equal importance as is in this thesis. However, Saaty (1990) has also used a unipolar nine point scale, where the number one is used to represent equal importance between the two criteria in a pair, obviously differing from the former. The unipolar scale is illustrated in Figure 5. The unipolar method may be viewed as a less natural fit with the paired comparison due to the single pole of greater importance in the comparison of two items, although its inclusion permits an interesting assessment of the differences in weightings and subsequent rankings when using one or two poles of importance.

Figure 6 – Unipolar Scoring Scale Example

The two bipolar methods of analysis used both produce an interesting weighting distribution, with an obvious high, mid and low weighting range across the twenty two criteria. However, the ordering of the criteria based upon these weightings differs between the negative marking and sum of differences scorings. Table 14 presents the three sets of weighting results and consequential ordering of criteria. The three highest and lowest weightings in each set have been identified in green and red respectively. This allows quick identification of the top three ranked criteria to be identical for each analysis method, although the weighting values do vary. It is in fact only beyond rank position five that there is any change in the criteria ordering between the three methods of analysis. Although the weighting distribution for the two bipolar analyses is more closely aligned than the unipolar results, the actual ordering of the criteria ranks present greater resemblance between the bipolar negative marking and the unipolar, they are indeed identical. It was expected that there would be some level of change in the rank order with each analysis method due in part to the relatively large number of items within the set being assessed. The variation is considered minimal and the results are therefore considered stable due to the level of consistency presented overall.

The finalised set of assessment criteria weightings presented in Table 15 are determined by the bipolar scale as illustrated in Figure 4. This is due to the dual poles associated with this scale. The sum of differences scoring method has been used to calculate the scores and resultant weightings from this bipolar scale, as this method allows identification of the more important criterion in the pair and to what extent, without over penalisation of the criterion considered less important.

Table 11 – Bipolar Negative Scoring Ranked Assessment Criteria

No	Criteria	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7	Exp 8	Exp 9	Exp 10	Exp 11	Mean	Normalised
C1	Cap cost	80	19	23	-9	39	28	26	-2	31	15	32	**25.64**	**9.03**
C9	Pot energy sav	40	22	73	36	21	23	21	-20	37	2	12	**24.27**	**8.79**
C10	Finan pybk	74	-1	17	14	18	24	30	-9	36	16	18	**21.55**	**8.31**
C19	Imp vap perm	-12	7	38	40	32	1	45	60	-33	10	-3	**16.82**	**7.49**
C18	Imp int air mov	-15	2	-28	16	24	3	1	54	37	5	-2	**8.82**	**6.09**
C13	Reliability	7	10	26	9	-8	18	21	-12	-4	8	-4	**6.45**	**5.67**
C4	Loss fabric	-1	-3	-26	62	-6	-36	39	58	-11	-3	-31	**3.82**	**5.21**
C8	Imp lay/spa	-4	-30	-16	17	8	-53	0	42	42	-8	26	**2.18**	**4.93**
C22	Env imp	12	12	-16	10	2	-5	14	29	-16	-4	-16	**2.00**	**4.90**
C7	Imp appear	13	-25	-39	62	-10	-4	17	27	8	-3	-30	**1.45**	**4.80**
C16	Lev impr comf	-2	-10	-29	-4	18	-31	1	-13	35	12	23	**0.00**	**4.55**
C14	Degradation	-3	7	33	-10	-5	22	-1	-8	-16	-5	-18	**-0.36**	**4.48**
C21	Emb energy	1	14	51	-11	-15	-11	-12	13	-20	-14	-10	**-1.27**	**4.32**
C2	Avail grant	-17	16	4	-21	-1	23	21	-36	-35	-11	-2	**-5.36**	**3.61**
C17	Imp exist serv	-10	-2	-25	-14	11	-2	-21	-48	10	0	-3	**-9.45**	**2.89**
C11	Chg maint cost	-19	-3	9	-24	-25	18	-20	-40	-6	1	3	**-9.64**	**2.86**
C12	Ease maint	-6	-7	-24	-7	-21	19	-17	-47	-14	4	-7	**-11.55**	**2.53**
C3	Ease instal	-15	-14	-26	-36	-14	21	-23	-5	3	-6	-14	**-11.73**	**2.50**
C6	Lev disrupt occup	-30	-22	-29	-15	5	-29	-41	-8	13	-7	20	**-13.00**	**2.27**
C20	Disp cost	-33	-5	-31	-32	-10	18	-19	7	-22	-9	-24	**-14.55**	**2.00**
C5	Req plan app	-28	6	-28	-35	-14	6	-27	-8	-45	1	1	**-15.55**	**1.83**
C15	Train occup	-32	7	43	-48	-49	-53	-55	-34	-30	-4	29	**-20.55**	**0.95**
												Total	**572.00**	**100.00**

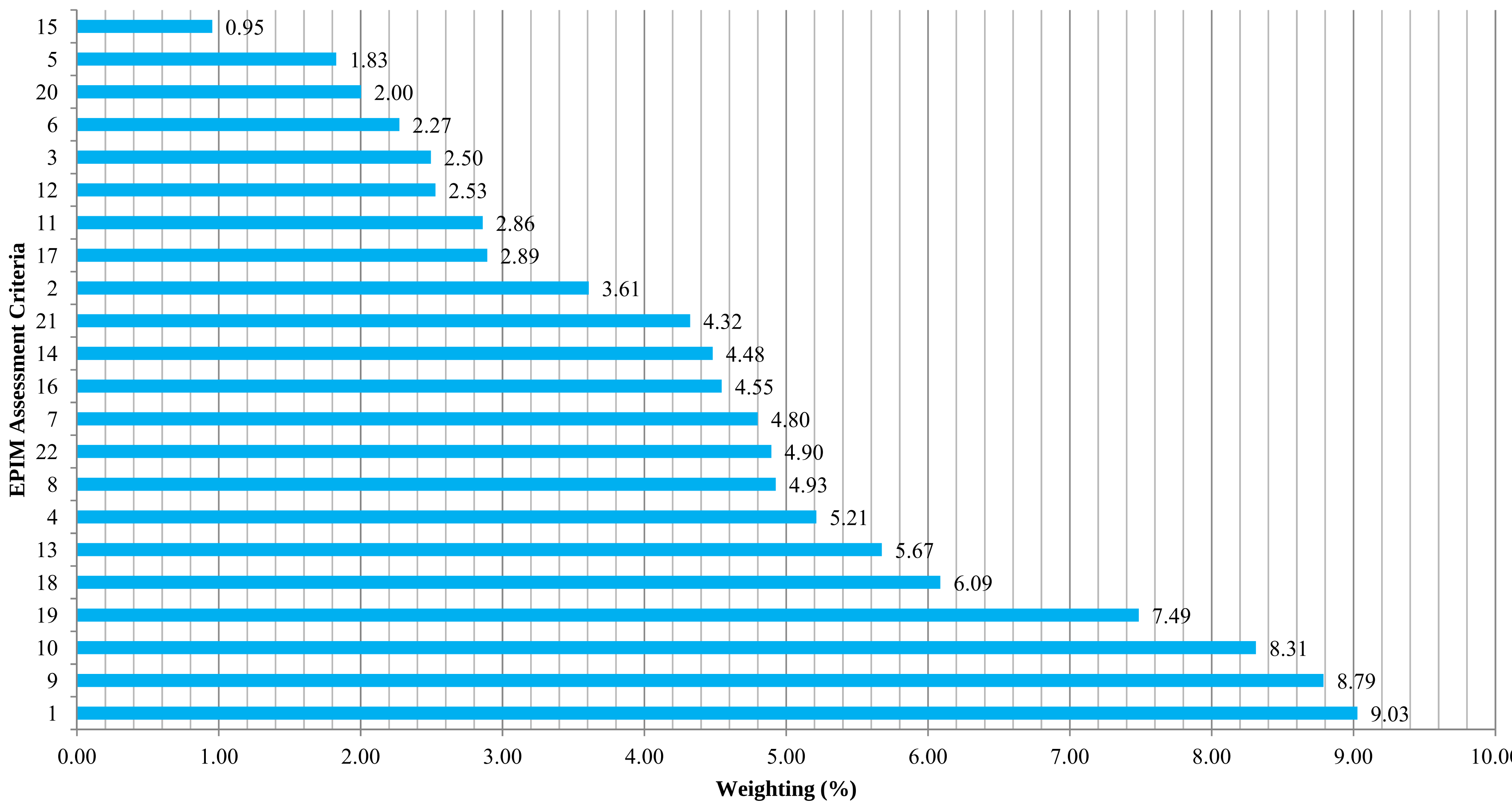

Figure 7 – Bipolar Negative Scoring Ranked Assessment Criteria

Table 12 – Bipolar Sum of Differences Ranked Assessment Criteria

No	Criteria	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7	Exp 8	Exp 9	Exp 10	Exp 11	Mean	Normalised
C1	Cap cost	80	19	38	13	39	28	31	22	33	18	32	**32.09**	**9.30**
C9	Pot energy sav	47	23	73	41	21	23	28	11	39	9	18	**30.27**	**8.77**
C10	Finan pybk	76	7	34	27	18	24	32	15	39	18	22	**28.36**	**8.22**
C19	Imp vap perm	5	8	40	46	32	13	45	60	0	13	11	**24.82**	**7.19**
C18	Imp int air mov	5	8	2	25	24	13	15	56	39	11	9	**18.82**	**5.45**
C4	Loss fabric	9	8	1	62	3	6	39	58	9	7	1	**18.45**	**5.35**
C8	Imp lay/spa	8	5	12	25	10	1	12	47	43	5	30	**18.00**	**5.22**
C7	Imp appear	20	1	1	62	1	13	23	36	20	8	2	**17.00**	**4.93**
C13	Reliability	20	12	35	23	4	18	27	10	14	11	10	**16.73**	**4.85**
C16	Lev impr comf	12	7	0	16	19	4	16	14	37	15	30	**15.45**	**4.48**
C22	Env imp	24	14	7	22	8	10	23	37	7	7	4	**14.82**	**4.30**
C21	Emb energy	18	14	53	13	2	9	9	27	7	2	6	**14.55**	**4.22**
C14	Degradation	12	9	38	11	6	22	13	16	9	6	1	**13.00**	**3.77**
C2	Avail grant	3	18	22	12	6	23	28	6	3	6	11	**12.55**	**3.64**
C11	Chg maint cost	5	5	25	6	1	18	8	5	15	8	13	**9.91**	**2.87**
C6	Lev disrupt occup	1	2	4	10	10	6	2	19	22	7	24	**9.73**	**2.82**
C15	Train occup	0	11	46	0	0	1	0	7	3	8	31	**9.73**	**2.82**
C5	Req plan app	0	12	3	5	4	19	4	28	0	9	13	**8.82**	**2.56**
C17	Imp exist serv	7	5	2	7	13	14	6	2	20	6	12	**8.55**	**2.48**
C3	Ease instal	4	3	1	5	3	21	7	24	15	6	3	**8.36**	**2.42**
C12	Ease maint	8	5	3	13	2	19	6	1	10	10	9	**7.82**	**2.27**
C20	Disp cost	0	6	1	3	3	18	6	27	7	6	2	**7.18**	**2.08**
												Total	**345**	**100**

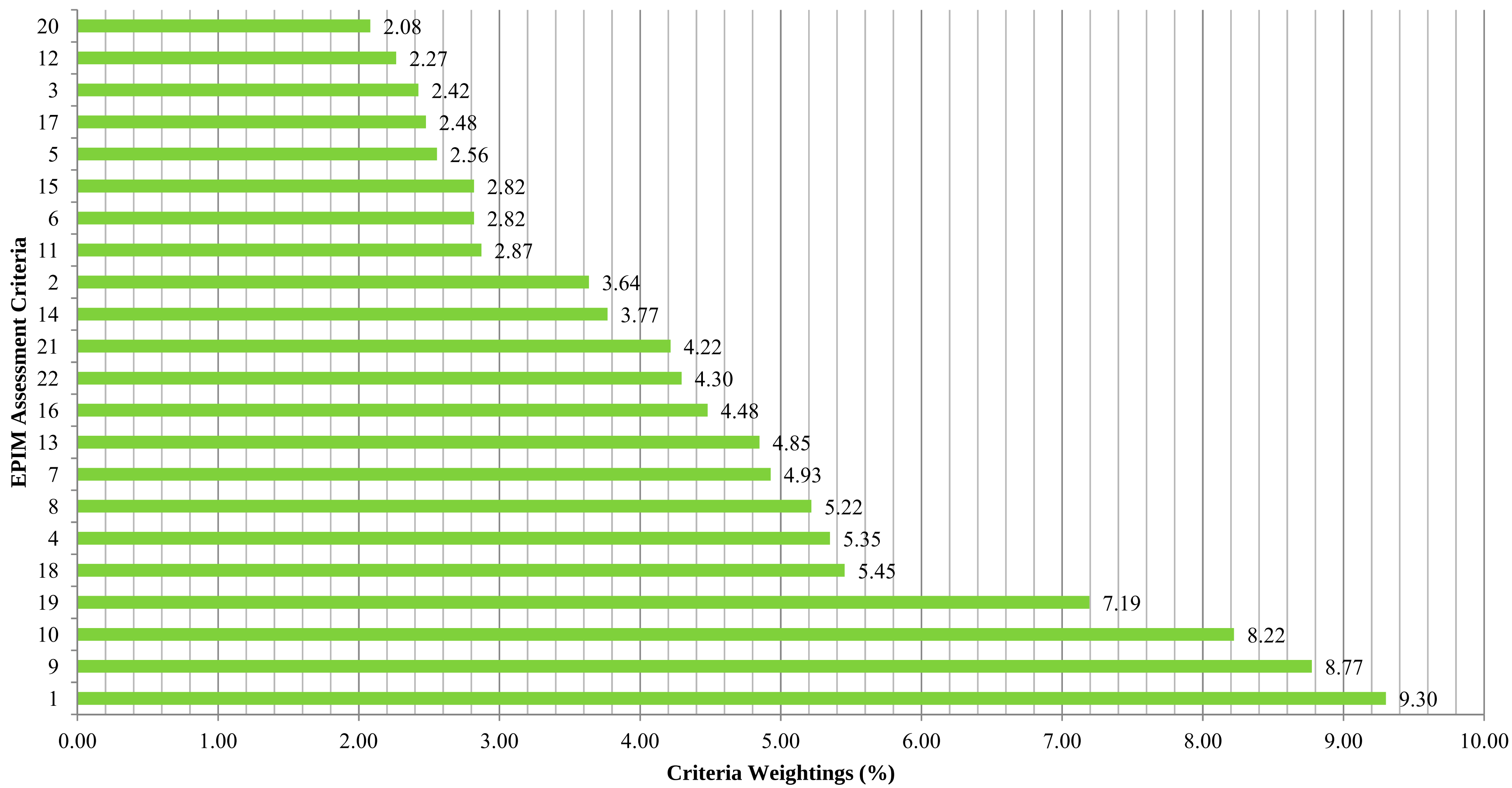

Figure 8 – Bipolar Sum of Differences Ranked Assessment Criteria

Table 13 – Unipolar Ranked Assessment Criteria

No	Criteria	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7	Exp 8	Exp 9	Exp 10	Exp 11	Mean	Normalised
C1	Cap cost	185	124	128	96	144	133	131	103	136	120	137	130.64	5.66
C9	Pot energy sav	145	127	178	141	126	128	126	85	142	107	117	129.27	5.60
C10	Finan pybk	179	104	122	119	123	129	135	96	141	121	123	126.55	5.48
C19	Imp vap perm	93	112	143	145	137	106	150	165	72	115	102	121.82	5.27
C18	Imp int air mov	90	107	77	121	129	108	106	159	142	110	103	113.82	4.93
C13	Reliability	112	115	131	114	97	123	126	93	101	113	101	111.45	4.82
C4	Loss fabric	104	102	79	167	99	69	144	163	94	102	74	108.82	4.71
C8	Imp lay/spa	101	75	89	122	113	52	105	147	147	97	131	107.18	4.64
C22	Env imp	117	117	89	115	107	100	119	134	89	101	89	107.00	4.63
C7	Imp appear	118	80	66	167	95	101	122	132	113	102	75	106.45	4.61
C16	Lev impr comf	103	95	76	101	123	74	106	92	140	117	128	105.00	4.55
C14	Degradation	102	112	138	95	100	127	104	97	89	100	87	104.64	4.53
C21	Emb energy	106	119	156	94	90	94	93	118	85	91	95	103.73	4.49
C2	Avail grant	88	121	109	84	104	128	126	69	70	94	103	99.64	4.31
C17	Imp exist serv	95	103	80	91	116	103	84	57	115	105	102	95.55	4.14
C11	Chg maint cost	86	102	114	81	80	123	85	65	99	106	108	95.36	4.13
C12	Ease maint	99	98	81	98	84	124	88	58	91	109	98	93.45	4.05
C3	Ease instal	90	91	79	69	91	126	82	100	108	99	91	93.27	4.04
C6	Lev disrupt occup	75	83	76	90	110	76	64	97	118	98	125	92.00	3.98
C20	Disp cost	72	100	74	73	95	123	86	113	83	96	81	90.55	3.92
C5	Req plan app	77	111	77	70	91	111	78	97	60	106	106	89.45	3.87
C15	Train occup	73	112	148	57	56	52	50	71	75	101	134	84.45	3.66
												Total	**2328.82**	**100.00**

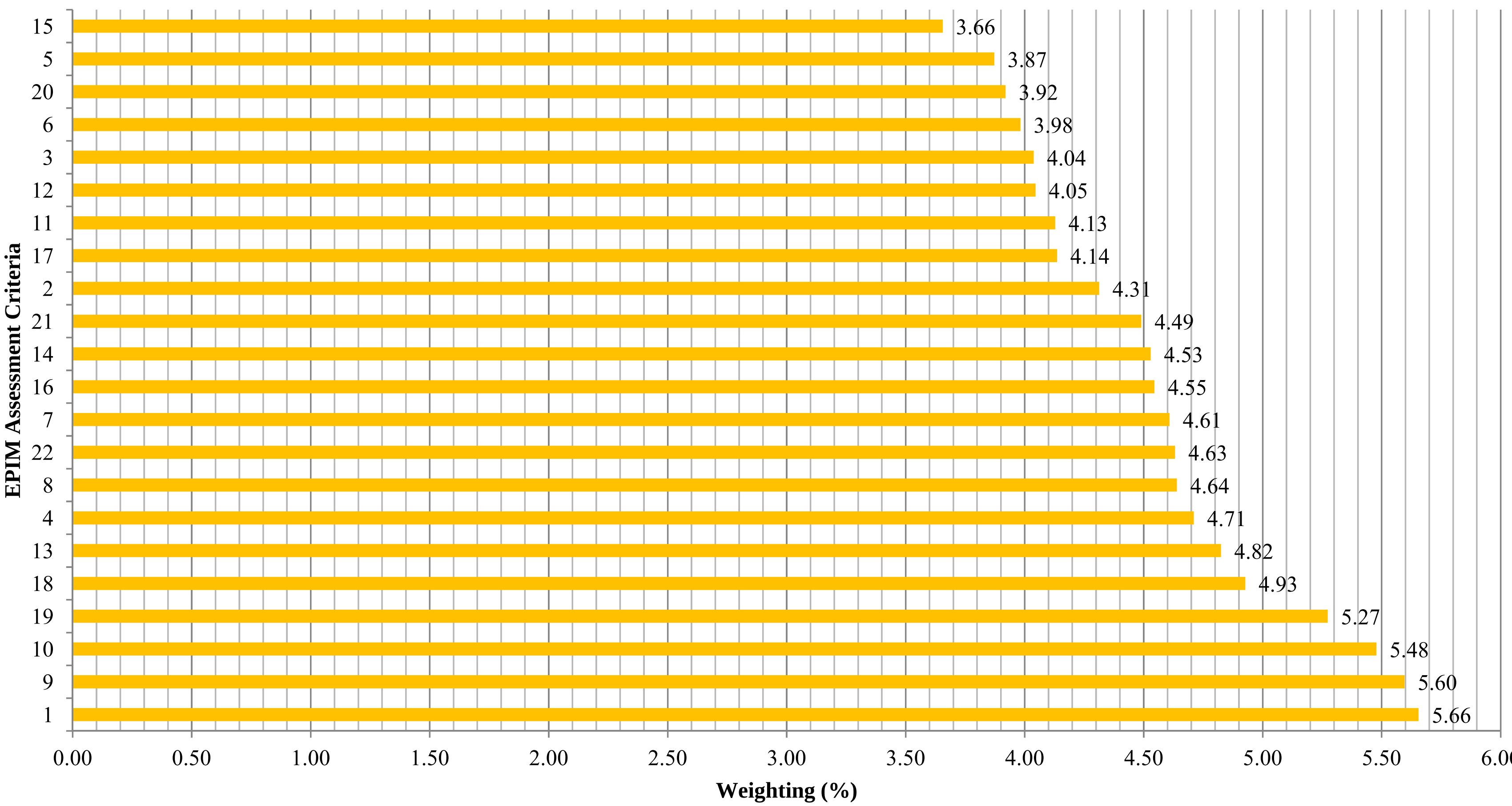

Figure 9 – Unipolar Ranked Assessment Criteria

No	Assessment Criteria	Bipolar Negative	Bipolar Sum of Differences	Unipolar
1	Cap cost	**9.03**	**9.30**	**5.66**
2	Avail grant	3.61	3.64	4.31
3	Ease instal	2.50	**2.42**	4.04
4	Loss fabric	5.21	5.35	4.71
5	Req plan app	**1.83**	2.56	**3.87**
6	Lev disrupt occup	2.27	2.82	3.98
7	Imp appear	4.80	4.93	4.61
8	Imp lay/spa	4.93	5.22	4.64
9	Pot energy sav	**8.79**	**8.77**	**5.60**
10	Finan pybk	**8.31**	**8.22**	**5.48**
11	Chg maint cost	2.86	2.87	4.13
12	Ease maint	2.53	**2.27**	4.05
13	Reliability	5.67	4.85	4.82
14	Degradation	4.48	3.77	4.53
15	Train occup	**0.95**	2.82	**3.66**
16	Lev impr comf	4.55	4.48	4.55
17	Imp exist serv	2.89	2.48	4.14
18	Imp int air mov	6.09	5.45	4.93
19	Imp vap perm	7.49	7.19	5.27
20	Disp cost	**2.00**	**2.08**	**3.92**
21	Emb energy	4.32	4.22	4.49
22	Env imp	4.90	4.30	4.63

Table 14 – Comparison of Scoring Method Results

Rank	Assessment Criteria		Weighting (%)
1	C1	Capital cost	9.30
2	C9	Potential energy/carbon savings	8.77
3	C10	Financial payback	8.22
4	C19	Impact on building's vapour permeability/'breathability'	7.19
5	C18	Impact on building's internal air movement/ventilation	5.45
6	C4	Loss of significant building fabric	5.35
7	C8	Impact on building's space/internal layout	5.22
8	C7	Impact on building's appearance	4.93
9	C13	Reliability of EPIM's performance	4.85
10	C16	Level of improvement in building occupants' comfort	4.48
11	C22	Environmental impact of EPIM	4.30
12	C21	Embodied energy/carbon of EPIM	4.22
13	C14	Degradation of EPIM performance	3.77
14	C2	Availability of grants, tax allowances and other financial incentives	3.64
15	C11	Change to maintenance costs	2.87
16	C6	Level of disruption to building occupants during works	2.82
17	C15	Training building occupants in the use of new system(s)	2.82
18	C5	Requirement of planning and/or building control approvals	2.56
19	C17	Impact on existing building services	2.48
20	C3	Ease of installation of EPIM	2.42
21	C12	Ease of maintenance of EPIM	2.27
22	C20	Disposal cost of EPIM at end of useful life	2.08
		Total:	**100**

Table 15 - Finalised Expert Assessment Criteria Weightings

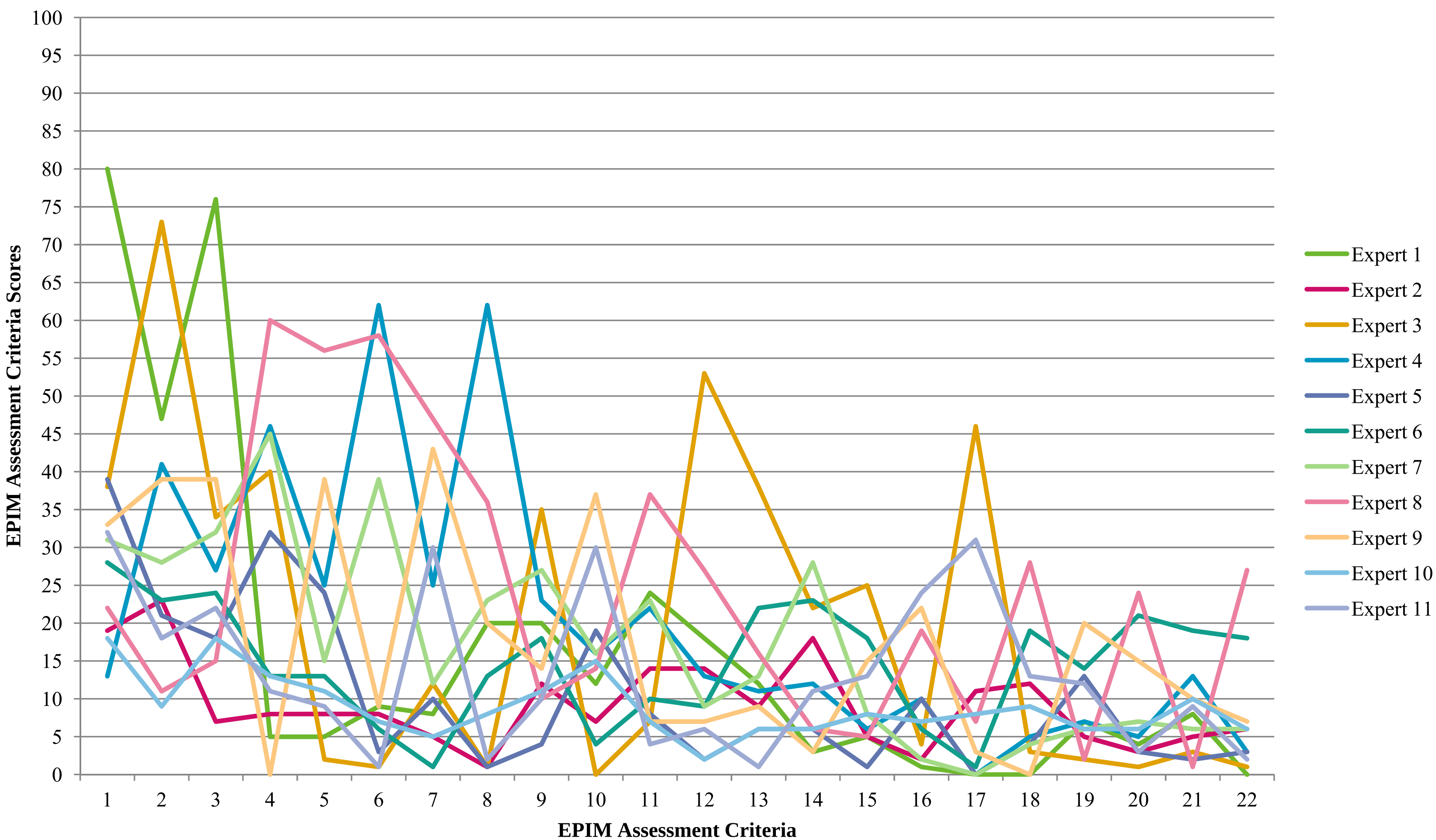

Figure 10 - Finalised Expert Assessment Criteria Scores

No	Position	Organisation	Category				
			Client	Guidance	Heritage	Industry	Non-heritage
1	Environment Officer	City Council		x			x
2	Energy Manager	Government Executive Agency	x	x	x		
3	Senior Building Surveyor	Engineering Consultancy				x	x
4	Senior Project Manager	Conservation Charity			x	x	
5	Project Manager	Project Management Consultancy				x	x
6	Sustainability Consultant	Project Management Consultancy				x	x
7	Associate Director	Engineering Consultancy			x	x	
8	Senior Technical Officer	Government Executive Agency		x	x		
9	Energy and Sustainability Manager	Financial Services Firm	x				x
10	Sustainable Development Manager	Government Body	x				x
11	Principal Sustainability Consultant	Architecture Consultancy		x		x	x
12	Property and Services Coordinator	Government Body	x				x
13	Architect	Architecture Consultancy				x	x

Table 16 – Knowledge Resource Categorisation

Category	Explanation
Client	Experts who work within an organisation with a significant building portfolio, who are involved in the management and works to that portfolio.
Guidance	Experts who work within an organisation who set standards or guidelines for construction standards or experts who are involved in and promote research into energy in buildings.
Heritage	Experts working within an organisation who work to safeguard the historic built environment.
Industry	Experts who work within the construction industry.
Non-heritage	Experts who have a technical background with an understanding of the historic built environment but are involved in a broader range of building types.

Table 17 – Knowledge Resource Category Explanation

Criteria	Client Weightings (%)	Guidance Weightings (%)	Heritage Weightings (%)	Industry Weightings (%)	Non-heritage Weightings (%)
C1	8.87	11.02	5.46	8.56	11.97
C2	3.42	2.74	4.11	4.82	3.31
C3	3.04	2.45	2.50	1.89	2.37
C4	3.04	5.48	10.73	5.30	1.61
C5	2.66	3.82	3.15	2.27	2.14
C6	3.93	3.31	2.12	2.65	3.31
C7	3.68	4.25	7.84	4.82	2.90
C8	6.72	6.48	5.72	4.26	4.87
C9	9.00	7.13	6.62	9.65	10.28
C10	8.11	8.65	5.20	7.43	10.32
C11	3.55	2.02	1.54	3.36	3.80
C12	3.17	1.66	1.61	2.46	2.73
C13	4.69	3.75	4.62	5.53	5.00
C14	3.04	2.74	3.15	4.30	4.20
C15	2.79	3.53	1.16	3.69	3.98
C16	7.48	4.54	3.40	4.02	5.23
C17	3.93	1.87	1.28	2.55	3.31
C18	7.35	5.62	6.68	4.16	4.60
C19	2.66	6.05	10.21	8.85	5.09
C20	2.41	2.52	2.70	1.56	1.65
C21	2.92	4.68	4.05	4.35	4.33
C22	3.55	5.69	6.17	3.50	2.99

Table 18 - Summary of Categorised Experts' Assessment Criteria Weightings

Table 18 shows the normalised mean of each criterion for each expert category. Table 16 and 17 presents the experts and how they have been categorised. Some of the experts can be included in one or more categories due to their professional activities. The total group of thirteen experts participated in the Delphi process to determine the assessment criteria. Only participants 1 – 11, as listed in Table 16 completed the paired comparison survey to determine the assessment criteria weightings, possible reasons for participants dropping out are discussed in 5.2. Appendix E presents the detailed scoring responses for the five categories of experts, which have been summarised and presented in Table 18. Figure 10 presents the categorised experts' weightings in a radar diagram; this allows ease of visual identification of differences in opinion between the categories. These are discussed in 5.4.

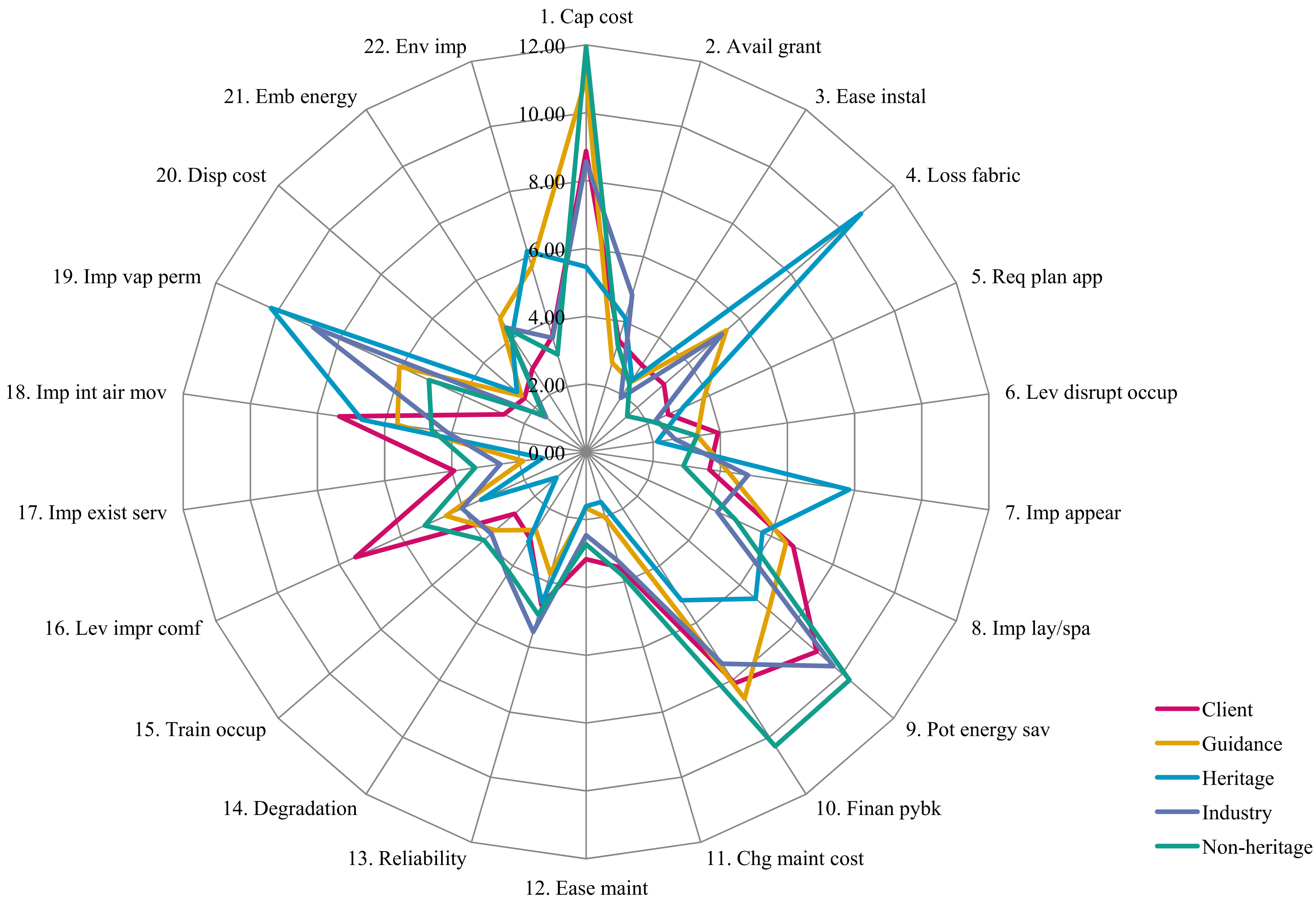

Figure 11 - Categorised Experts' Assessment Criteria Weightings

5.4 Discussion of Energy Demand Interventions

5.4.1 Introduction

The results in 5.3 show twenty-two defined, categorised and weighted assessment criteria to be used in determining the suitability of an EPIM when applied to an existing, office building of traditional construction. The study results and their analysis will be discussed here.

5.4.2 Structured Decision Making

In the final Delphi round, at the request of a number of the experts, the assessment criteria were categorised into an organised format to support decision making. This is shown in Table 9. The criteria have been defined by the lifecycle of the EPIM. The EPIM is to be applied within a traditionally constructed property, in which it is difficult to define an end of useful life compared to those of modern construction. As a result, the lifecycle of the EPIM, not the building it will be applied to, is the focus of the criteria set.

This defined format aids the decision maker to undertake an informed decision, as it provides a structured, methodical approach to intervention selection and (once weighted) prioritisation. It is an approach that takes into consideration both the short and long term impacts of the intervention, upon the building in question. It encourages the decision maker to assess not only financial, but also technical, practical and social acceptability factors within the intervention selection process.

5.4.3 Assessment Criteria Weightings Distribution

As presented in this chapter, the assessment criteria were determined and subsequently weighted. The graph shown in Figure 7 presents the assessment criteria weightings of relative importance, in which groupings of high, medium and low importance can be quickly identified.

The graph allows identification of four criteria that have been assigned the highest importance relative to the criteria group. In descending order, these are: Criterion 1 ‘Capital cost’, Criterion 9 ‘Potential energy/carbon savings’, Criterion 10 ‘Financial payback’ and Criterion 19 ‘Impact on building’s vapour permeability/breathability’. It was expected that Criteria 1, 9 and 10 would be the most heavily weighted of the criteria set, as these three criteria represent the basic input and output of an energy performance improvement decision. The fundamental input being the financial amount required to fund the decision (Criterion 1 'Capital cost') and the output being both the financial and energy/carbon return on investment in taking the decision to intervene (Criterion 9 'Potential energy/carbon savings' and Criterion 10 'Financial payback'). Furthermore, Criterion 9 'Potential energy/carbon savings' and its high ranking was anticipated as the criteria set are applicable to the non-domestic sector. In the domestic sector, the focus of energy performance improvement is upon cost; capital and payback. Conversely, within the non-domestic sector, there is a greater level of accountability of both public and private sector organisations to wider society; therefore the reporting of energy/carbon performance of their building portfolios, increasingly a necessity of regulation, becomes essential.

The ranking of these three criteria shows the views of the participants to be pragmatic, as they are aware that a typical user of the DST, in which the assessment criteria will be utilised, will be concerned with the financial impact of their decision upon their organisation, particularly if they are to construct a business case to support the decision. However, the inclusion of a further nineteen assessment criteria shows that the participants do not believe the decision should be limited to these three fundamental criteria and therefore promote informed, considered decision making within energy-led refurbishment.

The fourth criterion, Criterion 19 'Impact on building's vapour permeability/breathability', is also ranked highly. This may be viewed as unexpected and the comparative weighting to the set is interesting as it is a highly technical EPIM attribute to assess. One reason for its ranking could be the traditional form of construction that this criteria set have been designed to specifically address. Traditional buildings are known to be more complex in the way in which the building fabric manages moisture, when compared to modern, impermeable construction forms. Therefore, any EPIM's that directly impact the building fabric and how it interacts with the environment could have a detrimental effect upon the original building as well as the EPIM's performance if the EPIM is not compatible or not appropriately applied to the traditional construction form, consequently rendering the EPIM decision futile. One Delphi expert stated "...traditional buildings enable moisture to move through their fabric, get that wrong and you get an impervious building that gets damp and rotten quickly" (Participant 4, 2011). Criterion 19 essentially represents the

EPIM's suitability for the construction form undergoing improvement. It would be interesting to see how highly this criterion would have been weighted if the assessment criteria were designed to address an existing building of modern construction, one that was not classed as hard to treat.

Figure 7 shows four criteria that have been assigned the lowest weightings; these can be quickly identified from the graph. Although these criteria have the lowest weightings, they are relevant to the decision making process as they have been included in the criteria set, as they would have otherwise been excluded during the Delphi process. Instead of evaluating the twenty two criteria collectively, the paired comparison process allows the participant to evaluate each criterion against every other criterion, one pair at a time. This reduces the amount of information the participant has to evaluate at once, causing them to think about the meaning of every individual criterion and how it compares in importance, in their opinion, to the other criterion in the pair. The participants' responses to the paired comparison survey can be found in Appendix E and these show other criteria to have taken favour over the four lowest weighted criteria in the majority of pairs, consequently producing lower total scores and lower weightings for these criteria. Figure 9 shows the four lowest criteria to have been scored consistently low across the majority of experts, all below thirty out of a potential eighty that each criterion could achieve.

There are many reasons for the low weighting of these four criteria. One explanation for the low weighting of Criterion 3 'Ease of installation of EPIM' and Criterion 12 'Ease of maintenance of EPIM', could be attributed to the fact that it is often external contractors who would carry out these works and the risk associated with installation and maintenance ease is passed onto them. Criterion 19 'Impact on building's vapour permeability/breathability' and Criterion 4 'Loss of significant building fabric' clearly relate to the building fabric and the consequential impact of an EPIM upon it. As discussed, these two criteria are weighted relatively highly, sitting within the top six rankings. Criterion 17 'Impact on existing building services' is weighted relatively low, and is ranked at position nineteen. The stark contrast between the importance placed on the fabric and services impact is quite apparent. One reason for this could be due to the traditional form of construction the criteria address, and the complex behaviour of the fabric in comparison to modern methods.

The criteria that define the required input and consequential output of the EPIM decision are weighted heavily. If an EPIM meets these criteria satisfactorily then it is likely that the user will ensure that the EPIM and its application in the building is considerate of the conditions that Criterion 5 'Requirement of planning and/or building control approvals' will address. It is therefore not considered as influential in the decision making process, rather a standard that has to be considered, and an EPIM will be adapted as far as possible to meet this standard.

5.4.4 Application in Traditional Construction

The EPIM assessment criteria are to be used within a Decision Support Tool (DST), as described in Chapter 4. The criteria will alter the generic DST template into a process that could be applied to existing office buildings of traditional construction, as defined in section 5.1. There are essentially four assessment criteria that have been included to aid EPIM selection for this specific building type; the first, and most highly weighted being Criterion 19 'Impact on building's vapour permeability/breathability' and this has already been discussed in 5.4.2.

Criterion 4 'Loss of significant building fabric' is ranked two positions below Criterion 19, although a fairly significant difference in weighting (comparative to the spread of the remaining criteria) of 1.84% is presented. The experts decided that Criterion 4 should be included in the set in addition to Criterion 7 'Impact on building's appearance'. One Delphi participant stated "Some improvement measures may have a low visual impact but require substantial removal of a building's original fabric, where this is significant, it should be factored into the decision making." (Participant 2, 2011). Criterion 7 'Impact on building's appearance' is ranked at position eight out of the twenty-two, therefore two positions below Criterion 4. This demonstrates how the experts view the physical impact to be more important than the purely visual impact upon the building fabric.

The third criterion to address traditional construction, Criterion 18 'Impact on internal air movement/ventilation' has been assigned a similar weighting as Criterion 4, but ranks slightly higher at position five. Criterion 18 deals with the impact of ventilation upon the internal environment, therefore addressing comfort as well as impact on the building fabric. The issue of ventilation within a traditional building is incredibly important in preventing deterioration of the existing fabric. This is a difficult issue to address when selecting EPIM's as heat loss tends to be one of the key causes of energy inefficiency associated with this construction form. The prevention of air infiltration through various draught-proofing measures can be a simple and often inexpensive EPIM. However, a reduction in air movement can alter the way in which the fabric expels moisture, consequently, potentially damaging the structure. The questions surrounding this issue arose in the Delphi process, "If adding the energy improvement to the building affects how it previously accommodated air movement then the impact needs to be assessed. Will less air movement lead to increasing condensation internally, within voids and interstitially? If this is the case, is there a need to add passive or mechanical ventilation to control ventilation? Would this then outweigh the benefit of the energy improvement or not?" (Participant 6, 2011). These questions need to be asked when considering an EPIM for this building type, although the answers may not be definitive, if the EPIM is designed with these issues in mind then the risk can be minimised.

The relatively high ranking of the four criteria relating to traditional construction items demonstrates the appreciation the majority of the expert group have for this construction form. It also displays their understanding that the decision to install an EPIM successfully must not only be informed from a financial standpoint but also a practical perspective.

5.4.5 Criteria to Assess Occupants' Impact

The consideration of building occupants when undertaking works to a property is twofold: first, their comfort within the building and second, their understanding of how the building environment is controlled to maintain accepted comfort standards whilst simultaneously sustaining operational efficiency. The results of the weighting show two criteria addressing occupancy comfort; consequently, the decision maker will consider these during the selection process. This will aid the decision maker to communicate the benefits of the works to the users. An understanding of these benefits would support and encourage participation in training of new systems post refurbishment; this is the third occupancy related criterion of the set.

Criterion 16 'Level of Improvement in Building Occupants' Comfort' sits just within the top ten criteria rankings. It was expected that this criterion would be ranked quite highly, especially when addressing the traditional construction form which is often portrayed as an uncomfortable, draughty environment due to high air infiltration levels. It is therefore necessary that their comfort be considered, when selecting a specific EPIM, as well as a success factor for the overall project. Criterion 6 'Level of Disruption to Building Occupants during the Works' is the second criterion that refers to occupancy comfort. This relates to the short term discomfort or inconvenience caused by the EPIM works. It is within the lower quartile of weightings, ranked at position sixteen, followed by Criterion 15 'Training Building Occupants in the Use of New System(s)', with the same weighting as the former, ranked at position seventeen. Table 11 shows the summary of the expert scores, and it can be seen here that the majority of experts have scored Criterion 6 and 15 similarly, with only two to three participants disagreeing with notably higher scores of importance. The rather low ranking of these two criteria could be seen as unexpected, particularly Criterion 15, as there is notable interest in the impact of building occupants have upon the operational efficiency of a building. Mechanisms to address negative behaviours are common place in many major organisations, with internal campaigns to raise staff awareness surrounding energy and wider sustainability issues and training for those occupants who interact within building controls and systems. It may be unusual to therefore see Criterion 15 ranked at position seventeen out of twenty-two. However, this observation is dependent upon interpretation of the results. The participants were asked to identify the criteria that should be considered when determining the suitability of an EPIM. As a result, the experts indicated training must be taken into consideration during the decision making process, as the criterion was included in the finalised set. Although, whether an EPIM requires some form of training or not, is not so important that it is going to cause an EPIM to be taken out of consideration within an energy-led refurbishment scheme. It signifies that the experts view training as inherent to the installation of the EPIM as the lower weighting means it doesn't have such an impact upon whether the EPIM is selected, training is an accepted occurrence for specific EPIM's that require it. An alternative view of occupant training is that it may be unnecessary for the majority of building users as they have limited access to building controls, for example, some office buildings do not have localised controls, instead lighting, heating, cooling and ventilation, even window openings are controlled centrally by an internal or external facilities management team via a building management system or similar. However, this may not be relevant for some offices of traditional construction as they often have a number of local user controls for such functions.

Criterion 6 'Level of Disruption to Building Occupants during Works' and its relatively low weighting should not be misinterpreted, as occupants' discomfort being disregarded by the experts, but instead that it should be considered, although its low weighting is unlikely to cause an EPIM to be rejected. The reason for this could be that many large organisations operating within a varied, existing building portfolio will often have an internal property management team who manage annual repair and maintenance works within the portfolio, and procedures will be in place to allow works to be carried out to an occupied building that limits disruption to the users. This is typically out of hours working with a communication procedure in place to keep the office manager informed of any temporary changes required during working hours. One reason it must still be considered is to make the decision maker aware of an EPIM that may require out of hours works which are charged at a premium rate by contractors.

5.4.6 Reliability Analysis

A reliability analysis of the eleven experts' responses to the paired comparison survey was carried out using SPSS Statistics V17.0 to determine the level of agreement between the participants' views. The experts were categorised based upon their professional activities, so a difference in opinion between some of the experts due to their varied disciplines was therefore expected to some extent. However, their mutual interest in the energy performance of buildings meant the responses would be expected to be largely consistent. The Intraclass Correlation Coefficient was calculated for a two way random model. The output of the reliability analysis can be seen in Appendix F. The reliability statistics in Table F.1 (within Appendix F) show a Cronbach's Alpha of 0.662. A Cronbach's Alpha of ≥ 0.7 is desirable, although >0.6 is viewed to indicate an acceptable level of internal consistency in some literature (Antony et al, 2007). Table F.2 (within Appendix F) shows the item total statistics, where the identification of participants with controversial views can be eliminated to test the impact on internal consistency. Appendix F also shows the results of the reliability analysis if experts eight and eleven were to be eliminated. This increases the Cronbach's Alpha to 0.705, and gives an improved internal consistency within the results.

Further investigation into the scores of experts eight and eleven permits identification of controversial scoring, of extreme high or low scores assigned to particular criteria in comparison to the more conservative allocations of other experts and vice-versa. Figure 12 shows a line graph displaying data sets for the two experts' scores. This allows quick recognition of extreme opposing views regarding the importance of particular criteria. The associated data table, Table 19, shows the scores and the deviation in scoring values between experts eight and eleven. A deviation in scores of thirty or more is indicated by red shading, therefore identifying Criterion 4 'Loss of significant building fabric', Criterion 7 'Impact on building's appearance', Criterion 18 'Impact on building's internal air movement/ventilation', Criterion 19 'Impact on building's vapour permeability/breathability' and Criterion 22 'Environmental impact of EPIM' as the issues where the greatest difference in opinion is evident, with expert eight scoring the five criteria significantly higher than expert eleven. This combined with expert eleven's significantly low scoring of these five criteria creates the notable deviation. As shown in Table 16, expert eight is a senior technical officer within the heritage sector of the construction industry, and their views are therefore reflective of their intimate knowledge of traditional buildings. Four of the five criteria could be considered as more relevant to a traditional building than one of modern construction. Expert eight's professional experience may therefore indicate the cause of their heavy scoring of these criteria, whereas expert 11 has less experience of traditional buildings.

There are criteria where expert eleven has assigned considerably higher scores than expert eight, although not to the same extent as the above five criteria, and these are all indicated by amber shading meaning a deviation in scoring of ten to thirty. It is with Criterion 15 'Training building occupants in the use of new system(s)' and Criterion 16 'Level of improvement in building occupants' comfort' that expert eleven has scored notably higher than expert eight. Table 16 indicates expert eleven as an industry professional out with the heritage sector who is involved in research. Expert eleven's research interests lie within building occupancy and how their interaction with the building impacts energy performance. This may indicate the reasoning behind their relatively high scores for these two occupancy related criteria.

Experts eight and eleven display little disagreement regarding the importance of the remaining criteria: Criterion 2 'Availability of grants, tax allowances and other financial incentives', Criterion 6 'Level of disruption to building occupants during works', Criterion 9 'Potential energy/carbon savings', Criterion 10 'Financial payback', Criterion 11

‘Change to maintenance costs’, Criterion 12 ‘ Ease of maintenance of EPIM’, Criterion 13 ‘Reliability of EPIM’s performance’ and Criterion 20 ‘Disposal cost of EPIM at end of useful life’.

The exclusion of both of these experts improves the internal consistency of the survey results, yet they do not pose similar views upon the criteria set. It could be suggested, following examination of their scores, that they are polar extremes of the group, one favouring heritage related criteria and the one that does not.

Criteria	Expert 8	Expert 11	Mean	Standard Deviation	Difference
1	22	32	18.3	12.9	**10.0**
2	6	11	6.3	3.7	**5.0**
3	24	3	10.0	9.9	**21.0**
4	59	1	21.3	26.7	**58.0**
5	28	13	15.3	9.5	**15.0**
6	19	24	16.3	7.6	**5.0**
7	36	2	15.0	15.0	**34.0**
8	47	30	28.3	16.0	**17.0**
9	11	18	12.7	3.9	**7.0**
10	15	22	15.7	4.9	**7.0**
11	5	13	9.7	3.4	**8.0**
12	1	9	7.3	4.6	**8.0**
13	10	10	11.0	1.4	**0.0**
14	16	1	10.3	6.6	**15.0**
15	7	31	17.7	10.0	**24.0**
16	14	30	20.0	7.1	**16.0**
17	2	12	10.3	6.2	**10.0**
18	56	9	27.7	20.4	**47.0**
19	60	11	30.0	21.5	**49.0**
20	24	20	21.3	1.9	**4.0**
21	27	6	18.0	8.8	**21.0**
22	37	4	21.0	13.5	**33.0**

Table 19 – Comparison of Expert 8 and 11's Assessment Criteria Scoring

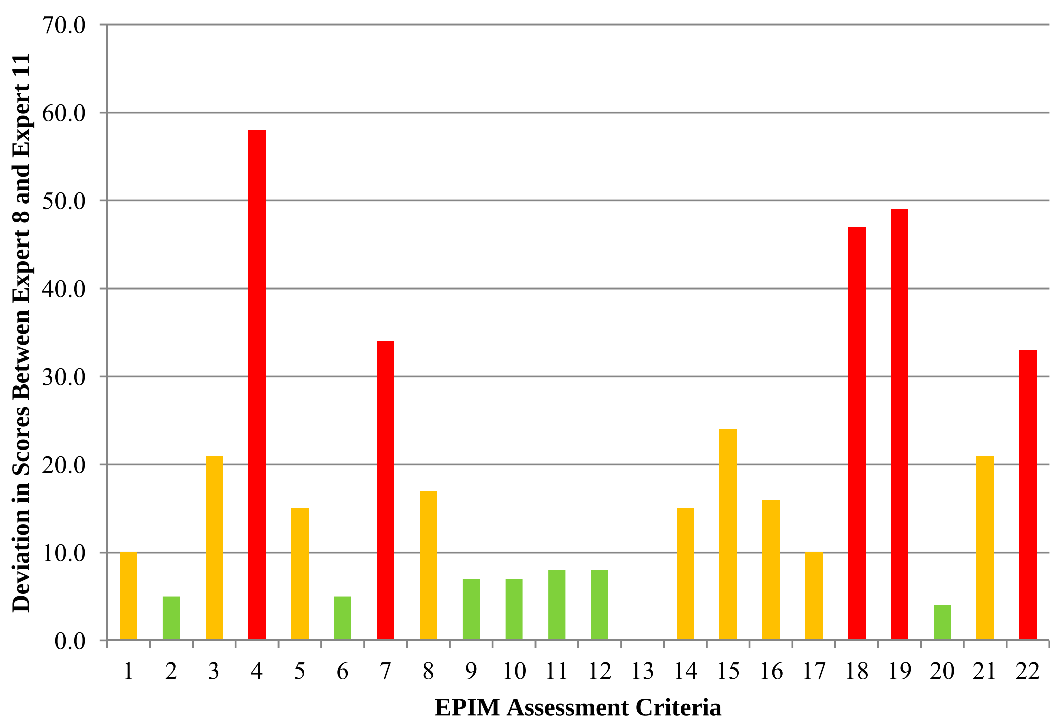

Figure 12 – Deviation between Expert 8 and 11's Scoring

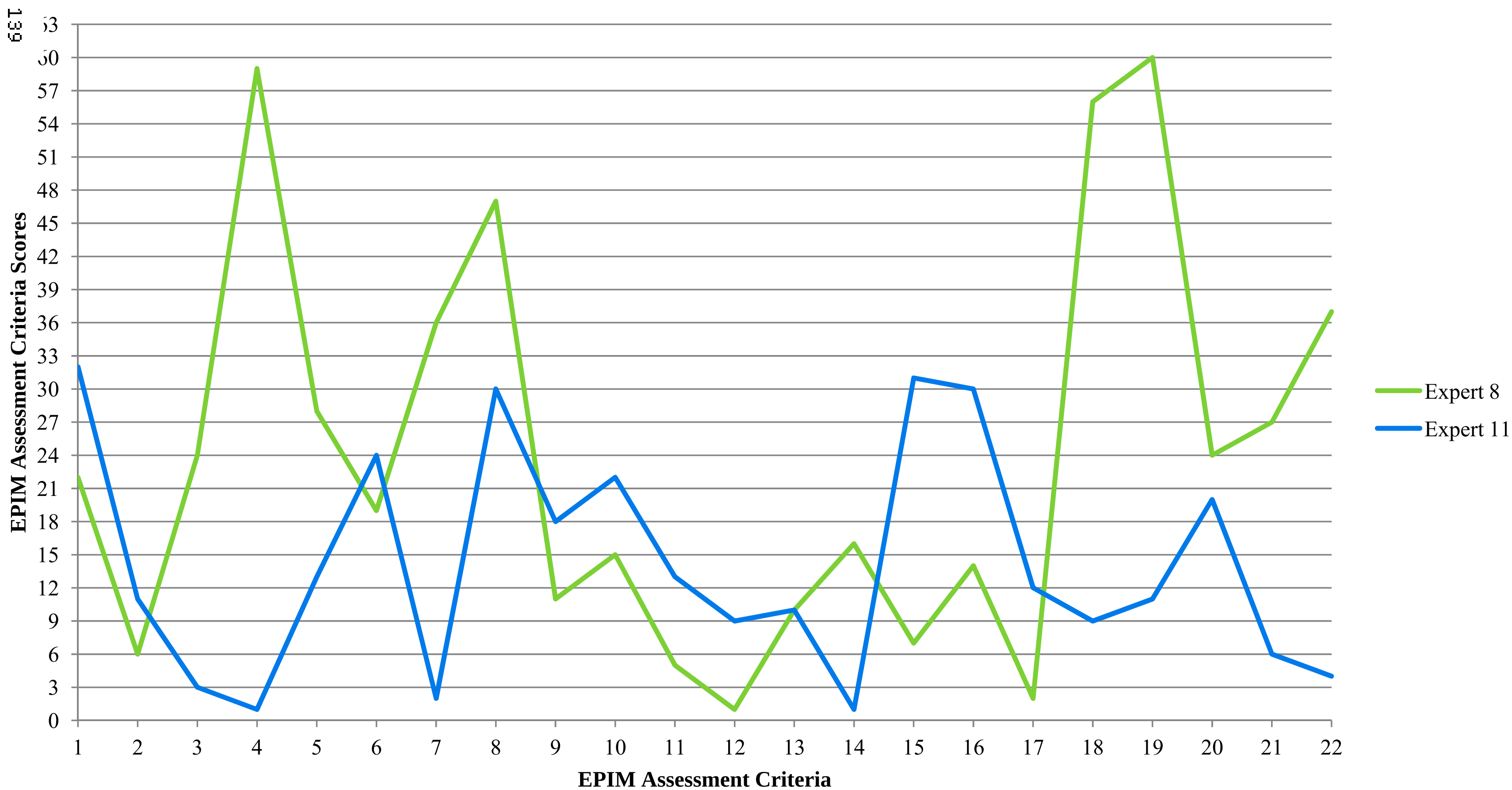

Figure 13 – Summary of Expert 8 and 11's Assessment Criteria Scores

5.4.7 Delphi Participant Categorisation

Table 16 shows the nomination of the expertise employed in this study, their occupation and categorisation in one of five categories: client, guidance, heritage, industry and non-heritage. Figure 10 shows a radar chart with the weightings of each category. This allows identification of agreement and disagreement between the expert groups. Largely, the radar pattern is synonymous for each category, with the exception of peaks where certain groups present stronger preferences. However, there are some occurrences where there are notable differences in opinion; these are between the heritage and non-heritage categories, an expected result.

Table 16 shows four of the eleven participants identified as working within the heritage sector of the construction industry. Table 18 shows the paired comparison results with the four heritage experts removed, i.e. the 'non-heritage group weightings'. The rankings change and, most notably, the top three criteria have a larger proportion of the overall weighting percentage than previously. Criterion 1 'Capital cost' achieves almost 12% of the overall weightings, whilst Criterion 10 'Financial payback' and Criterion 9 'Potential energy/carbon savings' increase to over 10% each. Criterion 16 'Level of improvement in building occupants' comfort', previously ranked at position ten is now within the top ten at position four. Interestingly, Criterion 19 'Impact on building's vapour permeability/breathability', previously at position four, has dropped to position five, a less significant relegation than anticipated due to the specificity to traditional buildings and therefore those working in the heritage sector.

The three other criteria identified as addressing traditional construction requirements, as discussed in 5.4.3, will now be examined. Criterion 4 'Loss of significant building fabric' has moved from sixth to twenty-second position, a significant decrease in impact upon decision making. Criterion 18 'Impact on building's internal air movement/ventilation' is shown in eighth, formerly fifth, therefore a less significant change in weighting. Criterion 7 'Impact on building's appearance' sits in sixteenth position, previously shown in eighth, another notable change. A reasonable explanation for the significant change in Criterion 4 and 7 is that these criteria relate directly to the level of intervention in the fabric. This is, rather expectedly, held in higher regard by the heritage sector than the non-heritage sector. However, the heritage-related criteria that address technical issues; Criterion 18 and 19, retain their relatively high rankings. It therefore could be suggested that the assessment criteria produced by the entire expert group could be utilised in assessing decisions in the energy-led refurbishment of listed properties due to the importance placed upon the appearance and impact upon the fabric. Conversely, the non-heritage group's assessment criteria could be more applicable to an unlisted property, as it still considers the technical performance issues of the traditional construction form whilst providing greater leniency towards changes in the building's aesthetics.

In Figure 10, it is evident that the client expert group have identified relatively consistent low weightings for the majority of the assessment criteria. The exceptions where they have allocated higher weightings of importance include: Criterion 1 'Capital cost', Criterion 8 'Impact on building's space/internal layout', Criterion 9 'Potential energy/carbon savings', Criterion 10 'Financial payback', Criterion 16 'Level of improvement in building occupants' comfort', and Criterion 18 'Impact on building's internal air movement/ventilation'. Therefore, the client group's interests clearly lie with financial and occupancy comfort issues. Criteria 1, 9 and 10 could be described as relevant to the financial factors within an EPIM decision. Criteria 16 and 18 address the building user's comfort. They encourage assessment of levels of disruption to the workplace and quality of the internal environment. Criterion 8 is two-fold within the decision, as it addresses the financial impact of altering the total usable floor area as well as the functionality of the property for the occupants; how comfortable the internal space is to use for the purpose in which it is intended.

5.5 Conclusion

A set of weighted assessment criteria by which to determine the suitability of an EPIM for an existing, hard to treat, office building, has been defined in this study. The criteria, their presentation and weightings provide an element of standardisation to the complex multiple attribute decision making process of energy performance improvement. They consider all stages of an EPIM's lifecycle and, when utilised within the Chapter 4 DST function, they can aid informed decision making and ultimately, selection of an optimum EPIM improvement package.

Chapter 6: General discussion, conclusion and further research

6.1 General discussion

This research set out to determine an approach to the energy-led refurbishment of non-domestic buildings that could be adopted as a standard methodology by property professionals.

This thesis has documented an approach that is an amalgamation of three individual studies. First the form and level of professional competence required to execute a successful energy-led refurbishment project. Second, a unique decision-making methodology to guide professionals in this specialised branch of refurbishment. Third, an original set of weighted assessment criteria by which to design a refurbishment strategy. Together, these three components contribute to the determination of an approach to energy-led refurbishment of non-domestic property.

A review of the literature revealed that there are a variety of drivers, financial, social, environmental, technical and legislative in nature, that are causing and will continue to cause building owners and users to assess and improve the energy performance of their property. Furthermore, a breadth of methodologies for the assessment of both new and existing building energy performance were evident. However, a defined approach to building energy performance improvement, a methodology for assessing the appropriateness of individual refurbishment measures and the professional skills required to undertake such assessment was notably lacking.

Historically, in the UK, the solution provided for property owners and users rest with the well established professionals of the construction industry, such as the architect, surveyors and engineers. In light of an increasing number of drivers for energy efficient property, it is these professionals that owners and users will require to advise and support them in this complex transition. Chapter 3 examined the effectiveness of existing construction professionals' competencies, as defined by their governing professional institutions, for delivering energy-led refurbishment services. Analysis of interviews held with construction industry professionals and clients revealed a deficiency between the competencies that clients desire and those currently provided by professionals. Client interviews therefore led to the definition of an optimum competency specification, which upon cross-examination with the existing competency specifications set out by professional institutions, affirmed this deficiency. Interviewing the industry professionals identified a number of barriers that they must overcome in order to satisfy client requirements. One barrier identified was the ambiguity surrounding the appropriate route to specialisation or further learning in this field that would improve the professionals' competency to a satisfactory level. It was noted that if a professional were to undertake some form of retraining then it would have to result in a recognised accreditation to attain merit with industry clients. This level of commitment, in itself, leads to identification of an additional barrier to professional development, time constraints. Interviews revealed that professionals felt the time and support required to undergo retraining was lacking from their employers due to the pressures to deliver and continuously improve the competencies that are core to their role. It is surmised that this pressure is only further amplified as a result of the recent recession, impacting the global economy post-2007, and consequently the security of employment in the construction industry. Furthermore, the traditional structure of the construction industry, with well defined procurement routes has resulted in a clearly defined design team. As a result, this formation raises uncertainty and apprehension regarding the integration of a new professional to deliver energy performance improvement services, from both a hierarchical and financial perspective.

Opportunity for low carbon skills within the construction industry lies not only within existing professionals. New professionals in the form of university graduates present a key resource. Interviews with professionals revealed their awareness of graduates entering the industry with a notable level of knowledge and interest within the energy performance of the built environment. The increasing relevance of this subject area within society has resulted in the adjustment of existing construction undergraduate degrees to incorporate key sustainability and energy issues within the context of construction, as well as the creation of new postgraduate programmes specifically addressing these issues. New entrants to the industry arising from such programmes present great opportunity for the dissemination of their knowledge to existing professionals. However, this resource cannot be solely relied upon because their level of influence for evoking the considerable change that is required, within a long-established industry is likely to be insufficient. There must be a combination of both new entrants and retraining of existing professionals to lead to an industry that is competent as a whole.

The desired outcome of retraining existing professionals is also uncertain. Essentially, two alternatives arise. First, the creation of an entirely new profession, the competencies for which have been presented in Chapter 3, similarly to the creation of the dedicated Project Management role in construction in the last 40 years. Alternatively, an expert could arise through specialisation within an existing discipline, as has occurred within the Architecture and Building Surveying disciplines, with specialisation in building conservation. Both approaches face barriers that must be overcome, and despite how it is achieved, this specialist will require the foundation of a competent network of professionals, with a common understanding of energy in buildings, to facilitate successful transition to a low carbon built environment.

The existing built environment poses a significant challenge in the transition to a low carbon society. The operation of existing buildings and their multiple energy applications contributes to approximately 40% of the UK's carbon emissions (Carbon Trust, 2010). It is estimated that 60% of the current building stock will still exist in 2050 (Farmer, 2009), and therefore presents the energy performance improvement of existing property as a priority in meeting Government emission reduction targets. The non-domestic sector of the existing building stock presents further complexities, due to the heterogeneous nature of their physicality, operation and ownership hierarchies. Although the agenda of sustainability in property has been present for over 10 years, with the introduction of the EPBD in 2002 (European Union, 2002), its application within existing, non-domestic property remains uncertain. One key challenge identified in the refurbishment of existing non-domestic property for improved energy efficiency is the existence of ill defined roles and processes that lack clarity, methodologies and evaluation criteria (BBP, 2010). In order to support construction industry professionals in delivering energy performance improvement within this multifaceted sector of the built environment, a clearly defined approach is required, one that will aid informed decision making. Upon determination of such an approach, its automation into functioning Decision Support Tool (DST) software could benefit property professionals - building owners and users – to undertake an energy-led refurbishment of an entire property portfolio as well as provide a useful platform for energy performance data management and analysis. The creation of DST software would enable these property professionals to make informed decisions regarding energy performance in an efficient and effective manner. However it is in no way a substitute for the introduction of low carbon skilled professionals within the construction industry.

Skilled professionals would still be required to provide context to the software outputs, demonstrating their relevance within individual buildings.
An investigation into existing decision support mechanisms within the property sector was undertaken through examination of the available academic literature. A selection of DSTs were identified that were representative of the various decision support mechanisms in the literature. Their analysis revealed a number of positive attributes that would be useful in supporting energy-led refurbishment decision-making. However, financial performance assessment was the only attribute that all of the DSTs reviewed addressed comprehensively, some providing the user with significant cost information and analytical functionality, including budget setting capabilities, to arrive at the optimum refurbishment scheme from a financial perspective. The review of existing DSTs combined with knowledge of the existing built environment, led to the identification of an optimum DST approach, encompassing the modification of useful functionality detailed in the existing literature with original attributes for decision support. This optimum DST consists of a seven step process, detailed within Chapter 4, and could be implemented as a manual or automated decision support mechanism for energy-led refurbishment of existing, non-domestic property. It differs from existing DSTs through a variety of elements that address every stage of the refurbishment lifecycle. Key attributes of the optimum DST include:

- Integration of building users' views both pre and post refurbishment.
- A clearly defined hierarchical methodology for refurbishment intervention appraisal.
- Inherent consideration of intervention practicality, including the separation of energy demand and supply improvement measures.
- Adjustment of operational energy management plans post refurbishment to align with the refurbished building state.
- A mechanism for continuous improvement of the portfolio that permits retrospective analysis and benchmarking of building performance.

These features of the DST were subsequently validated through the examination of a real energy-led refurbishment of an existing office building. The case study refurbishment project was used to determine the needs of property owners and users when undertaking building improvements, specifically how key decisions were made. The case study affirmed the need for a clearly defined approach, drawing the following conclusions:

- A need for a graduated, supportive approach to the entire energy-led refurbishment process due to the new nature of its implementation.
- The relevance of a tiered format of energy performance improvement measures' proposition and assessment.
- Confirmation of the multiple criteria decision making process that is apparent in this form of refurbishment, particularly pertinent in hard to treat, non-domestic properties.
- A need to reinforce and support (Post-Occupancy Evaluation) POE of refurbished properties.
- A requirement for a DST to address entire portfolios, as the optimum DST in this thesis proposes, instead of individual building assessment and improvement.

Chapter 4 identified a crucial step within energy-led refurbishment to be the multiple criteria decision making process applied to the selection of individual refurbishment intervention options. It was identified that no set of criteria currently exists for the purposes of assessing the appropriateness of an individual refurbishment intervention for an existing property. The optimum DST is targeted at non-domestic building refurbishment and as a result, public and private sector organisations and businesses. This research revealed the increasing pressures placed upon property managers within such organisations to meet and sustain year-on-year reductions in energy consumption, either through a contractual requirement or a bonus incentivised scheme. This pressure to deliver savings competently and consistently combined with the overwhelming range of energy performance improvement measures (EPIMs) results in a highly complex decision making process, one that requires guidance to ensure informed decisions are taken. Although the optimum DST could be applied to potentially any type of non-domestic property, the assessment of appropriate EPIMs is typically specific to a particular property type or function. In developing a set of assessment criteria for informed EPIM selection, an existing office building, classed as hard to treat due to its traditional construction form, was used. In the context of this thesis, this is defined by the following attributes:

- The property is likely to pre-date 1919.
- It will be of mass masonry (stone or brick) wall construction.
- Originally single glazed windows.

- Originally have no additional insulation materials built into the fabric.
- It is likely to have high air infiltration levels.

Buildings of this construction type can often be found in the building portfolios of service sector and public sector organisations, providing them with a presence in many major city centres.

The Delphi methodology utilising a group of property experts determined a unique set of twenty-two assessment criteria. This set was structured across three categories that represent the EPIM's lifecycle, installation, operation and disposal, as the expert group believed that this approach would aid informed decision-making, ensuring that all aspects of the improvement was considered pre-refurbishment. The set of assessment criteria addresses all aspects of energy-led refurbishment considerations, including; environmental, financial, legislative, social and technical. Once the assessment criteria set was defined and agreed, the same expert group used a pairwise comparison weighting methodology to assign weightings of relative importance to each criterion. The weightings aid the decision maker to score individual EPIMs in terms of their appropriateness for the specified property type. Weighting systems currently exist for the assessment of building designs in terms of their sustainability, taking into consideration their impact upon specific elements such as energy, waste and water (Cole 2005, 2006). However, weighted criteria for the assessment of individual energy performance building improvement measures are not available; it is this lack of weighted criteria that the final study satisfies. By providing weighted criteria, decision makers (property owners, occupants and managers) are supported to make informed selections when improving an existing building's energy efficiency.

6.2 Conclusions

- Professionals with responsibility to corporate employers for reducing energy consumption and carbon emissions in non-domestic buildings of generally traditional construction often lack the skills to make sound decisions about energy-led refurbishment of their properties. Furthermore, there is a gap between competencies desired by corporate clients and those currently provided by professionals such as architects, surveyors and engineers.

- The set of competencies could be the basis for either a new profession, similar to the Project Management profession that has developed over the last few decades, or an expert specialisation within an existing profession, similar to the Architects accredited in conservation that has formed within the architecture profession.

- Professionals required to make decisions about energy-led refurbishment lack a framework of support for decisions. Based upon those which already exist, a seven-step decision support tool has been defined, consisting of (step one) assess current building state, (step two) energy demand interventions assessed, (step three) post energy demand interventions building state assessed, (step four) energy supply interventions assessed, (step five) post refurbishment performance assessed, (step six) energy management action plan, and (step seven) continuous improvement.

- The seven step DST has been validated by a case study of a refurbishment project undertaken on a typical traditionally constructed office.

- A crucial step in energy-led refurbishment is the multiple criteria decision-making process applied to the selection of individual refurbishment interventions. A Delphi survey identified 22 criteria, spanning installation, operation and disposal stages of the lifecycle against which decisions are made.

- A unique set of assessment criteria for such work has been defined, and includes: capital cost, potential energy/carbon savings, financial payback, impact on building's vapour permeability/'breathability', impact on building's internal air movement/ventilation, loss of significant building fabric, impact on building's space/internal layout, impact on building's appearance, reliability of EPIM's performance, level of improvement in building occupants' comfort, environmental impact of EPIM, embodied energy/carbon of EPIM, degradation of EPIM performance, availability of grants, tax allowances and other financial incentives, change to maintenance costs, level of disruption to building occupants during works, training building occupants in the use of new system(s), requirement of planning and/or building control approvals, impact on existing building services, ease of installation of EPIM, ease of maintenance of EPIM and disposal cost of EPIM at end of useful life.

- Pairwise comparisons using the expert group assigned weightings of relative importance to each criterion, which can be used by decision-makers to score refurbishment interventions for appropriateness to their own property.

- All experts gave high weightings to capital cost, financial payback, potential energy savings and impact on the vapour permeability of the building fabric, while those experts with a heritage focus also weighted loss of fabric and impact on appearance highly. Reliability of the intervention was weighted the same but less highly by all experts. Experts with a client focus weighted internal comfort, existing services and impact on internal air movement more highly than other expert groups.

6.3 Limitations and Future Areas of Research

There are some limitations within the present thesis and some of these should be considered for future areas of research within this field.

Having determined a deficiency in professional competency for servicing clients' needs for energy efficient, non-domestic property, an opportunity for future research arises. The identification and examination of available routes to specialisation of existing construction industry professionals, whilst taking into consideration the barriers identified within this thesis, surrounding accreditation, design team integration, dissemination of knowledge across industry and finance of expertise, is a logical progression into professional competency research.

The proposed DST within this research was clearly outlined, and significant development has been undertaken, but this was limited to one module of the process, due to time and resource constraints. In line with full DST development, future research should identify the optimum platform for such a tool, including the most appropriate simulation software to integrate with the DST. The DST was initially developed to overcome the lack of a defined methodology in refurbishment, and specifically, energy-led refurbishment on non-domestic property. The DST could be further developed to overcome other barriers to this form of refurbishment, such as the commercial barriers, through addressing multi-tenanted non-domestic property. Future research could identify how the tool could be utilised as a platform for energy data sharing between property owners and occupiers, as well collaborative decision making between the two parties.

The assessment criteria defined within this thesis were designed to address energy performance improvement for a specified building type. Additional criteria sets could be developed to support this form of decision making within a range of property types, e.g. offices, retail, industrial, hospitals and schools. It is anticipated that the majority of criteria and weightings would remain consistent across all types, with exceptions where the criteria address impact on building operations and building fabric as these will vary widely within the building stock.

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Appendix A Professional Competency Interview Questions

Interview of Construction Industry Clients

Introduction

Present the abstract to the interviewee and explain the background of the research.

Ask the interviewee to describe, in their own words:

- their profession
- the governing body of their profession
- how long they have worked in that industry
- how long they have worked within their current role
- what their job title is
- what their academic and professional background is
- what are the key responsibilities of their job

Interview Questions

Overarching question of the interview: 'Does the current professional structure of the construction industry meet the needs of refurbishment clients?'

1. How would you describe your company's attitude towards refurbishment of its building stock?
2. In particular, what is the attitude towards energy performance improvements to its stock?
3. Have you seen a change in your company's attitude towards environmental issues and in particular energy performance improvements of its buildings? Can you describe this?
4. If yes, what do you believe to have contributed to this change in attitude? What pressures/influences have you become aware of that may have caused this change?
5. What is your company-wide strategy towards improvement of your building stock?
6. Does your company set its own carbon/energy performance targets?
7. What is the relative importance of the energy performance of your buildings to other performance requirements they must fulfil?
8. What drivers would make your business undertake works to an existing property?
9. What drives the decision to undertake energy performance improvements to your building stock? How do you prioritise the following drivers for energy performance improvements; cost savings, corporate-social responsibility, indoor environmental quality, build quality, achieving company set targets and meeting government policies. Are there any other drivers that you feel are important?
10. When the decision to refurbish has been undertaken, who do you consult when designing a refurbishment scheme, do you have an in-house team or do you consult external construction professionals?

11. Do you have any contractual relationships with other companies to carry out works to your existing buildings?
12. If yes, do these contracts include any clauses relating to energy performance targets or levels these companies must achieve?
13. What competencies would you expect from construction professionals in terms of their knowledge of sustainability?
14. Do you see a difference in the client requirements you are taking to those you consult on refurbishment works? I.e. more energy focused requirements? Have the changing attitudes of your company manifested themselves in your client requirements?
15. To what extent are you involved (as a client) in the decisions made during the refurbishment/works to a company building? Are you as a client heavily involved, setting criteria by which various interventions have to be assessed, or is the decision making delegated to the technical consultants used? What level of technical input do you have as a client?
16. If you were to carry out a completely energy focused refurbishment project, what type of professional would you select to lead the project design, procurement and construction? Why would that professional be chosen?
17. To what extent would it be beneficial for businesses like yours to have a defined construction professional (like an architect, building surveyor, project manager, services engineer etc) who is accredited and could deliver a fully compatible, innovative and holistic energy focused intervention package within a refurbishment project?

Review: Overarching question: [Does the current professional structure of the construction industry meet the needs of refurbishment clients?].

Interview of Construction Industry Professionals

Introduction

Present the abstract to the interviewee and explain the background of the research.

Ask the interviewee to describe, in their own words;

- their profession
- the governing body of their profession
- how long they have worked in that industry
- how long they have worked within their current role
- what their job title is
- what their academic and professional background is
- what are the key responsibilities of their job

Interview Questions

[Overarching question: Does the current professional structure of the construction industry meet the needs of refurbishment clients?]

1. What do you understand by the term refurbishment?

2. How often do you work on refurbishment projects, is it a major part of your role?

3. What comes to mind when you hear the phrase “energy led refurbishment of existing non-domestic buildings”?

4. Do you think that your original education and training has equipped you with the competencies/skills you require in your current role as...?

5. Do industry professionals feel under any pressure to become more knowledgeable of low carbon building design and construction as well as operational energy usage in buildings?

6. (Have you personally undertaken any retraining within this area due to such pressures?)

7. Do you feel that your profession’s governing body is adapting to incorporate energy efficiency in buildings into its competency skill set?

8. Can you envisage sustainability related skills becoming a core competency of your particular profession?

9. (Or is it more suited to another profession, which?)

10. How would you describe your company’s attitude towards energy led construction projects?

11. Do they encourage clients to consider the energy usage associated with their building(s)?

12. Do they enable clients to address energy performance of their building(s)?

13. Have you seen a recent change in your company’s attitude towards energy performance in buildings and if yes, what do you feel has caused this change?

14. Do you feel equipped to accommodate and reflect the change in your company’s attitude within the services you provide to clients? Is your company assisting you to do so? Is your professional body assisting you to do so? And how are they assisting you?

15. To what extent are client attitudes towards energy performance of their buildings changing?

16. Do they prioritise energy performance more highly than felt previously?

17. If yes, why do you believe this change in attitude has come about?

18. What do you believe is the relative importance of the energy performance of a building to other performance requirements they must fulfil?

19. What are the relative positions of cost, energy performance, carbon emissions, corporate-social responsibility, aesthetics, and general building performance on the refurbishment agenda?

20. To what extent are clients involved in the decision making within a refurbishment scheme?

21. How are decisions made within a refurbishment project, how are the interventions selected, how is a holistic approach achieved?

22. In your experience, what type of construction professional is chosen to lead an energy related refurbishment project, and do you believe this is the optimum professional for this role?

23. To what extent would it be beneficial for a company like yours that provides multiple services, to have a defined construction professional who is accredited and could lead an energy focused refurbishment project from beginning to end? (Who encompasses the technical, social and business skills required to deliver a truly innovative, compatible, comprehensive intervention package).

Review: Overarching question: [Does the current professional structure of the construction industry meet the needs of refurbishment clients?].

Appendix B Case Study Interview Questions

Case Study Project Information

Interview Questions

PART ONE

1.1 What were the drivers in taking the decision to improve this building?

1.2 How did the energy performance of the building factor into this decision?

1.3 What were the success factors for this project?

1.3.1 How were these measured and were they achieved?

1.4 What expertise was employed on this project and why?

1.4.1 How was the project team structured? Who led and why?

1.5 Pre-refurbishment, what methodology did the building assessment follow?

1.5.1 How were the views of the building users incorporated into this assessment?

1.6.1 How was energy performance incorporated into this assessment?

1.7.1 What were the results of the building assessment?

PART TWO

2.1 What approach was taken to improving the energy performance of the building?

2.2 How were energy performance improvement measures selected for this building?

2.3 What criteria were used to assess the suitability of the energy performance improvement measures individually and as a package?

2.4 How did the building's traditional form of construction factor into the energy performance improvements?

2.5 Was the building fully operational and occupied during the works?

2.5.1 How was disruption minimised, and comfort maintained, for the occupants during the works?

PART THREE

3.1 Was a post-occupancy evaluation carried out?

3.1.1 What were the results of this evaluation?

3.2 Post-refurbishment how was the energy performance of the building assessed?

3.2.1 What were the results of this and how did they compare to the pre-refurbishment assessment? Were expectations met?

3.3 How was the property/facilities manager of the building trained in any new systems at handover?

3.4 What were the lessons learned on this project?

3.5 How often will the building’s energy performance be reviewed?

3.5.1 How will this review be carried out?

Appendix C Delphi Survey Questionnaire

PART ONE: ASSESSMENT CRITERIA: ROUND ONE

Exit this survey

PART ONE: ASSESSMENT CRITERIA

We want to create a tool that allows an individual working within an organisation - who is responsible for the management and improvement of that organisation's existing building stock - to make INFORMED DECISIONS about improvement measures applied to that building stock.

The tool will specifically aid energy performance improvements implementation within existing, non-domestic office buildings that are of traditional* construction.

*Traditional construction within the context of this research refers to buildings that;
1. Are likely to pre-date 1919
2. Are of mass masonry (stone or brick) wall construction
3. Have single glazed windows
4. Have no additional insulation materials built into the fabric
5. Are likely to have high air infiltration levels

Our survey consists of 7 short questions and should take approximately 10 minutes to complete.

Next

PART ONE: ASSESSMENT CRITERIA: ROUND ONE

Exit this survey

PART ONE: ASSESSMENT CRITERIA (cont'd)

What criteria should built environment professionals use to assess the suitability of an energy performance improvement measure for an existing building?

A list of criteria by which suitability of an Energy Performance Improvement Measure* can be assessed against is shown below.

Energy Performance Improvement Measure* = Works carried out to a building with the purpose of improving the energy efficiency of that building. E.g. upgrading the level of thermal insulation or improving the level of air tightness etc.

List of Assessment Criteria

1. Capital cost
2. Financial payback
3. Additional maintenance costs
4. Reduced energy bills
5. Potential energy savings
6. Potential reduction in associated carbon emissions
7. Embodied Energy of the Energy Performance Improvement Measure
8. Embodied carbon of the Energy Performance Improvement Measure
9. Ease of installation
10. Level of disruption to building occupants during works
11. Training building occupants in the use of new system(s) post refurbishment
12. Reliability
13. Impact on building's appearance
14. Level of improvement in building occupants' comfort
15. Requirement of Planning and/or Building Control Approvals

1. In your opinion, does the list contain sufficient criteria to assess the suitability of an Energy Performance Improvement Measure?

- ◯ Yes
- ◯ No

2. Are there any criteria that should be added to the above list?

- ◯ Yes
- ◯ No

3. If yes, then please describe what additional criteria should be added.

4. If yes, then please explain why these additional criteria should be added.

5. Are there any assessment criteria that should be omitted from the above list?

- ◯ Yes
- ◯ No

6. If yes, then please describe what criteria should be omitted.

7. If yes, then please explain why these criteria should be ommitted.

Prev Done

Appendix D Paired Comparison Survey Template and Guidance

William Arrol Building, Heriot Watt University, Currie, Edinburgh, EH14 4AS

Ref: WAC/001
27th January 2012

REF: Part 2 Survey: Weighting the Assessment Criteria

Dear [Participant],

I am writing to you regarding the Part 2 Survey: Weighting the Assessment Criteria. This survey follows on from the Part 1 Survey where the expert group determined and finalised a list of Assessment Criteria by which to assess the suitability of an Energy Performance Improvement Measure (EPIM). The Part 2 Survey will be the final exercise and will not be repeated.

The purpose of the Part 2 Survey is to allow the expert group to weight the EPIM Assessment Criteria in terms of their relative importance. Please find enclosed the following documentation that will allow you to complete the Part 2 Survey;

1. Finalised list of EPIM Assessment Criteria and their Definitions

2. Part 2 Survey Guidelines

3. The Part 2 Survey: Weighting the Assessment Criteria: A Pair-wise Comparison

The Survey Guidelines will detail when and how to return your completed survey.

Your participation is very much appreciated and I look forward to your response. If you require any further information then please contact me on my details below.

Yours sincerely,

Megan Strachan
Mobile: +44 (0)798 888 9484
Email: mes8@hw.ac.uk

PART 2 SURVEY: ENERGY PERFORMANCE IMPROVEMENT MEASURE ASSESSMENT CRITERIA

WEIGHTING THE ASSESSMENT CRITERIA

SURVEY GUIDELINES

1.0 Survey Overview

The purpose of this exercise is to determine weightings of relative importance for the twenty-two, pre-determined Assessment Criteria.

The initial question presented to you at the beginning of this process was,

'What criteria should built environment professionals use to assess the suitability of an energy performance improvement measure for an existing building?'

The existing building type referred to in this study is a non-domestic office building of traditional* construction.

**Traditional construction within the context of this study refers to buildings that:*

1. Are likely to pre-date 1919

2. Are of mass masonry (stone or brick) wall construction

3. Have single glazed windows

4. Have no additional insulation materials built into the fabric

5. Are likely to have high air infiltration levels

You should keep this in mind when weighting the Assessment Criteria.

2.0 <u>Survey Instructions</u>

A pair-wise comparison survey has been created to allow you to weight the twenty-two Assessment Criteria. This is where each criterion is compared against every other criterion in pairs, allowing the participant, through the use of a rating scale to indicate how much more important they believe one criterion is over another.

Please see an example of a pairwise comparison below.

Example

'A'	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	'B'
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	Ease of installation

- You must mark one box on the scale.
- You will see in the example above, that there is an Assessment Criterion on each end of the 9-point scale.
- You must determine how much more important you believe Assessment Criteria 'A' is over Assessment Criteria 'B', ranging from 'Very strongly more important' to 'Very strongly less important'.
- The closer you mark to an Assessment Criterion, the more relative importance you are attaching to that Assessment Criterion.
- If you believe the Assessment Criteria are of equal importance, then you can mark the central box on the 9-point scale to indicate this.

3.0 Return of Completed Survey

Return of Completed Survey Deadline: Monday 20th February 2012

There are a large number of pair-wise comparisons within the survey. However, this survey type will allow you to truly identify which Assessment Criteria should hold greater relative importance over others.

It is dependant upon the individual to how long it will take to complete the survey. We have provided it in a hard copy form to make the survey more easily accessible.

Once you have completed the survey, please return it to me via the freepost envelope included in this package. Or you can scan and email the completed survey to my address: mes8@hw.ac.uk.

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Availability of grants, tax allowances and other financial incentives**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of disruption to building occupants during works**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Potential energy/carbon savings**
Ease of maintenance of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Reliability of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of installation of EPIM**
Training building occupants in the use of new system(s) post refurbishment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Impact on existing building services	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's appearance**
Impact on building's vapour permeability/'breathability'	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Potential energy/carbon savings**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Requirement of planning &/or building control approvals**
Environmental impact of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Ease of maintenance of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Degradation of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Level of improvement in building occupants' comfort	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Impact on building's internal air movement/ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Embodied energy/carbon of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of installation of EPIM**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Ease of installation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Requirement of planning &/or building control approvals**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of disruption to building occupants during works**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Potential energy/carbon savings**
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Financial payback**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Change to maintenance costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Training building occupants in the use of new system(s) post refurbishment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Reliability of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Ease of maintenance of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's appearance**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Requirement of planning &/or building control approvals**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of disruption to building occupants during works**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's appearance**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Change to maintenance costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Level of improvement in building occupants' comfort	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Embodied energy/carbon of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**
Degradation of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Impact on existing building services	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Potential energy/carbon savings**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Financial payback**
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Change to maintenance costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Ease of maintenance of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Reliability of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Degradation of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Training building occupants in the use of new system(s) post refurbishment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Impact on building's vapour permeability/'breathability'	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Capital cost**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Availability of grants, tax allowances and other financial incentives**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**
Embodied energy/carbon of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Reliability of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's appearance**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**
Impact on building's internal air movement/ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Impact on building's vapour permeability/'breathability'	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Degradation of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Training building occupants in the use of new system(s) post refurbishment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**
Impact on building's internal air movement/ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Requirement of planning &/or building control approvals**
Change to maintenance costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Availability of grants, tax allowances and other financial incentives**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Training building occupants in the use of new system(s) post refurbishment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of installation of EPIM**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Financial payback**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Impact on building's vapour permeability/'breathability'	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Capital cost**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Degradation of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Level of improvement in building occupants' comfort	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Impact on existing building services	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Impact on building's internal air movement/ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's appearance**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of installation of EPIM**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Requirement of planning &/or building control approvals**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Level of improvement in building occupants' comfort	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Capital cost**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Potential energy/carbon savings**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Embodied energy/carbon of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Requirement of planning &/or building control approvals**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Environmental impact of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**
Ease of maintenance of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Level of improvement in building occupants' comfort	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Potential energy/carbon savings**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Disposal cost of EPIM at end of useful life	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Ease of maintenance of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Reliability of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Degradation of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Training building occupants in the use of new system(s) post refurbishment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Impact on building's internal air movement/ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Capital cost**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Availability of grants, tax allowances and other financial incentives**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Potential energy/carbon savings**
Disposal cost of EPIM at end of useful life	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Financial payback**
Embodied energy/carbon of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's appearance**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Capital cost**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of installation of EPIM**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Reliability of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Disposal cost of EPIM at end of useful life	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of disruption to building occupants during works**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Level of disruption to building occupants during works										**Change to maintenance costs**
Impact on building's appearance										**Level of improvement in building occupants' comfort**
Change to maintenance costs										**Impact on existing building services**
Ease of maintenance of EPIM										**Disposal cost of EPIM at end of useful life**
Reliability of EPIM's performance										**Impact on building's internal air movement/ventilation**
Degradation of EPIM's performance										**Environmental impact of EPIM**
Change to maintenance costs										**Embodied energy/carbon of EPIM**
Disposal cost of EPIM at end of useful life										**Degradation of EPIM's performance**
Ease of maintenance of EPIM										**Training building occupants in the use of new system(s) post refurbishment**
Level of improvement in building occupants' comfort										**Embodied energy/carbon of EPIM**
Capital cost										**Impact on building's appearance**
Capital cost										**Degradation of EPIM's performance**
Impact on building's internal space/layout										**Availability of grants, tax allowances and other financial incentives**
Ease of installation of EPIM										**Level of improvement in building occupants' comfort**
Availability of grants, tax allowances and other financial incentives										**Impact on building's vapour permeability/'breathability'**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Availability of grants, tax allowances and other financial incentives**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Degradation of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of installation**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Impact on building's vapour permeability/'breathability'	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Impact on building's internal air movement/ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's appearance**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Disposal cost of EPIM at end of useful life	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Impact on existing building services	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Disposal cost of EPIM at end of useful life	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Potential energy/carbon savings**
Environmental impact of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Financial payback**
Change to maintenance costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Embodied energy/carbon of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Reliability of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Change to maintenance costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Financial payback**
Embodied energy/carbon of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Environmental impact of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Capital cost**
Impact on building's internal air movement/ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Availability of grants, tax allowances and other financial incentives**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Capital cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Environmental impact of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Availability of grants, tax allowances and other financial incentives**
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Impact on building's internal air movement/ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of installation**
Degradation of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Requirement of planning &/or building control approvals**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Level of improvement in building occupants' comfort	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Financial payback**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Ease of maintenance of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Reliability of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Training building occupants in the use of new system(s) post refurbishment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Disposal cost of EPIM at end of useful life	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Impact on building's vapour permeability/'breathability'	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Change to maintenance costs**
Disposal cost of EPIM at end of useful life	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Level of improvement in building occupants' comfort	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Reliability of EPIM's performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Financial payback**
Ease of maintenance of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of disruption to building occupants during works**
Ease of maintenance of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**
Level of improvement in building occupants' comfort	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Requirement of planning &/or building control approvals**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Level of disruption to building occupants during works	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Impact on building's appearance	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Impact on building's internal space/layout	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Degradation of EPIM's performance**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's vapour permeability/'breathability'**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Reliability of EPIM's performance**
Training building occupants in the use of new system(s) post refurbishment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal space/layout**
Impact on building's vapour permeability/'breathability'	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of installation of EPIM**
Change to maintenance costs	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Ease of installation of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Embodied energy/carbon of EPIM**
Financial payback	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Embodied energy/carbon of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Potential energy/carbon savings**
Training building occupants in the use of new system(s) post refurbishment	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Financial payback**
Impact on existing building services	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**
Environmental impact of EPIM	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Level of improvement in building occupants' comfort**
Availability of grants, tax allowances and other financial incentives	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disposal cost of EPIM at end of useful life**

	Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
Loss of significant original building fabric	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on existing building services**
Requirement of planning &/or building control approvals	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Ease of maintenance of EPIM**
Potential energy/carbon savings	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Impact on building's internal air movement/ventilation**
Impact on building's internal air movement/ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Loss of significant original building fabric**
Impact on building's vapour permeability/'breathability'	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Training building occupants in the use of new system(s) post refurbishment**
Impact on existing building services	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmental impact of EPIM**

Appendix E Paired Comparison Participants' Scored Responses

BIPOLAR SUM OF DIFFERENCES SCORING

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
	3	0	1	1	0	0	0	1	2	2	0	2	3	0	0	2	0	0	1	0	0	3
	4	0	0	1	0	0	0	0	3	4	0	0	2	0	0	1	0	0	1	0	2	2
	3	0	2	0	0	0	0	1	2	4	3	0	0	1	0	1	0	0	0	0	0	0
	4	0	0	1	0	0	1	0	0	4	0	1	0	0	0	0	0	0	0	0	2	0
	4	0	0	0	0	0	2	0	3	3	0	0	0	2	0	0	2	0	0	0	0	1
	4	0	0	0	0	0	3	0	3	4	0	0	0	0	0	0	0	0	0	0	1	0
	4	1	0	1	0	0	3	0	3	4	0	1	2	0	0	0	0	1	0	0	0	2
	4	0	0	0	0	0	1	1	3	4	0	0	2	1	0	0	3	0	0	0	0	3
	4	1	0	0	0	0	0	0	3	4	0	0	0	1	0	2	0	0	0	0	0	3
Expert 1	4	0	0	0	0	0	0	0	4	4	0	2	0	0	0	3	0	0	0	0	1	2
	4	0	0	0	0	0	2	0	4	4	0	1	0	0	0	1	0	0	0	0	1	0
	4	0	1	0	0	0	1	0	3	4	0	0	3	2	0	0	0	0	0	0	1	2
	4	0	0	1	0	0	0	1	0	4	0	0	0	0	0	0	0	1	0	0	1	0
	2	0	0	0	0	0	0	1	0	3	0	0	0	1	0	0	0	0	0	0	0	0
	4	0	0	1	0	0	0	0	0	4	0	0	2	0	0	0	0	0	1	0	2	2
	4	0	0	0	0	0	2	0	3	4	2	0	2	2	0	0	0	1	1	0	2	0
	4	1	0	1	0	1	2	0	3	4	0	0	2	2	0	0	0	0	1	0	2	1
	4	0	0	0	0	0	0	1	2	0	0	0	0	0	0	1	0	0	0	0	0	1
	4	0	0	1	0	0	1	0	1	4	0	0	1	0	0	0	2	1	0	0	0	0
	4	0	0	1	0	0	0	0	2	4	0	0	1	0	0	1	0	1	0	0	1	1
	4	0	0	0	0	0	2	2	3	4	0	1	0	0	0	0	0	0	0	0	2	1
SUM	**80**	**3**	**4**	**9**	**0**	**1**	**20**	**8**	**47**	**76**	**5**	**8**	**20**	**12**	**0**	**12**	**7**	**5**	**5**	**0**	**18**	**24**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
	0	1	0	0	1	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0
	2	2	0	1	1	0	0	0	2	0	0	0	0	1	0	0	0	0	0	1	0	3
	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
	0	0	1	0	0	2	1	0	0	0	0	0	2	0	2	0	0	0	0	0	2	0
	2	2	2	0	1	0	0	0	0	0	0	0	0	0	2	0	1	0	0	2	1	1
	1	1	0	0	1	0	0	0	2	0	0	2	0	0	0	0	0	2	0	0	1	2
	1	2	0	0	1	0	0	0	2	1	1	0	1	0	0	0	0	0	1	0	0	0
	2	1	0	0	1	0	0	0	0	0	0	0	1	1	2	0	0	1	0	0	0	0
	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Expert 2	1	0	0	1	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	1
	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0
	0	0	0	0	2	0	0	2	0	0	0	0	1	0	0	0	1	1	0	0	0	0
	1	2	0	0	1	0	0	1	0	2	2	0	0	0	1	0	0	0	0	0	3	1
	0	0	0	0	1	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	2	0	1	0	1	0	0	2	1	0	1	0	1	1
	0	0	0	2	0	0	0	0	2	2	0	0	0	2	0	2	0	0	0	1	2	0
	1	2	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	2	1
	1	2	0	1	0	0	0	0	2	0	1	0	2	0	1	0	1	1	1	0	1	0
	1	0	0	0	0	0	0	2	2	1	0	0	0	1	1	2	1	1	0	0	0	0
	2	2	0	1	0	0	0	0	2	0	0	0	2	1	0	1	0	1	2	0	0	1
	0	0	0	0	2	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	1	1
SUM	**19**	**18**	**3**	**8**	**12**	**2**	**1**	**5**	**23**	**7**	**5**	**5**	**12**	**9**	**11**	**7**	**5**	**8**	**8**	**6**	**14**	**14**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 3	4	0	0	0	0	2	0	0	3	0	0	0	2	0	4	0	0	0	0	0	3	4
	3	0	0	0	2	0	0	2	3	0	0	0	0	3	3	0	0	0	2	0	4	1
	2	2	0	1	0	0	0	1	3	2	0	0	3	3	3	0	0	0	2	0	2	0
	3	0	1	0	0	0	0	0	3	1	0	1	3	3	3	0	0	0	2	0	3	0
	3	0	0	0	0	0	0	0	3	0	2	0	3	0	3	0	0	0	3	0	3	0
	0	0	0	0	1	0	0	2	4	0	0	0	2	0	3	0	0	0	3	0	3	0
	2	0	0	0	0	0	0	0	4	3	2	0	3	3	0	0	0	0	3	0	3	0
	3	3	0	0	0	0	0	0	4	0	0	0	3	3	3	0	0	0	0	0	0	1
	2	2	0	0	0	0	0	0	3	0	1	0	0	2	1	0	0	0	3	0	0	0
	1	0	0	0	0	0	0	0	3	3	4	0	2	0	0	0	1	0	2	0	3	1
	3	0	0	0	0	0	0	0	2	2	3	0	3	2	0	0	0	0	3	0	4	0
	0	2	0	0	0	0	0	4	4	3	0	0	2	0	4	0	1	0	0	1	3	0
	3	3	0	0	0	0	0	3	4	0	0	0	0	0	2	0	0	0	2	0	3	0
	0	0	0	0	0	0	0	0	4	3	2	0	0	2	2	0	0	0	2	0	0	0
	0	2	0	0	0	0	0	0	4	3	2	2	2	2	3	0	0	2	3	0	3	0
	0	1	0	0	0	0	0	0	4	3	1	0	3	3	3	0	0	0	2	0	4	0
	0	3	0	0	0	0	0	0	4	1	0	0	0	2	3	0	0	0	3	0	4	0
	2	2	0	0	0	0	1	0	4	4	2	0	2	2	3	0	0	0	2	0	3	0
	3	0	0	0	0	0	0	0	4	3	2	0	0	3	3	0	0	0	0	0	2	0
	3	0	0	0	0	2	0	0	4	3	2	0	2	2	0	0	0	0	3	0	0	0
	1	2	0	0	0	0	0	0	2	0	2	0	0	3	0	0	0	0	0	0	3	0
SUM	**38**	**22**	**1**	**1**	**3**	**4**	**1**	**12**	**73**	**34**	**25**	**3**	**35**	**38**	**46**	**0**	**2**	**2**	**40**	**1**	**53**	**7**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 4	2	2	0	4	0	0	2	1	2	0	0	3	0	3	0	2	0	0	3	0	0	2
	0	0	0	3	0	0	2	1	2	3	0	0	3	1	0	1	0	3	2	0	0	1
	0	2	0	0	0	0	4	2	1	2	2	1	2	1	0	0	1	0	4	0	0	0
	2	0	0	4	0	0	4	0	1	3	0	0	0	1	0	0	0	0	2	0	2	2
	0	1	0	3	0	2	3	0	1	2	1	0	1	0	0	0	0	3	0	0	0	1
	4	0	0	2	0	0	4	0	2	0	0	0	0	1	0	0	1	0	1	0	0	0
	0	2	0	4	1	0	4	1	3	2	0	2	0	0	0	0	0	2	4	0	0	2
	0	0	0	1	0	0	4	3	3	3	0	1	2	0	0	0	0	3	4	0	0	3
	0	0	0	4	0	0	3	1	4	1	0	1	0	2	0	0	0	0	2	0	0	3
	0	0	0	4	0	1	3	0	3	0	0	0	0	0	0	3	1	2	3	0	2	0
	0	0	0	2	0	1	3	1	2	3	0	0	0	0	0	0	0	0	1	0	0	1
	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	1	2	2	0	1
	0	3	0	4	0	0	1	0	2	0	0	0	0	0	0	2	0	2	4	0	0	0
	0	0	0	3	0	0	2	3	0	0	0	0	1	0	0	0	1	0	3	0	0	2
	2	0	1	3	2	0	0	0	0	0	0	0	3	0	0	0	1	1	3	1	2	2
	0	2	2	2	0	0	4	2	3	1	0	0	2	0	0	2	1	3	2	0	1	0
	0	0	0	4	0	3	3	1	3	1	0	2	4	0	0	1	0	1	4	0	2	0
	1	0	0	4	0	0	4	2	2	2	0	2	0	2	0	2	0	0	1	0	0	0
	0	0	2	3	0	2	4	2	0	1	2	0	3	0	0	1	1	3	1	0	0	0
	2	0	0	3	0	1	2	1	4	2	1	0	2	0	0	1	0	1	0	0	2	2
	0	0	0	2	2	0	3	4	3	1	0	1	0	0	0	1	0	0	0	0	2	0
SUM	**13**	**12**	**5**	**62**	**5**	**10**	**62**	**25**	**41**	**27**	**6**	**13**	**23**	**11**	**0**	**16**	**7**	**25**	**46**	**3**	**13**	**22**

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	3	0	0	0	0	0	0	0	2	0	0	0	0	3	0	0	0	0	3	1	0	1
	3	0	1	0	0	0	0	0	2	2	0	0	3	0	0	0	0	2	2	0	0	0
	2	0	0	0	0	0	0	2	1	3	1	0	0	0	0	0	1	1	2	0	0	0
	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	3	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	2	0	0	0
	4	0	0	0	0	0	0	0	3	0	0	0	0	0	0	2	0	2	2	0	1	0
	3	2	0	0	2	0	0	1	2	2	0	0	0	0	0	0	0	1	2	0	0	0
	1	2	0	0	0	0	0	0	0	0	0	1	0	0	0	1	3	2	3	0	0	0
	3	0	0	0	0	0	0	0	4	2	0	0	0	1	0	2	1	1	0	0	0	1
Expert 5	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0
	2	0	0	0	1	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	2
	3	0	0	0	0	1	0	0	0	0	0	0	1	2	0	1	0	2	2	0	0	2
	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	2	3	0	0	0	1
	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	2	0	0	0	0
	2	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	1	0	2	2	0	0
	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	2	0	0	0
	0	0	0	1	0	1	0	1	0	1	0	0	0	0	0	2	0	2	2	0	0	0
	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	3	0	0	0
	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	3	3	0	0	0
	2	0	0	0	0	0	0	1	1	1	0	0	0	0	0	2	0	0	2	0	1	1
	1	0	0	0	0	2	0	2	2	3	0	0	0	0	0	1	0	0	0	0	0	0
SUM	**39**	**6**	**3**	**3**	**4**	**10**	**1**	**10**	**21**	**18**	**1**	**2**	**4**	**6**	**0**	**19**	**13**	**24**	**32**	**3**	**2**	**8**

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	0	0	4	0	3	0	3	0	0	0	0	0	0	4	0	0	0	0	2	0	0	0
	0	2	1	2	1	0	0	0	0	0	0	0	3	2	0	0	0	0	0	3	0	2
	4	1	2	0	0	0	0	0	0	0	3	0	2	2	0	0	1	1	0	2	2	0
	0	1	2	1	1	0	0	0	0	0	0	1	1	1	0	0	3	1	0	0	0	0
	1	0	2	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	2	3	0	0
	4	0	0	0	3	0	0	0	0	2	1	2	2	1	0	0	1	1	1	0	0	1
	0	4	0	0	3	0	0	0	1	0	2	0	1	1	0	0	2	0	0	1	0	0
	4	0	2	0	0	0	1	0	1	0	1	2	0	0	1	1	2	0	2	1	0	0
	0	2	0	0	0	0	0	0	4	2	1	2	1	1	0	0	0	2	0	1	0	3
Expert 6	0	1	1	0	0	3	2	0	1	1	0	2	1	0	0	1	1	0	0	1	0	0
	2	0	1	0	0	0	3	0	2	0	0	3	0	0	0	0	0	2	2	0	0	0
	0	3	0	0	0	1	0	0	1	2	0	0	0	0	0	0	1	0	0	1	0	2
	2	0	1	0	0	0	0	1	0	4	3	0	0	0	0	0	0	2	1	1	2	0
	0	0	0	0	4	2	2	0	3	1	1	1	0	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	1	0	2	2	1	1	0	0	0	0	0	2	1	2	0	0
	0	0	3	3	0	0	0	0	3	3	0	0	1	2	0	0	0	1	0	1	2	0
	1	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	2
	3	3	0	0	0	0	0	0	2	0	1	0	3	0	0	0	0	0	0	0	0	0
	1	0	0	0	1	0	1	0	2	2	0	1	1	3	0	2	1	0	0	0	0	0
	2	1	1	0	0	0	0	0	0	1	1	2	1	1	0	0	0	1	1	1	3	0
	1	1	1	0	3	0	0	0	1	3	2	1	0	3	0	0	2	0	0	0	0	0
SUM	**28**	**23**	**21**	**6**	**19**	**6**	**13**	**1**	**23**	**24**	**18**	**19**	**18**	**22**	**1**	**4**	**14**	**13**	**13**	**18**	**9**	**10**

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Expert 7	0	1	0	2	0	0	0	0	3	2	0	0	2	2	0	2	0	0	3	0	0	1
	2	0	1	3	0	0	0	0	2	2	0	0	3	2	0	1	0	1	2	0	0	0
	0	2	2	1	0	0	0	2	1	1	2	0	1	0	0	0	0	1	3	1	0	0
	2	0	0	4	0	0	2	0	1	2	0	0	0	0	0	0	0	0	1	0	0	0
	3	2	0	1	0	0	3	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1
	3	2	0	0	0	0	2	0	2	0	0	0	0	0	0	1	0	0	2	0	0	1
	3	3	0	2	2	0	2	0	2	3	0	0	1	0	0	0	0	0	2	0	0	1
	2	2	0	2	0	0	0	0	0	0	0	2	2	2	0	0	1	2	4	0	0	2
	3	2	0	3	0	0	0	0	3	2	0	1	0	2	0	2	0	0	2	0	0	2
	0	0	0	2	0	1	0	0	2	1	0	2	1	0	0	3	0	1	2	0	1	1
	0	0	0	3	0	0	3	0	0	1	0	0	2	1	0	0	0	0	2	0	0	2
	1	2	2	2	0	0	1	0	1	2	0	0	2	0	0	0	2	1	2	1	1	3
	2	3	0	0	0	0	0	3	0	2	0	0	1	0	0	1	0	3	3	0	1	0
	0	0	0	1	0	0	3	2	1	0	0	0	1	0	0	0	0	1	1	0	0	1
	2	0	0	3	0	0	0	0	1	0	0	0	2	0	0	0	2	0	2	3	0	2
	0	3	2	2	0	0	0	0	3	3	0	0	2	2	0	1	0	2	2	0	0	0
	0	3	0	2	0	1	1	0	0	2	0	0	1	2	0	2	0	0	3	0	2	0
	1	1	0	2	0	0	2	1	2	0	2	0	1	0	0	2	0	0	3	0	0	0
	2	0	0	0	2	0	2	2	0	1	1	0	2	0	0	0	1	1	2	0	0	0
	3	2	0	2	0	0	1	0	2	3	2	0	2	0	0	1	0	2	2	1	2	2
	2	0	0	2	0	0	1	2	2	4	0	1	0	0	0	0	0	0	2	0	2	4
SUM	**31**	**28**	**7**	**39**	**4**	**2**	**23**	**12**	**28**	**32**	**8**	**6**	**27**	**13**	**0**	**16**	**6**	**15**	**45**	**6**	**9**	**23**

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Expert 8	3	0	0	4	0	0	0	3	2	3	0	1	0	2	0	3	0	0	3	0	0	1
	2	0	3	3	0	0	3	2	2	3	0	0	3	1	1	0	0	3	3	0	1	0
	0	2	0	3	2	0	1	2	0	0	0	0	0	2	0	0	0	2	2	2	0	3
	3	0	0	3	0	0	2	0	0	2	0	0	0	0	1	2	0	2	3	3	3	2
	2	0	0	4	3	0	3	1	0	0	3	0	2	0	0	1	0	4	0	3	0	4
	3	0	3	4	0	3	3	0	0	0	0	0	0	2	0	0	0	3	4	0	3	3
	2	1	0	4	3	0	0	3	2	0	0	0	0	0	0	0	0	4	4	3	2	0
	0	2	1	2	0	0	0	4	0	1	0	0	0	0	0	0	0	4	4	0	0	3
	0	0	3	4	2	0	4	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3
	0	0	0	4	0	3	0	3	0	0	0	0	0	0	0	2	0	3	4	0	0	0
	0	0	4	4	4	2	2	4	0	3	0	0	2	2	0	0	0	1	2	0	0	2
	0	0	0	4	4	0	3	0	0	0	0	0	1	2	0	0	0	3	2	0	2	1
	4	0	0	4	4	0	0	2	0	0	0	0	1	0	2	0	0	1	2	0	0	0
	0	0	3	3	0	3	2	3	0	0	0	0	1	3	0	3	0	2	2	0	0	3
	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4	0	3	3
	1	1	3	0	0	0	4	3	0	3	1	0	0	0	0	0	0	4	4	2	3	3
	0	0	2	2	0	2	1	3	2	0	1	0	0	0	0	3	2	4	4	4	2	0
	0	0	2	0	0	0	2	0	0	0	0	0	0	0	3	0	0	4	4	3	0	0
	0	0	0	0	0	2	3	4	0	0	0	0	0	0	0	0	0	4	4	2	2	0
	2	0	0	4	3	0	3	3	0	0	0	0	0	0	0	0	0	4	1	3	3	2
	0	0	0	1	3	4	0	4	0	0	0	0	0	0	0	0	0	4	4	2	3	4
SUM	**22**	**6**	**24**	**58**	**28**	**19**	**36**	**47**	**11**	**15**	**5**	**1**	**10**	**16**	**7**	**14**	**2**	**56**	**60**	**27**	**27**	**37**

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	2	0	1	1	0	0	0	1	3	0	0	0	0	2	0	2	1	2	0	0	0	2
	0	0	3	0	0	0	0	2	3	2	0	0	2	0	0	0	3	3	0	1	1	0
	2	2	0	0	0	0	0	2	3	3	2	0	0	0	0	3	2	3	0	0	0	0
	2	0	0	2	0	2	2	2	0	3	2	0	0	0	0	1	0	2	0	0	3	0
	3	1	1	0	0	3	1	0	2	3	0	1	0	1	0	0	1	0	0	0	0	2
	3	0	2	0	0	3	0	3	1	3	2	0	1	1	0	3	1	3	0	0	0	0
	2	0	1	1	0	0	3	3	3	2	0	2	0	0	0	1	0	3	0	0	0	1
	0	0	0	1	0	0	2	3	2	3	1	1	2	0	0	1	1	3	0	0	0	1
	3	0	0	0	0	0	1	3	2	2	1	0	2	1	0	3	1	2	0	0	1	0
	1	0	1	0	0	2	0	1	3	0	2	0	0	0	0	1	3	0	0	0	1	0
Expert 9	3	0	0	0	0	1	3	3	4	3	0	0	1	1	0	3	1	0	0	0	0	0
	3	0	1	0	0	2	1	1	0	2	0	0	2	2	0	2	0	3	0	2	0	0
	1	0	0	3	0	2	2	1	0	0	0	0	0	0	0	2	1	3	0	2	0	0
	0	0	2	0	0	0	0	2	0	1	0	1	0	0	0	3	0	2	0	0	0	0
	2	0	0	0	0	0	0	3	0	2	1	0	0	0	1	2	1	1	0	1	0	0
	0	0	1	0	0	0	3	1	2	1	1	0	1	0	1	2	1	3	0	0	0	0
	2	0	0	0	0	3	1	3	4	3	0	1	1	1	0	2	0	2	0	0	0	0
	0	0	0	0	0	2	0	3	1	0	0	0	0	0	0	2	1	0	0	0	0	1
	1	0	1	1	0	0	1	1	2	0	1	1	2	0	0	0	1	2	0	0	0	0
	1	0	0	0	0	1	0	2	2	3	1	1	0	0	0	2	0	1	0	0	1	0
	2	0	1	0	0	1	0	3	2	3	1	2	0	0	1	2	1	1	0	1	0	0
SUM	**33**	**3**	**15**	**9**	**0**	**22**	**20**	**43**	**39**	**39**	**15**	**10**	**14**	**9**	**3**	**37**	**20**	**39**	**0**	**7**	**7**	**7**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
	3	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	1	2	0	1	0	0	0	1	1	1	0	1	0	1	1	0	1	0
	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1
	0	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	1	0	0	0
	2	0	1	1	1	2	1	1	1	0	0	0	0	1	0	0	0	1	0	0	0	1
	1	1	0	0	0	1	1	1	0	1	0	0	1	0	0	0	0	1	1	0	0	0
	1	0	0	0	1	0	1	0	1	0	1	0	0	0	0	1	1	0	1	1	0	0
Expert 10	1	1	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	1	0	1
	1	0	0	0	1	0	1	1	0	1	0	0	1	0	0	1	0	0	1	1	0	1
	0	0	0	0	0	1	1	0	0	1	0	1	0	0	1	0	0	1	2	1	0	1
	0	0	0	0	2	0	1	0	0	1	1	1	1	0	0	1	1	0	1	0	0	0
	1	1	0	0	0	0	0	0	0	1	0	1	1	0	1	1	1	2	0	0	1	0
	0	0	0	1	0	0	0	0	0	2	1	1	1	1	0	2	0	0	0	2	0	1
	1	0	0	1	0	0	0	1	1	1	1	1	1	0	1	2	0	0	1	0	0	1
	1	0	0	1	0	0	0	0	1	1	0	0	2	0	0	0	1	0	1	0	0	0
	1	2	1	1	1	0	0	0	0	2	0	1	1	1	1	1	0	1	1	0	0	0
	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	0	0	0	0
	1	0	0	0	0	0	0	0	2	1	1	1	1	0	0	1	1	0	1	0	0	0
	2	1	1	0	0	0	0	0	1	1	1	1	0	1	2	1	0	1	0	0	0	0
SUM	**18**	**6**	**6**	**7**	**9**	**7**	**8**	**5**	**9**	**18**	**8**	**10**	**11**	**6**	**8**	**15**	**6**	**11**	**13**	**6**	**2**	**7**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
	3	0	3	0	0	2	0	0	1	2	1	3	3	0	2	0	2	0	2	0	0	0
	2	1	0	0	2	0	0	0	1	0	0	0	0	0	1	0	1	1	1	2	0	0
	2	0	0	1	2	0	0	1	2	1	0	0	0	0	0	2	2	0	0	0	2	0
	2	2	0	0	1	2	0	2	0	2	2	0	2	0	2	0	0	2	0	0	0	0
	0	1	0	0	0	2	0	2	2	2	2	0	0	0	1	2	2	0	2	0	1	1
	2	0	0	0	0	1	0	1	2	1	0	0	1	0	2	2	1	2	2	0	1	0
	2	0	0	0	0	1	2	2	0	1	0	2	0	0	2	1	0	1	0	0	0	0
	2	1	0	0	0	0	0	2	0	0	0	0	1	0	2	3	0	1	0	0	0	0
	2	0	0	0	0	0	0	2	0	2	2	1	1	0	2	2	0	1	0	0	0	0
Expert 11	0	1	0	0	0	0	0	2	2	2	0	0	1	0	2	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	2	2	2	0	0	0	0	1	2	1	0	0	0	0	0
	2	1	0	0	0	0	0	3	1	2	0	0	0	0	2	3	1	0	0	0	0	0
	2	2	0	0	2	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1
	0	0	0	0	2	2	0	1	0	2	0	0	0	0	0	1	0	0	0	0	0	0
	1	2	0	0	2	2	0	2	1	0	1	2	0	0	2	2	1	0	0	0	0	0
	0	0	0	0	0	2	0	0	2	0	1	0	1	0	2	2	0	0	0	0	0	0
	2	0	0	0	0	0	0	2	0	1	0	0	0	0	0	2	0	0	2	0	0	2
	1	0	0	0	0	2	0	2	0	0	1	0	0	0	2	0	0	0	0	0	0	0
	2	0	0	0	1	2	0	2	2	0	0	0	0	0	2	0	0	1	0	0	0	0
	1	0	0	0	1	2	0	2	0	2	1	1	0	1	2	2	0	0	2	0	0	0
	2	0	0	0	0	2	0	0	0	0	2	0	0	0	2	2	1	0	0	0	2	0
SUM	**32**	**11**	**3**	**1**	**13**	**24**	**2**	**30**	**18**	**22**	**13**	**9**	**10**	**1**	**31**	**30**	**12**	**9**	**11**	**2**	**6**	**4**

BIPOLAR NEGATIVE SCORING

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 1	3	0	1	1	-1	0	0	1	2	2	-3	2	3	0	-3	2	0	0	1	-2	-2	3
	4	-1	0	1	-2	-1	0	-4	3	4	-2	0	2	-1	-3	1	0	0	1	-1	2	2
	3	0	2	0	0	-3	-3	1	2	4	3	0	0	1	-1	1	-1	-1	0	0	-1	-4
	4	-1	-1	1	-3	-3	1	0	-4	4	0	1	-2	0	0	-4	0	-2	-4	-2	2	-4
	4	-1	0	-4	0	-2	2	0	3	3	0	0	0	2	0	-2	2	-4	-1	-1	-1	1
	4	-3	0	-1	0	-1	3	0	3	4	-2	0	0	0	-2	-2	-1	-2	-1	-2	1	0
	4	1	-2	1	0	-4	3	-1	3	4	0	1	2	0	-1	-4	-2	1	0	-1	-1	2
	4	0	0	-1	-1	-4	1	1	3	4	0	0	2	1	-2	-1	3	0	0	-1	-3	3
	4	1	0	0	-2	-1	0	0	3	4	-1	0	0	1	-4	2	-1	0	0	-3	-1	3
	4	-1	-2	0	-1	0	0	0	4	4	-2	2	0	-3	0	3	0	0	0	-2	1	2
	4	-2	0	0	0	0	2	0	4	4	-4	1	0	0	-2	1	0	-1	0	-4	1	0
	4	0	1	-1	-4	-2	1	0	3	4	-2	-3	3	2	-1	0	0	-1	-2	0	1	2
	4	0	-2	1	-1	-1	0	1	-2	4	-1	-4	-3	-2	-3	0	0	1	-1	-1	1	-1
	2	-3	0	-3	-1	-1	0	1	-1	3	0	0	-4	1	-4	-1	-4	0	-4	-4	0	0
	4	-1	-4	1	0	-1	0	-2	0	4	-3	-2	2	-3	-1	0	0	0	1	0	2	2
	4	0	0	0	0	-2	2	-4	3	4	2	-4	2	2	0	0	0	1	1	-3	2	-3
	4	1	-3	1	-4	1	2	0	3	4	-4	0	2	2	0	0	-4	-2	1	-1	2	1
	4	-1	-4	0	-3	-1	0	1	2	-2	0	0	0	-4	0	1	0	-4	0	-2	-4	1
	4	-4	-1	1	-2	-2	1	0	1	4	0	-1	1	-1	-2	0	2	1	0	-1	-4	0
	4	-1	0	1	-1	0	-4	-1	2	4	0	0	1	-1	-3	1	-4	1	0	-2	1	1
	4	-1	0	0	-2	-2	2	2	3	4	0	1	-4	0	0	0	0	-3	-4	0	2	1
SUM	**80**	**-17**	**-15**	**-1**	**-28**	**-30**	**13**	**-4**	**40**	**74**	**-19**	**-6**	**7**	**-3**	**-32**	**-2**	**-10**	**-15**	**-12**	**-33**	**1**	**12**

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Expert 2	0	1	0	-1	1	0	-2	-3	2	0	-1	0	0	0	1	0	0	0	0	0	0	0
	2	2	0	1	1	-1	-2	-2	2	0	0	0	0	1	0	0	0	0	0	1	0	3
	2	0	0	1	0	-2	-1	-2	0	0	-1	0	0	0	0	0	0	0	1	1	0	2
	0	0	1	0	0	2	1	-2	0	0	0	-1	2	0	2	-1	-2	-1	-1	-1	2	0
	2	2	2	0	1	-2	0	0	0	0	0	0	0	0	2	-2	1	-1	0	2	1	1
	1	1	0	-2	1	-2	-1	-2	2	0	-1	2	-1	0	0	-2	-1	2	0	-2	1	2
	1	2	-1	-1	1	-2	-1	-3	2	1	1	-1	1	0	0	-1	0	-2	1	-1	0	0
	2	1	-2	-1	1	-2	-1	-2	0	0	-1	-1	1	1	2	-1	0	1	0	-1	0	0
	0	1	0	1	0	-1	-1	-2	0	-1	-1	-1	0	0	0	-2	0	1	0	0	0	-2
	1	0	-1	1	0	-1	-2	-2	2	-1	0	1	0	0	0	-1	-1	0	0	0	0	1
	2	0	-1	0	0	-1	-1	-2	0	-2	0	2	0	0	0	-1	0	0	2	0	0	0
	0	0	0	0	2	-2	-1	2	0	0	-2	-2	1	0	0	0	1	1	0	0	0	0
	1	2	-1	-2	1	-2	-2	1	0	2	2	0	0	0	1	-2	0	0	0	0	3	1
	0	0	-1	-2	1	0	0	-1	3	1	0	-1	-1	-2	-1	-1	-1	0	0	0	0	0
	0	-1	-2	0	0	-1	-1	-3	2	0	1	0	1	0	-2	2	1	0	1	-2	1	1
	0	0	-2	2	0	-1	-1	-2	2	2	0	-1	0	2	-1	2	0	-1	0	1	2	0
	1	2	-2	-1	-2	-1	-2	-1	-1	-2	0	-1	0	1	1	-1	-2	-1	0	1	2	1
	1	2	-1	1	-2	-1	-2	-2	2	0	1	0	2	0	1	0	1	1	1	-1	1	0
	1	0	-1	0	-2	0	-1	2	2	1	0	-1	0	1	1	2	1	1	0	0	0	0
	2	2	-1	1	0	-1	-2	-2	2	-2	0	-1	2	1	0	1	0	1	2	-1	0	1
	0	-1	-1	-1	2	-1	-2	-2	0	0	-1	-1	2	2	0	-2	0	0	0	-2	1	1
SUM	**19**	**16**	**-14**	**-3**	**6**	**-22**	**-25**	**-30**	**22**	**-1**	**-3**	**-7**	**10**	**7**	**7**	**-10**	**-2**	**2**	**7**	**-5**	**14**	**12**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 3	4	0	0	0	0	2	-4	-4	3	-4	-2	-4	2	0	4	0	0	-3	0	-1	3	4
	3	0	0	0	2	-3	-4	2	3	-3	0	-3	0	3	3	0	-2	-2	2	0	4	1
	2	2	0	1	-1	-4	-3	1	3	2	-2	-2	3	3	3	-2	-3	-4	2	-2	2	-1
	3	-3	1	-4	-1	0	-2	-3	3	1	-1	1	3	3	3	-2	0	-1	2	-2	3	-1
	3	-2	-1	-3	-1	-3	-2	-2	3	-2	2	0	3	0	3	-4	0	-3	3	0	3	-2
	-2	-4	0	-4	1	-3	-2	2	4	-2	-3	0	2	0	3	-4	0	0	3	-4	3	0
	2	-3	-2	-3	-3	-3	0	-3	4	3	2	0	3	3	0	-3	0	0	3	0	3	-3
	3	3	0	0	0	-3	0	-2	4	0	-2	-3	3	3	3	0	-3	0	0	0	-2	1
	2	2	-2	-2	-3	-3	-1	-2	3	-3	1	0	0	2	1	0	-3	0	3	-4	0	0
	1	-2	0	0	-3	-3	0	0	3	3	4	0	2	-2	0	-4	1	0	2	-4	3	1
	3	0	0	0	-2	-2	-3	-3	2	2	3	0	3	2	0	-3	-3	0	3	-3	4	0
	-2	2	0	0	-3	-4	-2	4	4	3	-3	-3	2	0	4	-3	1	-1	0	1	3	-3
	3	3	-3	0	0	-2	-3	3	4	-2	-1	-2	-3	-3	2	0	-2	-3	2	-2	3	0
	-4	-4	0	-2	0	0	-2	-1	4	3	2	-2	-1	2	2	-2	-3	-3	2	-1	0	-3
	-2	2	-3	-2	0	0	-1	-1	4	3	2	2	2	2	3	0	0	2	3	-3	3	0
	-3	1	-3	-2	-2	0	-2	-3	4	3	1	-2	3	3	3	0	-2	0	2	0	4	-4
	-2	3	-4	0	-3	0	-3	-1	4	1	-2	-3	0	2	3	-2	-3	-3	3	0	4	0
	2	2	-3	-2	-4	0	1	0	4	4	2	0	2	2	3	0	0	-3	2	-3	3	-3
	3	0	-3	-3	-3	0	-3	0	4	3	2	-3	-3	3	3	0	0	0	0	0	2	-2
	3	0	0	0	-2	2	-3	0	4	3	2	0	2	2	-3	0	-3	0	3	0	0	-1
	1	2	-3	0	0	0	0	-3	2	-1	2	0	-2	3	0	0	0	-4	-2	-3	3	0
SUM	**23**	**4**	**-26**	**-26**	**-28**	**-29**	**-39**	**-16**	**73**	**17**	**9**	**-24**	**26**	**33**	**43**	**-29**	**-25**	**-28**	**38**	**-31**	**51**	**-16**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 4	2	2	-3	4	-3	-2	2	1	2	-2	0	3	0	3	-3	2	-2	-2	3	0	-2	2
	-1	-4	-2	3	-4	0	2	1	2	3	0	0	3	1	0	1	-3	3	2	-4	0	1
	-3	2	-2	0	-2	-3	4	2	1	2	2	1	2	1	-2	-4	1	0	4	-1	-3	-1
	2	-2	-3	4	-3	-3	4	-1	1	3	-2	-1	-3	1	-1	-1	-2	0	2	0	2	2
	0	1	-4	3	-1	2	3	-1	1	2	1	-1	1	-2	-2	-2	0	3	-3	-2	-4	1
	4	-3	-2	2	-1	0	4	-2	2	-3	-2	-2	-4	1	-1	-1	1	-3	1	-4	0	-1
	0	2	-3	4	1	-1	4	1	3	2	-1	2	-1	-2	-2	-1	-2	2	4	-1	-3	2
	-2	-2	-2	1	-3	-2	4	3	3	3	-1	1	2	-2	-4	-3	0	3	4	-3	-3	3
	0	0	-2	4	-2	-3	3	1	4	1	-2	1	-1	2	-1	-2	-1	-2	2	-2	-3	3
	-1	-2	-2	4	-4	1	3	-1	3	0	-3	0	0	0	-3	3	1	2	3	0	2	0
	-2	-4	-1	2	-1	1	3	1	2	3	-3	-1	0	-1	-3	-1	-1	-1	1	-2	0	1
	-2	-1	0	3	-2	-2	3	-2	0	0	-2	-2	0	0	-4	-2	-3	1	2	2	-1	1
	-1	3	-2	4	-1	-2	1	0	2	-1	-2	-2	-1	-1	-2	2	-1	2	4	-2	-1	-4
	-2	-2	-2	3	-4	-2	2	3	-1	-4	-3	-4	1	-1	-4	0	1	-1	3	-3	-1	2
	2	-4	1	3	2	-1	0	-1	-2	-3	-4	-3	3	-2	-2	-3	1	1	3	1	2	2
	-1	2	2	2	-2	-1	4	2	3	1	0	0	2	-2	-1	2	1	3	2	-4	1	-3
	-2	0	-2	4	0	3	3	1	3	1	0	2	4	0	-1	1	-3	1	4	-2	2	-1
	1	-3	-2	4	-3	-3	4	2	2	2	-1	2	-1	2	-1	2	-1	0	1	-2	-1	-1
	-3	-3	2	3	-2	2	4	2	-2	1	2	0	3	-4	-3	1	1	3	1	0	-2	0
	2	-2	-3	3	-2	1	2	1	4	2	1	-4	2	-3	-4	1	0	1	-1	0	2	2
	-2	-1	-4	2	2	0	3	4	3	1	-4	1	-3	-1	-4	1	-2	0	-2	-3	2	-1
SUM	**-9**	**-21**	**-36**	**62**	**-35**	**-15**	**62**	**17**	**36**	**14**	**-24**	**-7**	**9**	**-10**	**-48**	**-4**	**-14**	**16**	**40**	**-32**	**-11**	**10**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 5	3	0	0	0	-1	0	0	0	2	0	-1	0	0	3	-2	0	0	0	3	1	0	1
	3	0	1	-1	0	0	-1	0	2	2	-2	0	3	-1	-3	0	0	2	2	-1	0	0
	2	0	0	0	0	0	-1	2	1	3	1	0	-1	-1	-3	0	1	1	2	0	0	-1
	2	1	-2	2	0	-1	0	0	0	0	-1	-2	0	-2	-2	-1	1	1	0	0	-1	-1
	3	0	0	-1	-2	0	-1	0	2	1	-2	-2	0	-2	-2	0	0	0	2	-1	0	0
	4	0	0	-1	-1	0	0	0	3	0	0	-2	0	0	-2	2	0	2	2	-1	1	-1
	3	2	0	0	2	0	0	1	2	2	-2	0	-2	0	-1	0	0	1	2	-2	0	0
	1	2	-2	0	-2	-2	-1	0	0	0	-3	1	0	0	-2	1	3	2	3	-3	-2	0
	3	0	0	0	0	-2	0	0	4	2	-1	-1	-3	1	-3	2	1	1	0	-1	-3	1
	2	-2	0	0	-2	3	-1	0	0	0	0	-2	0	0	-3	2	2	0	0	0	-1	-1
	2	0	-1	0	1	1	1	0	0	1	-2	-1	0	0	-3	1	0	0	0	-2	-1	2
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	2	0	0	0	0	1	-2	0	0	0	-2	-3	-2	-1	-1	2	2	3	0	-2	-1	1
	0	-3	0	-2	0	0	0	2	0	1	-2	-2	-2	0	-4	0	-2	2	0	0	0	0
	2	0	-3	0	-1	0	0	0	1	1	0	1	0	-1	-2	1	1	0	2	2	0	0
	0	1	2	0	0	0	0	-1	0	0	-1	-3	0	0	-2	2	1	2	2	0	-2	0
	0	0	-3	1	-3	1	0	1	0	1	-3	-2	0	0	-3	2	0	2	2	0	-1	0
	1	0	-2	0	-2	1	0	1	0	0	-1	0	0	-3	-1	0	1	0	3	0	-2	-2
	0	0	0	-2	1	0	0	-1	1	0	0	-1	0	0	-1	0	0	3	3	0	-2	0
	2	-1	-2	-1	-1	0	-2	1	1	1	-1	0	-1	0	-4	2	0	0	2	0	1	1
	1	0	-2	-1	-2	2	-2	2	2	3	0	0	-1	0	-3	1	0	0	0	0	0	0
SUM	**39**	**-1**	**-14**	**-6**	**-14**	**5**	**-10**	**8**	**21**	**18**	**-25**	**-21**	**-8**	**-5**	**-49**	**18**	**11**	**24**	**32**	**-10**	**-15**	**2**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 6	0	0	4	-4	3	-2	3	-3	0	0	0	0	0	4	-1	-2	0	0	2	0	0	-1
	0	2	1	2	1	-1	-2	-4	0	0	0	0	3	2	-2	-2	0	-1	-1	3	-1	2
	4	1	2	-1	-1	-3	-1	-3	0	0	3	0	2	2	-2	-1	1	1	-1	2	2	-1
	0	1	2	1	1	-3	-1	-2	0	0	0	1	1	1	-2	-3	3	1	-1	0	-1	-1
	1	0	2	-2	-1	-2	-1	-2	0	0	1	1	1	1	-3	-2	-1	-1	2	3	-1	-1
	4	0	0	-2	3	-3	-1	-3	0	2	1	2	2	1	-2	-2	1	1	1	0	-1	1
	0	4	0	-3	3	-3	-1	-2	1	0	2	0	1	1	-3	-2	2	-1	-1	1	-1	0
	4	0	2	-2	-1	-2	1	-3	1	0	1	2	0	0	1	1	2	-1	2	1	-1	-1
	0	2	0	-2	-1	-1	-1	-3	4	2	1	2	1	1	-3	-3	-2	2	0	1	-2	3
	0	1	1	-2	-1	3	2	-2	1	1	0	2	1	0	-4	1	1	0	0	1	-1	-1
	2	0	1	-2	-1	-1	3	-3	2	0	0	3	0	0	-3	-2	-1	2	2	0	-1	-1
	0	3	0	-4	-1	1	-1	-3	1	2	0	0	0	0	-1	-2	1	-1	-1	1	-1	2
	2	0	1	-2	-1	-1	-1	1	0	4	3	0	0	0	-3	-2	-1	2	1	1	2	-1
	0	0	0	-4	4	2	2	-2	3	1	1	1	0	0	-4	-2	-2	-1	-2	0	-1	-1
	3	1	0	-2	-1	-1	1	-2	2	2	1	1	0	0	-4	-2	-1	2	1	2	-1	-1
	0	0	3	3	-1	-1	-1	-4	3	3	0	0	1	2	-3	-2	-3	1	-1	1	2	-1
	1	3	0	-3	-1	-3	-1	-3	0	1	0	0	0	0	-3	-2	-1	-1	1	0	-1	2
	3	3	0	-2	-1	-2	-2	-3	2	0	1	0	3	0	-2	-2	-2	-1	-1	0	-2	-1
	1	0	0	-2	1	-2	1	-3	2	2	0	1	1	3	-3	2	1	-1	-1	0	-3	-1
	2	1	1	-1	-1	-2	-2	-3	0	1	1	2	1	1	-4	-1	-2	1	1	1	3	-1
	1	1	1	-2	3	-2	-1	-1	1	3	2	1	0	3	-2	-1	2	-1	-2	0	-1	-1
SUM	**28**	**23**	**21**	**-36**	**6**	**-29**	**-4**	**-53**	**23**	**24**	**18**	**19**	**18**	**22**	**-53**	**-31**	**-2**	**3**	**1**	**18**	**-11**	**-5**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 7	0	1	-2	2	-1	-3	0	-1	3	2	-2	0	2	2	-3	2	-1	-2	3	0	-1	1
	2	0	1	3	0	-3	-1	-2	2	2	0	-2	3	2	-1	1	-2	1	2	-2	0	0
	-1	2	2	1	-1	-3	0	2	1	1	2	-1	1	0	-3	-3	-1	1	3	1	-3	-2
	2	-1	-2	4	-2	-2	2	-2	1	2	-3	-1	-1	-1	-3	-1	-2	-1	1	-2	-2	-2
	3	2	-2	1	0	-2	3	0	-1	1	1	-2	1	-2	-2	-2	-1	-2	0	-1	-2	1
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	3	3	-2	2	2	-3	2	-1	2	3	-2	0	1	-1	-2	-1	-2	-2	2	-1	-2	1
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	-1	-2	-2	2	-3	1	0	0	2	1	0	2	1	-2	-2	3	0	1	2	0	1	1
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	2	-1	-2	2	-2	-2	1	2	2	4	-3	1	-1	0	-4	-1	-3	-1	2	-3	2	4
SUM	**26**	**21**	**-23**	**39**	**-27**	**-41**	**17**	**0**	**21**	**30**	**-20**	**-17**	**21**	**-1**	**-55**	**1**	**-21**	**1**	**45**	**-19**	**-12**	**14**

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Expert 8	3	-3	-4	4	-2	-2	0	3	2	3	-1	1	0	2	-2	3	-3	0	3	-1	0	1
	2	-4	3	3	-4	-2	3	2	2	3	-2	-2	3	1	1	-1	-4	3	3	-2	1	0
	-3	2	-2	3	2	0	1	2	0	0	-2	-2	0	2	-1	-2	-2	2	2	2	-1	3
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	2	-3	-2	4	3	0	3	1	-1	-2	3	-2	2	-2	-3	1	-3	4	0	3	-3	4
	3	-2	3	4	-3	3	3	0	-2	-2	-3	0	0	2	-1	-3	-4	3	4	0	3	3
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	-3	-3	2	2	-2	2	1	3	2	-3	1	-2	0	-3	-3	3	2	4	4	4	2	-2
	-2	-4	2	0	-2	-3	2	-3	-1	0	-2	-3	-3	0	3	-3	0	4	4	3	0	-4
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	-2	-4	-4	1	3	4	-3	4	0	0	-4	-4	-3	-4	-4	-3	-4	4	4	2	3	4
SUM	**-2**	**-36**	**-5**	**58**	**-8**	**-8**	**27**	**42**	**-20**	**-9**	**-40**	**-47**	**-12**	**-8**	**-34**	**-13**	**-48**	**54**	**60**	**7**	**13**	**29**

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	0	-3	3	-2	-3	-1	0	2	3	2	-2	-1	2	-3	-1	0	3	3	-2	1	1	-3
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	2	-1	-2	2	-1	2	2	2	0	3	2	-3	-1	-2	-1	1	-1	2	-2	-1	3	-2
	3	1	1	-2	-3	3	1	-1	2	3	-1	1	-1	1	-1	-1	1	-1	-1	-3	-1	2
	3	-4	2	-2	-3	3	-1	3	1	3	2	-2	1	1	0	3	1	3	-1	-2	-1	-2
	2	-1	1	1	-1	-1	3	3	3	2	-2	2	-2	0	-1	1	-2	3	-1	-2	-2	1
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	3	-3	-1	-1	-1	0	1	3	2	2	1	-1	2	1	-3	3	1	2	-2	-2	1	-2
Expert 9	1	0	1	-1	0	2	-2	1	3	0	2	-1	0	0	-2	1	3	-1	-3	-1	1	-2
	3	-1	-1	-1	-1	1	3	3	4	3	-2	-2	1	1	-2	3	1	0	-2	-2	-3	-1
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	2	-3	-1	-1	-3	3	1	3	4	3	-3	1	1	1	-2	2	-3	2	0	-2	-2	-1
	-1	-3	-2	-1	-3	2	-1	3	1	0	-1	-2	-3	-3	-1	2	1	0	-1	-2	-2	1
	1	-3	1	1	-3	0	1	1	2	-1	1	1	2	-1	-3	-1	1	2	-2	-1	-2	0
	1	-3	-3	-1	-1	1	-3	2	2	3	1	1	-2	-1	-2	2	-2	1	-2	-1	1	-1
	2	-2	1	-2	-3	1	-3	3	2	3	1	2	-3	-3	1	2	1	1	-4	1	0	-1
SUM	**31**	**-35**	**3**	**-11**	**-45**	**13**	**8**	**42**	**37**	**36**	**-6**	**-14**	**-4**	**-16**	**-30**	**35**	**10**	**37**	**-33**	**-22**	**-20**	**-16**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
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	1	-1	0	0	-1	0	1	1	1	0	-1	0	0	1	-1	-1	0	1	1	-1	-1	-1
	-1	-1	-1	0	1	2	1	-1	0	1	1	-1	-1	-1	-2	-1	0	-1	-1	-1	-1	-1
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	0	-1	-1	-1	-1	-1	-1	-1	1	1	1	0	-1	-1	-1	1	-1	1	0	1	0	-2
Expert 10	0	-2	-1	-1	0	-1	-1	-2	0	1	0	1	1	0	0	0	-1	0	0	1	1	1
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	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 11	3	0	3	-2	0	2	-3	0	1	2	1	3	3	-2	2	0	2	0	2	-1	0	0
	2	1	-2	-2	2	0	-1	0	1	0	0	0	-1	-2	1	0	1	1	1	2	0	-2
	2	0	-2	1	2	-2	-2	1	2	1	0	0	-3	0	0	2	2	0	0	-2	2	-1
	2	2	-1	-2	1	2	-2	2	0	2	2	0	2	0	2	-1	-2	2	-2	0	-1	-2
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	2	-2	0	0	-2	1	2	2	0	1	-2	2	0	0	2	1	0	1	0	-2	0	0
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UNIPOLAR SCORING

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
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	9	4	5	6	3	4	5	1	8	9	3	5	7	4	2	6	5	5	6	4	7	7
	8	5	7	5	5	2	2	6	7	9	8	5	5	6	4	6	4	4	5	5	4	1
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	9	4	5	1	5	3	7	5	8	8	5	5	5	7	5	3	7	1	4	4	4	6
	9	2	5	4	5	4	8	5	8	9	3	5	5	5	3	3	4	3	4	3	6	5
	9	6	3	6	5	1	8	4	8	9	5	6	7	5	4	1	3	6	5	4	4	7
	9	5	5	4	4	1	6	6	8	9	5	5	7	6	3	4	8	5	5	4	2	8
	9	6	5	5	3	4	5	5	8	9	4	5	5	6	1	7	4	5	5	2	4	8
	9	4	3	5	4	5	5	5	9	9	3	7	5	2	5	8	5	5	5	3	6	7
Expert 1	9	3	5	5	5	5	7	5	9	9	1	6	5	5	3	6	5	4	5	1	6	5
	9	5	6	4	1	3	6	5	8	9	3	2	8	7	4	5	5	4	3	5	6	7
	9	5	3	6	4	4	5	6	3	9	4	1	2	3	2	5	5	6	4	4	6	4
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	9	4	5	5	3	3	7	7	8	9	5	6	1	5	5	5	5	2	1	5	7	6
SUM	**185**	**88**	**90**	**104**	**77**	**75**	**118**	**101**	**145**	**179**	**86**	**99**	**112**	**102**	**73**	**103**	**95**	**90**	**93**	**72**	**106**	**117**

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	6	5	4	6	5	4	3	3	7	4	5	6	5	5	5	4	4	5	5	5	5	6
Expert 2	7	5	4	5	5	4	4	3	5	3	5	7	5	5	5	4	5	5	7	5	5	5
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	7	3	5	5	2	4	5	8	5	7	6	4	4	2	6	7	6	6	5	6	3	4
	5	3	6	2	3	4	8	6	7	6	6	3	6	2	6	7	6	8	5	2	2	3
	7	2	4	4	2	8	6	8	9	8	2	6	6	6	3	7	2	7	5	3	3	4
	4	2	3	4	2	7	4	8	6	5	4	3	2	2	4	7	6	5	4	3	3	6
	6	2	6	6	2	5	6	6	7	4	6	6	7	4	2	4	6	7	3	4	3	5
	6	2	2	4	4	6	2	7	7	8	6	6	3	4	3	7	3	6	3	4	6	4
	7	3	6	3	2	6	2	8	7	8	6	7	2	2	6	7	6	6	1	6	5	4
SUM	**136**	**70**	**108**	**94**	**60**	**118**	**113**	**147**	**142**	**141**	**99**	**91**	**101**	**89**	**75**	**140**	**115**	**142**	**72**	**83**	**85**	**89**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Expert 10	8	4	7	5	5	6	5	4	4	7	5	5	5	5	5	6	5	5	5	5	5	4
	6	5	5	5	6	7	4	5	4	6	4	5	6	4	5	5	5	6	6	4	4	4
	6	4	5	5	4	5	6	6	6	5	4	5	5	6	4	4	5	6	6	4	4	4
	4	4	4	5	6	7	6	4	5	6	6	4	4	4	3	4	5	4	4	4	4	4
	5	6	4	6	6	6	6	6	6	6	5	4	6	4	4	5	6	5	6	4	4	6
	7	5	4	6	5	4	6	4	5	5	6	4	4	5	5	5	5	7	6	4	4	4
	6	4	4	6	7	4	6	5	4	6	4	6	5	4	6	4	4	3	6	4	3	5
	6	4	4	4	4	4	5	4	4	6	5	6	6	6	6	6	5	5	3	4	3	4
	5	4	4	4	4	4	4	4	6	6	6	5	4	4	4	6	4	6	5	6	5	3
	5	3	4	4	5	4	4	3	5	6	5	6	6	5	5	5	4	5	5	6	6	6
	6	4	4	4	4	4	4	4	5	5	4	6	5	5	4	6	4	5	6	6	4	6
	6	4	6	3	3	4	4	5	6	6	6	6	5	6	5	5	6	6	6	6	5	5
	6	6	6	5	4	3	4	3	3	5	4	5	4	4	6	6	5	6	6	4	5	5
	3	2	6	4	5	3	4	6	6	4	4	4	5	4	3	6	4	6	5	4	5	6
	7	4	4	6	5	4	5	6	6	4	4	4	6	4	6	6	6	4	6	7	4	6
	5	4	6	6	6	4	4	4	5	6	5	4	6	4	3	6	6	6	7	4	5	6
	6	6	5	6	5	5	6	5	5	6	5	6	6	6	6	6	5	5	5	4	6	6
	6	6	4	6	6	5	6	6	5	7	6	6	6	4	4	7	5	4	5	4	4	4
	5	4	4	4	6	5	6	5	4	6	6	6	7	4	6	7	6	6	6	4	3	4
	6	7	5	4	6	6	4	4	6	7	6	6	7	6	4	6	4	6	6	4	4	4
	6	4	4	4	4	4	3	4	7	6	6	6	5	6	7	6	6	4	5	4	4	5
SUM	**120**	**94**	**99**	**102**	**106**	**98**	**102**	**97**	**107**	**121**	**106**	**109**	**113**	**100**	**101**	**117**	**105**	**110**	**115**	**96**	**91**	**101**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
	8	5	8	3	5	7	2	5	6	7	6	8	8	3	7	5	7	5	7	4	5	5
	7	6	3	3	7	5	4	5	6	5	5	5	4	3	6	5	6	6	6	7	5	3
	7	5	3	6	7	3	3	6	7	6	5	5	2	5	5	7	7	5	5	3	7	4
	7	7	4	3	6	7	3	7	5	7	7	5	7	5	7	4	3	7	3	5	4	3
	5	6	5	5	5	7	3	7	7	7	7	5	4	5	6	7	7	3	7	3	6	6
	7	5	5	3	3	6	4	6	7	6	5	3	6	5	7	7	6	7	7	5	6	3
	7	3	5	5	3	6	7	7	5	6	3	7	5	5	7	6	5	6	5	3	5	5
	7	6	3	3	5	4	4	7	5	5	5	3	6	5	7	8	4	6	3	4	5	4
	7	4	5	3	4	5	4	7	3	7	7	6	6	4	7	7	5	6	5	5	3	3
Expert 11	5	6	5	4	3	5	3	7	7	7	2	3	6	2	7	3	5	3	4	5	3	3
	7	5	4	4	4	4	3	7	7	7	5	3	5	5	6	7	6	5	3	3	5	5
	7	6	5	2	3	5	4	8	6	7	4	4	4	5	7	8	6	5	5	3	3	3
	7	7	3	4	7	7	3	5	3	5	4	4	3	3	5	7	3	5	3	4	3	6
	5	2	5	3	7	7	3	6	5	7	4	5	5	4	3	6	3	5	4	3	5	5
	6	7	3	3	7	7	4	7	6	5	6	7	5	3	7	7	6	3	5	3	5	5
	5	3	4	4	5	7	3	3	7	4	6	3	6	3	7	7	4	5	4	3	3	5
	7	4	3	3	5	5	3	7	5	6	3	4	5	5	5	7	3	5	7	3	5	7
	6	3	4	4	5	7	5	7	3	5	6	5	3	3	7	3	4	3	5	4	3	3
	7	5	5	3	6	7	4	7	7	4	5	4	5	5	7	3	3	6	4	5	4	4
	6	4	4	2	6	7	3	7	5	7	6	6	3	6	7	7	3	3	7	3	3	3
	7	4	5	4	3	7	3	3	5	3	7	3	3	3	7	7	6	4	3	3	7	4
SUM	**137**	**103**	**91**	**74**	**106**	**125**	**75**	**131**	**117**	**123**	**108**	**98**	**101**	**87**	**134**	**128**	**102**	**103**	**102**	**81**	**95**	**89**

Appendix F Paired Comparison Reliability Analysis

(EXCLUDING EXPERTS 8 AND 11)

Scale: ALL VARIABLES

Case Processing Summary

		N	%
Cases	Valid	231	100.0
	Excluded[a]	0	.0
	Total	231	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.705	.717	9

Item Statistics

	Mean	Std. Deviation	N
VAR00001	.2078	2.11004	231
VAR00002	-.0260	1.20117	231
VAR00003	-.0563	2.34453	231
VAR00004	-.0216	2.26014	231
VAR00005	.1169	1.43230	231
VAR00006	.1342	1.76295	231
VAR00007	-.0823	1.88983	231
VAR00009	.2641	1.92115	231
VAR00010	-.1169	1.01691	231

Inter-Item Correlation Matrix

	VAR00001	VAR00002	VAR00003	VAR00004	VAR00005	VAR00006	VAR00007	VAR00009	VAR00010
VAR00001	1.000	.206	.301	.346	.449	.302	.521	.460	.287
VAR00002	.206	1.000	.436	-.096	.070	.324	.242	-.208	.126
VAR00003	.301	.436	1.000	.010	.067	.162	.179	-.044	.052
VAR00004	.346	-.096	.010	1.000	.323	-.080	.590	.271	.171
VAR00005	.449	.070	.067	.323	1.000	.188	.524	.475	.305
VAR00006	.302	.324	.162	-.080	.188	1.000	.226	-.073	.123
VAR00007	.521	.242	.179	.590	.524	.226	1.000	.160	.309
VAR00009	.460	-.208	-.044	.271	.475	-.073	.160	1.000	.209
VAR00010	.287	.126	.052	.171	.305	.123	.309	.209	1.000

Inter-Item Covariance Matrix

	VAR00001	VAR00002	VAR00003	VAR00004	VAR00005	VAR00006	VAR00007	VAR00009	VAR00010
VAR00001	4.452	.523	1.490	1.648	1.358	1.124	2.078	1.867	.616
VAR00002	.523	1.443	1.229	-.261	.120	.686	.550	-.480	.153
VAR00003	1.490	1.229	5.497	.055	.224	.668	.791	-.198	.124
VAR00004	1.648	-.261	.055	5.108	1.046	-.319	2.520	1.175	.393
VAR00005	1.358	.120	.224	1.046	2.051	.476	1.418	1.308	.444
VAR00006	1.124	.686	.668	-.319	.476	3.108	.755	-.249	.220
VAR00007	2.078	.550	.791	2.520	1.418	.755	3.571	.583	.595
VAR00009	1.867	-.480	-.198	1.175	1.308	-.249	.583	3.691	.409
VAR00010	.616	.153	.124	.393	.444	.220	.595	.409	1.034

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
VAR00001	.2121	54.377	.688	.525	.607
VAR00002	.4459	73.752	.244	.345	.701
VAR00003	.4762	65.972	.230	.249	.719
VAR00004	.4416	62.613	.350	.450	.689
VAR00005	.3030	65.395	.552	.453	.655
VAR00006	.2857	70.405	.227	.239	.707
VAR00007	.5022	58.086	.645	.607	.624
VAR00009	.1558	67.715	.279	.462	.700
VAR00010	.5368	73.293	.339	.147	.692

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
.4199	80.236	8.95745	9

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single	.210[b]	.168	.259	3.390	230	1840	.000
Average	.705	.644	.759	3.390	230	1840	.000

Two-way random effects model where both people effects and measures effects are random.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denomir

b. The estimator is the same, whether the interaction effect is present or not.

(ALL EXPERTS INCLUDED)

Scale: ALL VARIABLES

Case Processing Summary

		N	%
Cases	Valid	231	100.0
	Excluded[a]	0	.0
	Total	231	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.662	.684	11

Item Statistics

	Mean	Std. Deviation	N
VAR00001	.2078	2.11004	231
VAR00002	-.0260	1.20117	231
VAR00003	-.0563	2.34453	231
VAR00004	-.0216	2.26014	231
VAR00005	.1169	1.43230	231
VAR00006	.1342	1.76295	231
VAR00007	-.0823	1.88983	231
VAR00008	.1255	2.63204	231
VAR00009	.2641	1.92115	231
VAR00010	-.1169	1.01691	231
VAR00011	.3377	1.50890	231

Inter-Item Correlation Matrix

	VAR00001	VAR00002	VAR00003	VAR00004	VAR00005	VAR00006	VAR00007	VAR00008	VAR00009	VAR00010	VAR00011
VAR00001	1.000	.206	.301	.346	.449	.302	.521	.015	.460	.287	.192
VAR00002	.206	1.000	.436	-.096	.070	.324	.242	-.073	-.208	.126	.014
VAR00003	.301	.436	1.000	.010	.067	.162	.179	-.114	-.044	.052	.219
VAR00004	.346	-.096	.010	1.000	.323	-.080	.590	.459	.271	.171	-.208
VAR00005	.449	.070	.067	.323	1.000	.188	.524	.284	.475	.305	.211
VAR00006	.302	.324	.162	-.080	.188	1.000	.226	-.230	-.073	.123	-.151
VAR00007	.521	.242	.179	.590	.524	.226	1.000	.315	.160	.309	-.120
VAR00008	.015	-.073	-.114	.459	.284	-.230	.315	1.000	.067	-.108	-.195
VAR00009	.460	-.208	-.044	.271	.475	-.073	.160	.067	1.000	.209	.325
VAR00010	.287	.126	.052	.171	.305	.123	.309	-.108	.209	1.000	.236
VAR00011	.192	.014	.219	-.208	.211	-.151	-.120	-.195	.325	.236	1.000

Inter-Item Covariance Matrix

	VAR00001	VAR00002	VAR00003	VAR00004	VAR00005	VAR00006	VAR00007	VAR00008	VAR00009	VAR00010	VAR00011
VAR00001	4.452	.523	1.490	1.648	1.358	1.124	2.078	.082	1.867	.616	.612
VAR00002	.523	1.443	1.229	-.261	.120	.686	.550	-.232	-.480	.153	.026
VAR00003	1.490	1.229	5.497	.055	.224	.668	.791	-.706	-.198	.124	.776
VAR00004	1.648	-.261	.055	5.108	1.046	-.319	2.520	2.733	1.175	.393	-.710
VAR00005	1.358	.120	.224	1.046	2.051	.476	1.418	1.072	1.308	.444	.456
VAR00006	1.124	.686	.668	-.319	.476	3.108	.755	-1.069	-.249	.220	-.402
VAR00007	2.078	.550	.791	2.520	1.418	.755	3.571	1.567	.583	.595	-.342
VAR00008	.082	-.232	-.706	2.733	1.072	-1.069	1.567	6.928	.336	-.290	-.773
VAR00009	1.867	-.480	-.198	1.175	1.308	-.249	.583	.336	3.691	.409	.941
VAR00010	.616	.153	.124	.393	.444	.220	.595	-.290	.409	1.034	.361
VAR00011	.612	.026	.776	-.710	.456	-.402	-.342	-.773	.941	.361	2.277

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
VAR00001	.6753	71.072	.641	.539	.569
VAR00002	.9091	92.248	.201	.348	.657
VAR00003	.9394	83.918	.207	.306	.665
VAR00004	.9048	76.652	.418	.544	.618
VAR00005	.7662	80.423	.617	.523	.598
VAR00006	.7489	91.432	.112	.354	.673
VAR00007	.9654	73.721	.648	.621	.575
VAR00008	.7576	85.950	.112	.390	.694
VAR00009	.6190	83.246	.325	.485	.638
VAR00010	1.0000	91.235	.312	.242	.647
VAR00011	.5455	94.153	.065	.394	.676

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
.8831	98.321	9.91570	11

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single	.151[b]	.117	.192	2.958	230	2300	.000
Average	.662	.593	.723	2.958	230	2300	.000

Two-way random effects model where both people effects and measures effects are random.

a. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the (

b. The estimator is the same, whether the interaction effect is present or not.