ANGLIA RUSKIN UNIVERSITY

FACULTY OF SCIENCE AND TECHNOLOGY

BUILDING SUSTAINABILITY ASSESSMENT SCHEMES: THE ROLE OF CRITERIA IN TRANSLATING AIMS INTO EFFECT

COLIN HOBART

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ABSTRACT

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BUILDING SUSTAINABILITY ASSESSMENT SCHEMES: THE ROLE OF CRITERIA IN TRANSLATING AIMS INTO EFFECT

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Building sustainability assessment schemes (BSAS) such as BREEAM and LEED are used to generate a comprehensive design stage assessment of the sustainability of a building. Their use as a means of setting sustainability standards for new and refurbished buildings has achieved international political and commercial acceptance. However, BSAS are widely criticised within academic literature for lacking either a sound theoretical basis or empirical evidence of success. To be effective in their assumed role, BSAS must reliably differentiate buildings in terms of sustainability. In practice the broad range of indicators employed, the range of building types assessed and the lack of any feedback loop make quantitative assessment of efficacy challenging. Consequently, after over 20 years of use it remains unclear to what extent BSAS are effective in stimulating either specific or general sustainability improvements in buildings. This knowledge gap is addressed in this study, through examination of the application of the energy, water and health and wellbeing sections of the BREEAM scheme, to four recently constructed university buildings.

A review of assessment reports is combined with a post-occupancy evaluation to enable intended cause and effect paths to be identified and validated. Through examination of this data understanding of previously proposed theoretical limitations is expanded. This facilitates identification of both theoretical and observed strengths and weaknesses within the individual criteria employed. The underlying importance of well-configured criteria in producing overall effect clearly emerges. This allows specific recommendations to be made for their improvement in terms of appropriateness of content, appeal to users, potential for robust evidencing, scope and complexity. Although produced using a single BSAS, the above recommendations have potential to be generalised across similar scheme formats.

The research methodology employed has potential to be replicated, with certain refinements, across a range of scheme and building types. The increased understanding of BSAS criteria generated by this study and its potential expansion offer great potential to improve the functional capabilities of BSAS. Given the global importance of managing the sustainability of the built environment and the current lack of any viable alternative to BSAS, any such improvement should be of great interest to scheme operators and policy makers alike.

Key words: assessment methods, building assessment, environmental assessment, sustainability assessment, assessment criteria

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CHAPTER 1 – INTRODUCTION

1.1 Context

The built environment is unsustainable. Modern buildings make use of large quantities of finite materials at construction stage, consuming fossil fuels through every phase of their life. Consequently, buildings are understood to be responsible for around 30% of greenhouse gas emissions worldwide (UNEP, 2009). However, their broader impact in terms of sustainability is more complex and wide-ranging. Buildings exist in a social, economic, environmental and cultural context. They require land, consume water, generate waste, affect transport patterns and utilise materials that are extracted from the ground, grown or fabricated across international boundaries. Providing valuable space for social and cultural activity to take place and positively contributing to local and global economies. Through their construction, use, maintenance and demolition, buildings therefore have both positive and negative effects. However, their overall environmental impacts are generally negative.

If management requires measurement, then a means of assessing sustainability is needed to facilitate a transformation from a state of un-sustainability as described above, to a state of future sustainability (Pitts, 2004). The nature of this future state remains unclear, making objective measurement difficult. In spite of this, over the past 20 years the use of design stage criteria-based assessment methods has achieved a considerable level of political and commercial acceptance (Cole, 2005). Such Building Sustainability Assessment Schemes (BSAS) are typically configured to provide a comprehensive, design stage assessment, based upon compliance with a checklist of indicators (Ding, 2008; Happio and Viitaniemi, 2008). Schemes such as the Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) have achieved widespread international recognition and there are at least 65 different BSAS currently in global operation. BSAS are arguably the only recognised means of measuring the overall sustainability of buildings and as such they have potential to make an important contribution to managing the wider sustainability of society. However, despite their considerable and growing up-take BSAS are widely criticised within academic literature for lacking either a sound theoretical basis or empirical evidence of efficacy (Cole, 2005).

A widely cited limitation of BSAS is their reliance on “indicators” as a basis for applying dimensionless, numerical scoring systems (Ding, 2008; Beradi, 2011). Indicators are, by definition, an incomplete means of assessment. The subjective nature of their selection is amply evidenced by the variations in content observed across different schemes. A further closely linked limitation is the use of checklists. These are typically employed on a “balanced scorecard” approach (Barlow, 2011) and therefore allow buildings to be rewarded for achievement in certain areas, whilst remaining un-assessed in others. BSAS are also highly reliant upon design stage evidence to demonstrate compliance (Cole, 2005). These evidence requirements can be complex and may generate a substantial and unwelcome additional burden for project team members (Alwaer and Kirk, 2012). Perhaps most significantly of all, assessing sustainability based upon design stage evidence is an inherently uncertain method, with academic post-occupancy evaluation consistently demonstrating that design can be a poor predictor of performance in the construction industry (Bordass et al., 2001; Johnston et al., 2015; Menezes et al. 2012). Sitting alongside these procedural challenges, BSAS must additionally operate in a complex commercial context (Cole, 2005). The option to select indicators from a checklist, the burden of gathering evidence and reliance upon design documentation to predict performance provide project teams with both the scope and motivation to manipulate the application of a scheme to align with their own commercial and reputational aims.

Application of BSAS is typically an interactive process, in which a construction project team can actively select which credits they will attempt to evidence for their building. Credit may be achieved through verification of existing compliance, in which case the scheme acts as an assessment tool. Project teams do however have the option to alter the building design, construction or procurement process, or even location, to achieve the required number of credits (Cole, 2005). The targeting of a particular scheme rating in this manner may be motivated by individual aspirations or a desire to demonstrate corporate social responsibility. Alternatively, a particular rating may be required to meet standards dictated by town planning authorities and government funding bodies (Parker, 2012). In either case, where a particular rating level is sought, BSAS cease to act as an assessment method and instead become a de-facto performance specification for sustainability (Beradi, 2011). In this role, BSAS may act as a tool for market transformation, both for buildings themselves and the many material components and service providers that contribute to their creation. In this scenario, powerful commercial forces come in to play, particularly where certification level is a contractual or statutory requirement. As such, both project teams and the wider construction supply chain will inevitably be required to reconcile the requirements of BSAS certification with their existing functional, aesthetic and commercial aims.

1.2 Problems

By contrast with theoretical commentary, empirical research relating to the efficacy of BSAS is extremely limited. Research by Haroglu (2013) suggests that BSAS may be a relatively effective means of implementing design change; it is however increasingly understood that design stage modelling is an unreliable indicator of in-use performance (Johnston et al., 2015; Menezes et al. 2012). The combination of commercial context, reliance on design stage assessment, diverse and difficult to measure metrics and a lack of built in post occupancy evaluation make the existence of a "performance gap" for BSAS highly plausible. Furthermore, whilst attempts to compare the sustainability of certificated and non-certificated buildings are few, such work as has been carried out is not encouraging. In one instance, Scofield (2009) carried out a review of in-use energy consumption of buildings, which concluded that LEED certificated buildings performed no better statistically in terms of area weighted energy use than non-rated buildings. In a second study, Monfared and Sharples (2011) found that perceptions of health and wellbeing (a key BREEAM metric) actually reduced when a building population was transferred to a new BREEAM "excellent" building.

A particular problem associated with assessing BSAS performance is that expectations are not typically clearly expressed. When considered against recognised definitions modern buildings are typically highly unsustainable (Birkeland, 2008). Therefore, although awarding an "excellent" or "gold" rating to a building implies a substantial improvement, without a defined baseline, the expected quantitative improvement cannot be known. This lack of established benchmarks considered alongside variations in building characteristics presents considerable challenges from a research perspective. Although typically undefined within scheme literature, the use of a nominal scale for ratings and a lack of comparability of scores or ratings across schemes suggest that assessment is intended to be relative (Brandon and Lombardi, 2011). A certificated building should perhaps therefore be expected to be "sustainable" only in comparison to a typical notional building sharing similar fundamental characteristics such as location, layout, purpose and usage patterns. This view clearly informed the research approach employed by Monfared and Sharples (2013), which consisted of a longitudinal study of a population of office workers during their transfer from one building to another. This study provides robust results for the specific building considered, however sourcing similar and willing populations across a range of different building types and locations would likely prove challenging. Quantitative analysis of data across a large number of buildings presents a potential alternative approach to overcoming variations in building characteristics, however such datasets are rarely available in practice. The quantitative findings produced by Scofield (2009) were possible only through reinterpretation of data originally published by LEED to demonstrate a causal link with reduced energy use. Routine, robust, collection of even simple data such as energy consumption is unusual and may be commercially sensitive; large scale collection of data relating to the "comprehensive" assessment offered by BSAS simply does not, currently, occur. In summary, despite the long standing and expanding global use of BSAS as a means of managing sustainability of buildings, there is little evidence to suggest they are fit for purpose. Without a robust theoretical basis or empirical validation, further work is needed to understand their efficacy in terms of assessment and their appropriateness for setting standards, along with their suitability as tools for stimulating market change. Poorly performing BSAS at best represent a significant waste of resources and at worst will result in inadequately designed buildings being presented as exemplars. The aim and objectives of this research are set out below:

Knowledge gap

- The design and construction stage interventions promoted by BSAS do not appear to be a reliable means of improving overall building performance and whilst a number of general theoretical weaknesses have been identified within these methodologies, the particular factors limiting their effectiveness are currently poorly understood.

Research aim

- To increase evidence of the relationship between building sustainability, assessment schemes and building performance.

Research objectives

1. To assess BSAS content, by examining the operational effect of applying individual criteria in certified buildings.
2. To assess BSAS methodology, by examining the manner in which individual criteria have been applied during the design and construction of certified buildings.
3. To assess whether a BSAS rating is a useful sustainability differentiator, by comparing the in-use performance of certified buildings with established benchmarks.

4 To generate recommendations for increasing the efficacy of BSAS, based upon an improved understanding of the link between content, methodology and building performance.

1.3 Research approach outline

Given the difficulty in obtaining secondary data relating to BSAS, a top down approach to analysis has been identified as being problematic. In common with other studies relating to suspected performance gaps, this study therefore approaches validation and examination of BSAS from the bottom up, using a case study based methodology (Bordass et al., 2001; Johnston et al., 2015). Case studies allow for both close examination of the application of BSAS and post occupancy evaluation to determine its effects. This approach cannot robustly demonstrate whether BSAS will produce their purported effects in general; it can however provide insight as to whether individual scheme criteria were effective in particular instances. The potential power of this approach lies in the examination of a wide range of criteria, combined with a capacity to determine intent, process and resulting effect with a high degree of certainty. Although still present, the influence of variations in building characteristic diminish somewhat in this scenario as it is the relative effect which the scheme has on building design and performance that is being examined. Thus, whilst it may not be possible to establish that a particular criterion will produce a general effect across a range of buildings, it will be possible to say that particular criteria can produce a positive effect in a specific building. Furthermore, it will be possible to demonstrate that criteria may have no effect on a building. Equally as importantly, detailed mechanical examination of a BSAS method in application has provided an opportunity to establish why particular criteria are more or less effective. This, in turn, produces potential for generalisations to be made regarding criteria configuration, from which recommendations for improvement may be drawn.

1.4 Thesis structure

The remainder of this thesis describes the realisation of the research proposal described above. A detailed summary of existing pertinent literature is set out in Chapter 2, whilst Chapter 3 sets out my chosen methodology. Chapter 4 summarises the results, which are discussed in relation to the existing literature in Chapter 5. My conclusions are set out in Chapter 6.

CHAPTER 2 – LITERATURE REVIEW

This chapter comprises a critical review and summary of existing literature relating to the context, aims, characteristics and limitations of Building Sustainability Assessment Schemes.

2.1 Building sustainability assessment schemes – The historical context

Successive industrial and technical revolutions over the past two centuries have profoundly altered society in much of the world (Freeman, 2001) and with the resulting urbanisation and population increase, coupled with the changing needs of industry and commerce, massive demand has been stimulated for buildings of all kinds (Wheeler, 2004). Mechanisation and the availability of cheap fossil fuels have additionally changed the nature of construction (Yudelson, 2009), altering the economic landscape in favour of high performance (though finite and energy intensive) materials such as: brick, glass, concrete, steel and aluminium. Meanwhile, technical innovations such as domestic electricity, central heating, air conditioning and telecommunications have increased both the utility of buildings and the comfort expectations of users (Beaufoy, 1993). This has resulted in a trend towards more complex buildings with higher associated embodied energy, energy usage and maintenance requirements. Consequently, the expansion and maintenance of the modern built environment now consumes significant quantities of land, materials and energy.

However, growth and intensification of construction activity has occurred against a background of increasing awareness of its negative impacts (Sonneborn, 2007). From the 1960s, expanding exploitation of material and energy resources and the pollution often associated with it has emerged as a significant political issue. Furthermore, the 1970s oil crisis both highlighted the political perils of over reliance on fossil fuels for energy and provided a preview of future energy scarcity. It was, however, in the 1980s, against the background of a continuing rise in world population, that the wider concepts of sustainability and global carrying capacity began to be widely debated. Since this time, the built environment has come under considerable scrutiny (Pitts, 2004; Brandon and Lombardi, 2011). Its direct influence in terms of land, material and energy use is both significant and highly visible. Additionally, development may influence transport patterns and help facilitate many other industrial and domestic activities. Construction is also viewed as an area of relatively flexible demand, perhaps having greater potential for improvement than other significant sectors such as industry and transportation (IPCC, 2007; Beradi, 2011). As such, buildings sit at the heart of many decisions influencing sustainability and systematic methods of measuring their environmental impact have, therefore, become highly desirable (Bell and Morse, 2003; Brandon and Lombardi, 2011).

In 1990 the Building Research Establishment Environmental Assessment Method (BREEAM) was launched in the UK by the Building Research Establishment (then a government funded executive agency) and is widely credited as being the first to offer a holistic/comprehensive assessment of a building's environmental sustainability (Crawley and Aho, 1999; Cole, 2005; Ding, 2008; Haapio and Viitaniemi, 2008). Although nominally voluntary, the scheme was supported by the UK Government in its development and implementation, and made a pre-requisite for many government funded buildings. It was also applied to other privately funded buildings through the town planning system. Cole (2005) suggests that early assessment methods such as BREEAM filled a niche within a wider emerging culture of performance assessment at this time. Interestingly, however, although support for sustainability assessment methods was doubtless a response to a growing unease about the environmental impact of construction, it was perhaps equally driven by a need to evaluate the novel construction techniques and materials being developed to respond to it (Crawley and Aho, 1999; Haapio and Viitaniemi, 2008). In part, therefore, BREEAM was created as a response to differentiate holistically sustainable "green" buildings (Beaufoy, 1993) from those which may have been "green-washed" through the addition of features such as solar panels or timber cladding, purely to increase their appeal to planners, prospective owners, tenants or users (Cole, 2005). Credibility has always been a stated objective of BREEAM. This assumed role of policing both designers and contractors continues to frame this and other similar schemes in current times.

BREEAM was subsequently emulated in a number of developed countries, with many similar schemes introduced at national level (Figure 2.1.1). Additionally, with the continuing industrialisation of global society and increasing concern about global warming, a growing number of emerging economies now operate assessment schemes. A review of academic literature has identified reference to 65 current and commercially available building sustainability assessment schemes, operating across 29 countries internationally (Table 2.1.1).

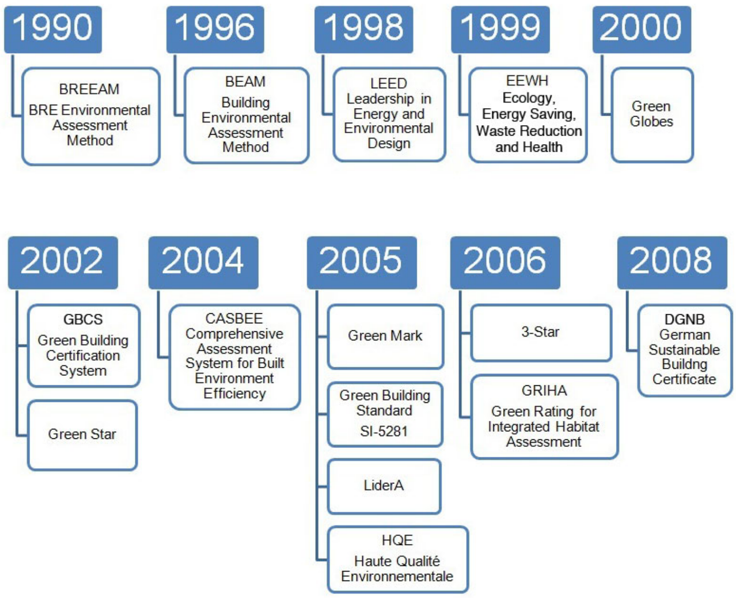

Figure 2.1.1 – BSAS Timeline (Koepke *et al*., 2010)

Table 2.1.1 – Building sustainability assessment schemes by region of operation

Country	Scheme	Reference(s)
International	BREEAM International	BRE Global, 2016
	BREEAM In-Use International	BRE, 2017a
	Green Globes	Green Building Initiative, 2014
	LEED v4	United States Green Building Council, 2017a
	LEED for homes international (pilot)	United States Green Building Council, 2017b
	SBTool (formerly GBTool)	International Initiative for a Sustainable Built Environment, 2009
	SPeAR	Gibberd, 2002
	Living Building Challenge (16 Countries)	Birkeland, 2008
Europe	EMAS	Lee, 2012
Australia	Green Star (Australia)	Green Building Council of Australia, 2015a
	Green Star Performance	Green Building Council of Australia, 2015b
	NABERS	National Australian Built Environment Rating System, 2017
Brazil	AQUA	Gomes *et al*., 2008
Canada	C-2000	Montross and Fraser, 1998
	BEPAC	Brandon and Lombardi, 2011
	BREEAM Canada	Gowri, 2004
	BOMA Best (Canada)	BOMA Canada, 2016
	LEED Canada	Canada Green Building Council, 2016a
	LEED Canada for homes	Canada Green Building Council, 2016b
	R-2000	Montross and Fraser, 1998
China	ESGB	Alwaer & Kirk, 2012; Lee, 2012
	GOBAS	Howard, 2005
Denmark	ABCPlanner (Denmark)	Cole 2005
Egypt	Green Pyramid Rating system	Ammar 2012
Finland	PromisE	Cole 2005
France	HQE (France)	Boonstra and Pettersen 2003
	Equer	Howard, 2005
Germany	BREEAM DE	Deutsches Privates Institut für Nachhaltige Immobilienwirtschaft, 2017
	DGNB	Alwaer & Kirk, 2012
Hong Kong	BEAM Plus V1.1 (HK)	Lee and Burnett, 2008
	CEPAS 2006 (HK)	The Government of Hong Kong, 2004
India	GRIHA	Alwaer & Kirk, 2012
	IGBC Green homes (India)	Indian Green Building Council, 2015a
	LEED India V1.0	Indian Green Building Council, 2015b
Israel	SI-5281 Green Building Standard	The Standards Institution of Israel, 2017
Italy	ITACA	Alwaer & Kirk, 2012
	LEED Italia	Green Building Council Italia, 2017
Japan	CASBEE 2010 (Japan)	Institute for Building Environment and Energy Conservation, 2017
Malaysia	Green Building Index	Barlow, 2011
Mexico	Consejo Mexicano de edificacion sustentable	Alwaer & Kirk, 2012
Netherlands	BREEAM NL	Dutch Green Building Council, 2017
	Greencalc	Bitard, 2009
New Zealand	BRANZ Green home scheme	International Energy Agency (IEA) 2005
	Green Star NZ	Alwaer & Kirk, 2012
Norway	BREEAM NORF	Norwegian Green Building Council, 2017
	EcoProfile	Boonstra and Pettersen 2003
Portugal	Lidera	Lidera, 2017
Singapore	Green mark (Conquas a)	Alwaer & Kirk, 2012
South Africa	Green Star SA	Alwaer & Kirk, 2012
	SBAT	Gibberd 2002
South Korea	Korea green building label	Howard, 2005
	Green building rating system (K-GBCS)	Alwaer & Kirk, 2012
Spain	BREEAM ES	Construcción Sostenible BREEAM ES, 2017
	Verde	Alwaer & Kirk, 2012
Sweden	BREEAM SE	Sweden Green Building Council, 2017
	EcoEffect	Happio, 2008
	Environmental Status Model – Miljöstatus	Boonstra and Pettersen, 2003
	Environmental Building – Miljöbyggnad	Boonstra and Pettersen, 2003
Taiwan	EEWH Green Building Labelling System	Lee, 2012
UAE	Estidama	Barlow, 2011
UK	BREEAM 2016	BRE, 2017c
	BREEAM Domestic Refurbishment	BRE, 2017d
	BREEAM Non-Domestic Refurbishment	BRE, 2017d
	CEEQUAL V5	CEEQUAL, 2017
	Code for sustainable homes	Department for Communities and Local Government, 2015
	CPA Comprehensive Project Appraisal	Ding, 2008
	DREAM	Ding, 2008
	DQI Design quality indicator	Cole, 2005
	SKA	Royal Institution of Chartered Surveyors, 2017
USA	Green Globes (USA)	Green Building Initiative, 2014
	LEED for homes	United States Green Building Council, 2017b
	NAHB Green Guidelines	Howard, 2005
	STARS	Association for the Advancement of Sustainability in Higher Education, 2017

2.2 Sustainability and the triple bottom line

The assessment methods under consideration in this project are explicitly concerned with sustainability as a concept. Therefore, it is desirable and appropriate that the origins and development of the concept are explored. Perhaps the most enduring and widely quoted definition of sustainability was generated by the United Nations World Commission on Environment and Development chaired by Gro Harlem Brundtland. The Commission was formed in 1983, with three objectives:

1. To re-examine critical environment and development issues and to formulate realistic proposals for dealing with them.
2. To propose new forms of international co-operation in the direction of needed changes, on issues that will influence policies and events.
3. To raise the levels of understanding and commitment to actions of: individuals, voluntary organisations, businesses, institutes and governments.

In April 1987 the Commission published its report “Our Common Future” (United Nations World Commission on Environment and Development, 1987), which included the following definition of sustainable development:

> “Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Written against a background of drought-triggered famine in Africa and the explosion of the Chernobyl nuclear reactor, the report presents a pre-dominantly anthropocentric viewpoint, and is focused upon maintaining the ability of the Earth to support its increasing human population, whilst simultaneously improving living standards. Our Common Future proposes “the possibility for a new era of economic growth, one that must be based upon policies that sustain and expand the environmental resource base.”

At a similar time Dr Karl-Henrick Robert led a group of Swedish scientists to form the Natural Step, which was launched in Sweden in 1989. Aiming to establish consensus, the Natural Step set down a framework for a society built upon basic incontrovertible scientific principles. This framework is as follows, and has subsequently been widely adopted as a guiding principal by scientists and corporations worldwide (Robert, 2002):

In the sustainable society, nature is not subject to systematically increasing:

1. Concentrations of substances extracted from the Earth's crust.
2. Concentrations of substances produced by society.
3. Degradation by physical means; and in that society:
4. Human needs are met worldwide.

The Brundland definition of sustainable development is categorised by some as weak sustainability because it is framed in terms of human needs, without aspiration to conserve the environment for its own sake (Bell and Morse, 2003; Jaeger, 2005). The Natural Step also has a regard for human need, but is based upon first achieving a steady state situation in the context of the wider environment. Our Common Future emphasises development and the dynamic nature of society, accepting both population growth and future technological innovation along the path to an uncertain state of future sustainability. Meanwhile, The Natural Step describes a theoretical destination and encourages organisations to chart a path towards it. It is worth noting that although the terms "sustainability" and "sustainable development" are often used interchangeably, development is explicit only in the Brundtland definition. Conversely, The Natural Step emphasise a steady state and advances a binary position for sustainability i.e. something is either sustainable or it is not (McElroy, 2011). Robinson (2004) suggests that academics have come to favour the term "sustainability", whereas, governments and the private sector may prefer "sustainable development". This may in part be a question of scope, as development of a single organisation or country may be achieved quite readily (at the expense of others). Whereas development at a global scale implies that additional resources must be found. Brandon and Lombardi (2011) suggest that sustainability must in reality occupy a range of possibilities with a spectrum of views. These range from a desire to find a technical fix only where issues threaten human wellbeing, to a "conserve at all costs" approach.

Both the Brundtland and the Natural Step definitions of sustainability emphasise the continuation of society, however the focus for action is arguably one of moderating environmental impact. Elkington (1987) develops this thinking somewhat by introducing the concept of the Triple Bottom Line and defines sustainability as “the principal of ensuring that our actions today do not limit the range of economic, social and environmental options open to future generations.” Significantly in this definition, economic, social and environmental sustainability are laid down as a minimum requirement and this alters the emphasis from one of making sacrifices to preserving the environment, to that of seeking a “win, win, win situation”. Elkington (1987) applies this concept specifically to business and suggests that the future operating environment for companies will be one of sustainable capitalism where successful businesses must operate in an environmentally and socially sustainable manner, as well as being economically viable. Increasing awareness of environmental and social issues within the general public combined with growing media scrutiny of business transactions is characterised as “the global goldfish bowl”. This will, it is argued, lead to great commercial advantage in aligning the values of a business with those of its prospective customers and workers. Elkington (1987) also suggests that the same public awareness of social and environmental issues will lead to increased statutory governance of markets, giving those businesses that pre-empt these future constraints further advantage. This voluntary balancing of economic interest with environmental and social issues has subsequently had significant influence on business theory and is commonly expressed as corporate social responsibility (CSR). Jones (2012) characterises the evolution of CSR in terms of three ages. Firstly, “The Age of Image, 1990-2000” in which businesses reacted to a growing interest in how they conduct their affairs by creating new communication strategies to establish a favourable image i.e. green washing. Secondly, “The Age of Advantage, 2000-2010” in which, with increasing transparency, those companies which genuinely made their business more socially responsible begin to gain market advantage. Thirdly, “The Age of Damage, 2010 to present” in which public expectations have increased to such an extent, that failure to act in a socially responsible manner may actively jeopardise the survival of a business.

The triple bottom line has now become an established concept within politics (Stern, 2009). This has been nowhere more apparent than in the international response to the threat of global warming, which arguably began in earnest with the Kyoto Protocol (UNFCCC, 1998). Here an environmental concern (global warming) has resulted in a demand to reduce the use of fossil fuels. This reduction has the potential to produce economic and social hardship. However, it is acknowledged that unchecked global warming may itself bring great economic and social hardship as well (Stern, 2009). Hence the problem becomes one of international triple bottom line accounting, albeit within a context which is greatly confused by scientific uncertainty and national game theory. A key argument posed by Elkington (1987) is that individuals in modern society can exert considerable influence on business and government. Elkington (1987) refers to these long-term changes in culture as “deep currents”. However, in the face of the complex and uncertain situation described above, individuals may respond to these deep currents in a range of ways. Many environmental problems are forms of social dilemma, situations in which acting from self- nterest harms the greater whole, or results in a “tragedy of the commons”. Hence an individual may support sustainable principles in theory, without supporting them in any practical sense (Koger and Scott, 2007). Guy and Moore (2005) also note that major historical changes in building codes, for example, were largely introduced in response to catastrophic fires and outbreaks of disease, whereas making changes to incorporate sustainability requires a degree of collective foresight. Such foresight must contend with uncertainty and whilst some may be prepossessed to assume the worst and act (or demand action) accordingly, others may favour the status quo and demand certainty before acting. Nevertheless, it is probable that to some extent most businesses and governments are influenced by individual opinions at a policy level. Added to this, there may also be a need to consider the influence of individuals at operational level and acknowledge that decisions relating to the built environment may be informed by both. In the context of building sustainability assessment methods this potentially points to schemes operating on a number of levels; for example, simultaneously being backed by government as a means of achieving carbon emission reduction targets, being used by a corporation to satisfy its CSR policy and perhaps being demanded by a local business manager to enhance staff morale. The concept of the triple bottom line is most commonly represented by a Venn diagram (Figure 2.2.1), where environmental, social and economic considerations overlap to describe a zone within which a “win, win, win” situation is possible. Alternatively Wheeler (2004) (Figure 2.2.2), proposes a nested model by emphasising that the economy operates within society and that society may itself only operate within the confines of the environment as a whole. This reinforces the concept of a carrying capacity for the environment, beyond which, no further human development is possible. An additional alternative also put forward is “the four pillars of sustainability”, which incorporates cultural vitality as a further essential aspect of a sustainable society (Hawkes, 2001; Partal, 2013) (Figure 2.2.3). This concept has been particularly adopted and promoted by United Cities and Local Governments (2010) who justify inclusion of culture as the fourth pillar of sustainability through identifying a need for “a healthy safe tolerant and creative society (rather than merely a financially prosperous one)”. This concept is similarly justified by Hawkes (2001), when he states that “there are many values informing our society that run counter to those based simply on the production of goods — that instead focus on good”.

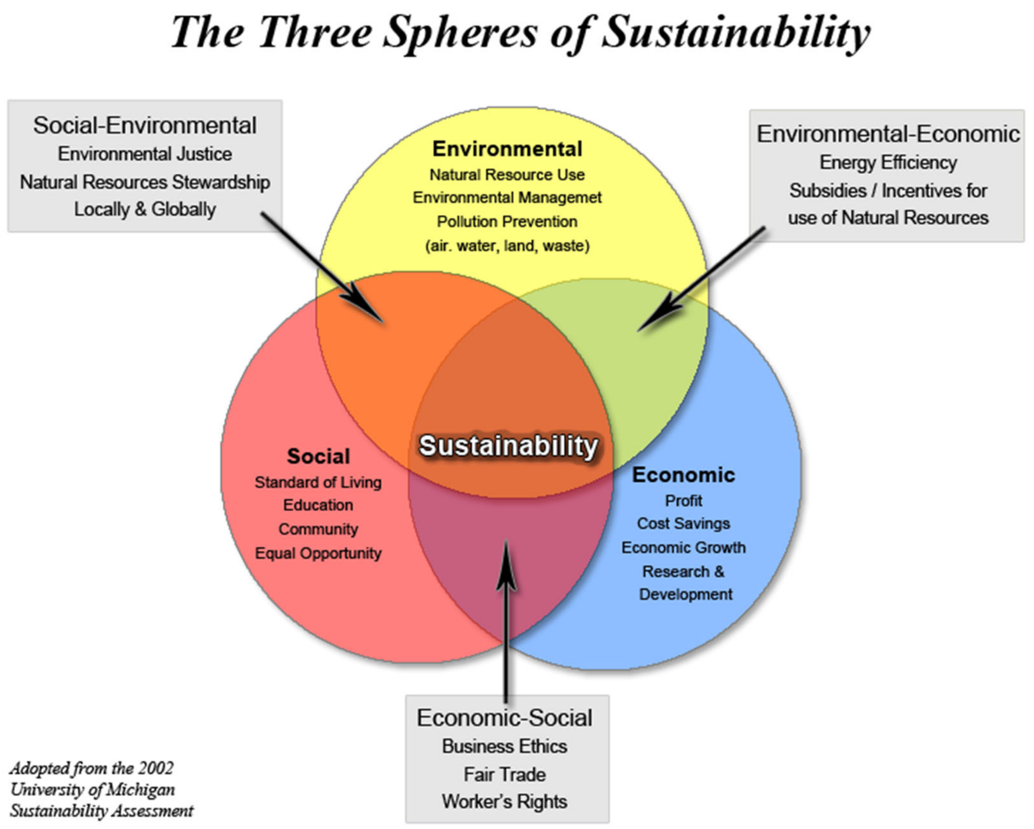

Figure 2.2.1 – The Three Spheres of Sustainability (Vanderbilt University, 2013)

Figure 2.2.2 – Strong Sustainability (Cato, 2009)

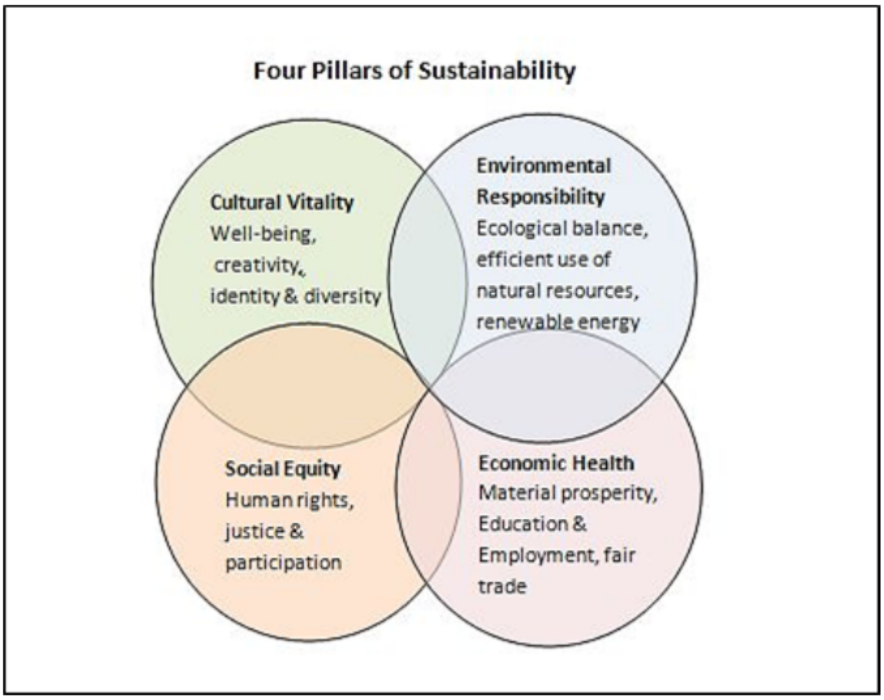

Figure 2.2.3 – The four pillars of sustainability (Partal, 2013)

2.3 Measuring the sustainability of buildings

It is a well-established principal in human affairs that management requires measurement (Pitts, 2004). If the sustainability of buildings is to be improved, it is clearly vital that the relevant metrics are evaluated (Brandon and Lombardi, 2011). Through assessment, BSAS offer potential to stimulate sustainability improvement. This is explicit in the BREEAM scheme who's first stated aim is "To mitigate the life cycle impacts of buildings on the environment". However, buildings host a highly complex interaction between people, materials and processes (Alwaer and Clements-Croombe, 2010), assessing sustainability is no simple task. Through all of its life stages, from design, through construction, operation and, ultimately, decommissioning, the built environment is intimately engaged with society, the economy and the environment. A building may generate wealth, provide people with rewarding employment, shelter or entertainment, be beneficial to local ecology, and possibly (for example in the case of carbon negative initiatives) benefit the global environment. On the other hand, poor development can result in financial losses, distress to the people that use it and be harmful to both the local and global environment. Any comprehensive attempt to measure the sustainability of a building must therefore balance multiple, complex, disparate (and often subjective) social, environmental and economic factors, against one another. It must also attempt to predict the future, with the on-going impacts of a building in use (and even the manner of its ultimate demolition) being assumed and balanced against its impacts during construction. If it is noted that, in addition to direct use of resources, a building will further influence its occupant's transport patterns, water use and waste production, then the environmental impacts of a building can be seen to be as complex as it is significant. Life cycle analysis techniques may be used to analyse partial elements of this calculation, for example by considering the embodied carbon of a building in relation to its emissions over an assumed life cycle. Despite being complex and relying on numerable assumptions and approximations, life cycle analysis itself can provide only a small component of the holistic evaluation proffered by building sustainability assessment schemes (Beradi, 2011; Ding 2008). In fact, many BSAS go further still in considering the wider social and cultural impacts of buildings, for example, it's effectual use on the long term health of its occupants and surrounding buildings (Beradi, 2011). In this case, it is not purely the impact of buildings that is being assessed, but perhaps rather the extent to which they support sustainable patterns of living for society (Cole, 2005).

Given the conceptual complexity described above, it is perhaps unsurprising that a lack of agreement remains as to what constitutes sustainability in a construction context. Guy and Moore (2005) note that "Three decades of debate about sustainable architecture and a search for some form of consensus around universal best environmental practice appear to have failed". Consequently since 1990, numerous different building sustainability assessment schemes have been developed, each seeking to improve on those already available. In 2006 the International Standards Organisation issued measures relating to such schemes (ISO, 2006), setting out a general framework for operation. An international standard also exists for establishing scope (ISO, 2011), and further work is ongoing within the European Union (BSI, 2010; Hakkinen, 2012) to standardise measurement metrics and facilitate easier comparison between schemes. Nevertheless, fundamental differences persist between schemes in terms of formulation and scope (Cole, 2005). Significant differences also exist in terms of detail. In reality, BSAS cannot consider every pertinent issue within their scope described above, not only because of the administrative burden this would place, but also because many aspects could not practically be estimated to an acceptable degree of accuracy (Brandon and Lombardi, 2011). Therefore, to simplify the task, rather than attempting to measure every impact, "comprehensive" methods rely on a system of "indicators" instead. These indicators are a selection of distinct criteria, chosen by the scheme operator to provide an indication of the wider sustainability of the building, against which a building can be more easily evaluated (Bell and Morse, 2003; Brandon and Lombardi, 2011). Indicators are typically grouped into categories relating to different aspects of sustainability. Categories vary between schemes, but typically include the following as a core (Beradi, 2011):

- Site selection
- Energy efficiency
- Water efficiency
- Materials and resources
- Indoor environmental quality
- Waste and pollution

Further to this, additional categories may also be included depending upon the scheme. In particularly Beradi (2011) identifies “innovation” (LEED & BREEAM), “construction management” (BREEAM), “mitigation and off-site solar energy” (CASBEE) and “cultural perception of sustainability” (SBTool). The indicators together form a checklist, against which a building can be rated and compared with others. Indicator selection can be seen to be at once subjective and also fundamental in determining the rating achieved by a building. On comparing the most popular sustainable building assessment schemes in current use, it can be seen that although they share many general themes, there are significant differences in emphasis (Beradi, 2011). At a macro level, schemes vary as to whether they account for social and economic issues as well as environmental ones; at the other end of the spectrum, the variation in detailed requirements within individual criteria is also significant (Cole, 2005; Ding, 2008; Hakkinen, 2012). If weight is given to the argument that scheme requirements may drive change, then indicator selection also has the potential to steer the course of that change (for example by promoting incremental technological improvements above innovation, or vice versa). Schemes therefore have an in-built “viewpoint” regarding the development of sustainable construction and corresponding potential to influence it.

The sustainability of a building is therefore a dynamic and complex metric. Measurement is subjective in terms of scope and definition and is additionally approached by BSAS using limited indicators of performance. This perhaps explains the current existence of numerous different BSAS. It also provides justification for questioning the robustness of the results generated; a view which is further supported both by a failure of scheme operators to declare margin of error (Haapio and Viitaniemi, 2008) and a lack of facility to compare results across different assessment methods (Alwaer and Kirk, 2012). Based on this analysis, although BSAS can and do contain measurement within them, they do not produce an overall measure of sustainability. Instead they provide an assessment of sustainability that is founded upon verifiable measurable issues, but is relative, unitless and subjective.

2.4 The accuracy and efficacy of BSAS

For BSAS to stimulate improvements in the sustainability of buildings, they must first provide a tolerably accurate assessment of the metrics they are assessing. The level of accuracy required to effect change, and its link with efficacy is however currently unclear. Relative, unitless measurement of progress along a pathway with an uncertain endpoint does not sit comfortably with many academic commentators who question the merit of producing ratings without benchmarks or proven cause and effect models (Alwaer and Kirk, 2012). Conversely, Poveda (2011) accepts this situation, describing BSAS as “practical undertakings in evaluation and decision making”. Similarly, Cole (2005) suggests that accuracy and precision must relate to the purpose for which the ratings are being generated, and the schemes may serve different purposes for different stakeholders. As already discussed, although assessment implies objective evaluation, BSAS are often conceived with the aim of effecting change. This is evidenced by schemes typically being entirely positive, in that they reward sustainable features where they exist, but seldom deduct credits for poor performance (GB Tool is an exception to this (Alwaer *et al.*, 2007; Alwaer and Kirk, 2012)). It is also reflected in the ratings themselves, which are typically overwhelmingly positive eg “good”, “very good”, “excellent”, “outstanding” (BREEAM) or “silver”, “gold”, “platinum” (LEED). This is perhaps an inevitable situation for voluntary schemes, as aspirational standards are hardly likely to be set at levels of poor or fair. Schemes are however designed to communicate something to the outside world (Beradi, 2011), and the way in which results may be perceived and understood is important.

Complexity is a further issue any method must address when provide a rating for wider dissemination. In particular, methods must provide comparison between projects and may also demonstrate compliance with standards. The mechanics of any successful method is therefore concerned with reducing an issue of almost boundless scope, into an outcome that can be understood by as wide a portion of society as possible whilst also maintaining an acceptable level of accuracy and objectivity. As already noted, when a building is rated by a BSAS as "very good", it does not mean that the building is actually sustainable against a recognised benchmark (Haapio and Viitaniemi, 2008). In the absence of such recognised benchmarks (Hakkinen, 2012), it may still be helpful to determine that a building rated "very good" is more sustainable (or less *unsustainable)* than one that is rated as "good". Yudelson (2009) proposes that zero net impact should be the starting point for sustainable design and emphasises reductions in absolute terms. Birkeland (2008) supports this view and suggests that the terminology used by assessment methods is akin to encouraging people to "smoke light cigarettes to improve their health". Guy and Moore (2004) accept that construction practice must follow a pathway to sustainability where change is incremental and lessons are learnt along the way, and it is this pretext which the majority of assessment methods appear to support.

Unfortunately, although quantitative research relating to the practical efficacy of BSAS in measuring and producing sustainability improvement has been extremely limited, such evidence as is available suggests that their efficacy in producing or measuring even relative change cannot be relied upon. Scofield (2009), for example, analysed energy performance data provided by the scheme operators for LEED, and found "no overall statistical difference between energy use in LEED and non-LEED buildings". Meanwhile, in relation to social sustainability, Monfared and Sharples (2011) studied the effect of measures in the BREEAM scheme designed to improve occupant comfort. They found that of 2000 staff moved from a conventional UK office building into a new BREEAM "excellent" rated building, just 20% felt that their comfort had increased, whilst 38% stated that it had decreased. Finally Turner and Arif (2012) conducted a pilot study to evaluate the effect of BREEAM in terms of economic business value and employee morale, and found that "Many of the users could not quantify the benefits of occupying a BREEAM "excellent" building" and that "Many of the features of BREEAM attained in the early stages appear to be lost in translation or do not have the desired impact on the building occupants as originally envisaged".

2.5 BSAS and the performance gap

A study by Haroglu (2013) suggests that BREEAM is relatively effective in affecting *design change*. Unfortunately however, it is increasingly understood that building design parameters routinely fail to produce corresponding performance, unless supported by a post occupancy evaluation feedback loop. The PROBE studies (CIBSE, 2017b) conducted in the 1990's made use of systematic building performance evaluation. The scope of this is particularly pertinent to BSAS, as they combine quantitative data including energy and water use with a building occupant survey designed to assess user health and comfort. The building occupant survey used for these studies was Building User Studies (BUS), who made use of Likert scales to generate a statistical picture of qualitative building performance. The results of individual studies were analysed by BUS and the benchmarks produced used a rolling sample of 50 buildings. These results show that building services often substantially fail to deliver their designed performance and that this is due to a range of factors including poor installation and commissioning, incorrect operation and inaccurate assumptions about building occupant behaviour. Ongoing research carried out by Leeds Beckett University since 2005 (Johnston *et al.*, 2015) has similarly demonstrated that due to a range of factors the fabric energy efficiency of new homes in the UK routinely falls substantially short of design performance. This includes incorrect design assumptions, poor workmanship and product substitution. Meanwhile, analysis of data collected through the Carbon Buzz Project (2017) by Menezes *et al*. (2012) indicates that buildings typically use 60-85% more electricity in-use than predicted at design stage. Incorrect assumptions relating to building occupation is suggested as a specific contributing factor to this. Therefore, there is ample evidence to suggest that design calculations represent a poor prediction of building performance. It is also apparent that a lack of routine use of POE for buildings allows poor performance to persist undetected. BSAS are a form of design-based predictor of performance but attempt a far more complex assessment of sustainability than that assessed by the Probe studies. This ranges across multiple, disparate and sometimes conflicting considerations. They also similarly lack an integral POE feedback loop. In the case of energy performance, academic research has begun to fill this gap, with detailed POE now being used as a basis for developing improvements both for performance itself and accuracy of prediction. However, BSAS are significantly more complex, with their multiple assessment considerations having been described as a cat's cradle of cause and effect (Leaman, 1999). Notwithstanding this, carefully considered POE making use of appropriate benchmarks surely has similar potential to provide greater understanding of both the accuracy and efficacy of BSAS.

2.6 The business context for BSAS

Aside from the technical challenges associated with implementing sustainability improvement using BSAS, a wider commercial context should also be considered. Research suggests that there is a movement within the commercial sector towards building a more sophisticated business case for sustainable buildings (Edwards, 2003; Sayce, 2010; Hayes, 2012). However, this comprises a number of overlapping and at times conflicting areas. In some cases sustainability improvements are driven directly by statutory requirements (such as Building Regulations or Planning Policy). In this event the business case for sustainable buildings becomes a matter of legal compliance. A similar situation exists where compliance with sustainability standards is linked to government funding. This is a significant factor in the UK, where town planning requirements or funding links were cited by construction clients as being the “main motivation” for carrying out a BREEAM assessment in 49% of cases (Parker, 2012). Long-term financial resilience may be a further associated consideration where the legislative landscape is expected to change over time, with incoming construction standards, or carbon taxes having the potential to turn an otherwise acceptable building into an economic liability. Examples of such issues currently affecting building stock in the UK are the introduction of a minimum energy efficiency requirement for rented buildings (Energy Act 2011), and the difficulty of obtaining insurance for buildings in flood risk areas (Pottinger and Tanton, 2012).

Operational cost savings are often cited by academic commentators as being a major potential benefit in association with sustainable buildings (Edwards, 2003; Preiser and Vischer, 2003; MacMillan, 2004; Baird, 2010). By incorporating sustainability into a design brief it is argued that significant long-term financial savings can be generated. This will translate into increased capital and or rental value. These material benefits may be usefully categorised as follows:

- Energy use – selection of natural ventilation strategies and use of thermal mass where appropriate, along with additional capital investment in efficient plant and thermal fabric insulation resulting in a long-term saving in energy costs.
- Water use – water efficient appliances, grey water re-use and/or rainwater collection are used to reduce consumption and generate a long term saving in water costs.
- Staff productivity – provision of a health and comfortable work environment may improve productivity and reduce absenteeism associated with poor working conditions and sick building syndrome.

Such benefits may be significant. The City of Melbourne invested AUS$11.3m on additional sustainable features in an AUS$29.9m base build, projecting that the additional investment in the "Council House 2" building would be recouped within 6 years (City of Melbourne, 2013). In the UK, the property investment fund Climate Change Capital actively target energy savings in their buildings based on a maximum pay back period of 5 years. Following this strategy they report that they have achieved an average 25% saving of energy costs in buildings they have purchased, achieved by a combination of tenant engagement and light touch improvements (Mockett, 2012). Of the above measures however, staff productivity has potentially the widest interest to business. Preiser and Vischer (2003) estimate that staff wages comprise 80% of the lifetime expenditure associated with a typical office building. Any increase in productivity therefore offers significant business advantage. Increasing the availability of natural light, reducing recirculation of air and giving occupants greater control over heating and cooling being widely cited as having potential to improve staff morale and reduce staff absence (MacMillan, 2004). Interestingly, these features could all be viewed as desirable in any building. The reason they are considered sustainable add-ons suggests that the business case for implementing them is uncertain. Additional capital investment for energy or water efficiency measures may appear sensible when taken in isolation, however the opportunity cost of this capital expenditure must also be considered. Furthermore the timescale over which savings will be realised may be uncertain and many businesses may prefer to limit their short-term liability in preference to generating potential future cost savings. This situation may be further complicated when design decisions are taken by a developer with no vested interest in running costs, or where leases dictate that such investment will be carried out by the owner, but that the tenant will benefit (CIBSE, 2017b). Such improvements may additionally be complex and produce uncertain results. Increasing natural light may involve fundamental changes to building configuration; increasing the supply of fresh air may be expensive in terms of additional heating and cooling requirements, and occupant control of heating and cooling can generate conflict in open plan environments. Without the impetus provided by BSAS, many building users may therefore prefer to focus their resources on core business areas before choosing to construct, refurbish or relocate to a building in the hope of reducing utility bills or boosting their staff performance.

A third distinct and potentially significant area concerning the business case for sustainability is reputation and brand value. As previously discussed, businesses mainly gain commercial advantage by aligning their practices with the expectations of their staff and/or customers (Elkington, 1997; Haddock-Fraser and Tourelle, 2010). Where staff or customers are concerned about sustainability, businesses may therefore wish to demonstrate leadership in this field. Success is dependent upon being seen to "do the right thing", and effective communication of strategies is therefore essential. Sustainable buildings may contribute to this in a number of ways:

- Publicity –incorporating sustainable features into new or existing buildings may generate positive publicity, possibly increasing brand awareness and loyalty.
- Reputation – as part of a wider CSR policy, occupying demonstrably more sustainable buildings may enhance brand-value and increase brand loyalty.
- Staff morale – distinct from the potential material health benefits. Investing in high quality buildings may also provide a psychological boost to staff, potentially improving both productivity and retention.

One leading example of a business using sustainability improvements to buildings to enhance brand value in the UK is retailer Marks and Spencer's. Their "Plan A" sets out an on-going scheme to increase the sustainability of their business. Through this they claim to have already achieved one aspiration for all of their stores, which is to be operating on a carbon neutral basis (Marks and Spencer, 2017).

A business case for sustainability assessment of buildings may therefore be built on a number of quite separate bases. A survey of businesses carrying out LEED certified green retrofits in the US (Lockwood, 2008) reveals, for example, motivation spread across the factors illustrated below (Figure 2.6.1), with indoor environmental quality ranking equal first with corporate environmental commitment. Only 31% expected an increased capital value and just 19% expected increased occupancy rates. Parker (2012) found that UK building owner-occupiers gave "main motivations" for undertaking a BREEAM assessment across a similar range of issues, with 76% citing funding or legislative requirements and 38% organisational or CSR factors. Again, commercial gain appears to have been a significant driver for only a minority of users (13%).

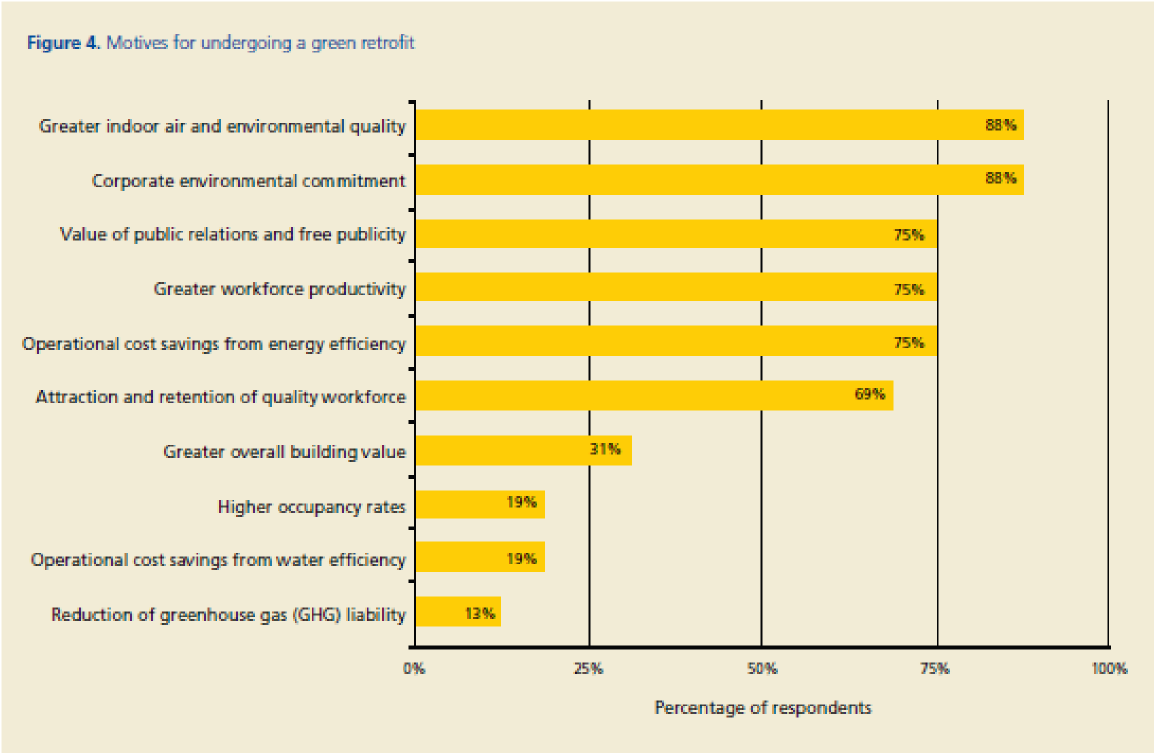

Figure 2.6.1 – Motives for undergoing a green retrofit (Lockwood, C. 2008)

The relationship between building users and BSAS is therefore a complex one. Some organisations require a sustainable building based on a quantitative business case, others will have had BSAS certification imposed on them by government and some are using the building as a means of communicating with their customers. In theory, BSAS offer a mechanism to effect all three of these requirements founded on an ability to quantitatively differentiate buildings in terms of their sustainability. However, It is apparent that for many users the certification is primarily sought (for legislative, funding or CSR purposes) rather than any improvement in building performance. As such, not only is POE lacking within BSAS but there is additionally little motivation for many owner occupiers to attempt to measure the performance of their own buildings. This disconnection between scheme aims and user motivation is critical. Suggesting not only that assessment of the effects of BSAS is lacking, but also that popularity may exist completely independently of efficacy.

Unfortunately, the disconnection identified above is not limited to building users. Further uncertainty is introduced when it is considered that the parties involved in constructing or managing buildings may also be significantly removed from those making use of them. BSAS are based upon implementing design change and the approach of the design and construction stage project team will therefore also be fundamental to their successful application. This is usefully illustrated by Parker (2012) who found that the main motivation for using BREEAM was perceived quite differently by a range of scheme participants (Figure 2.6.2).

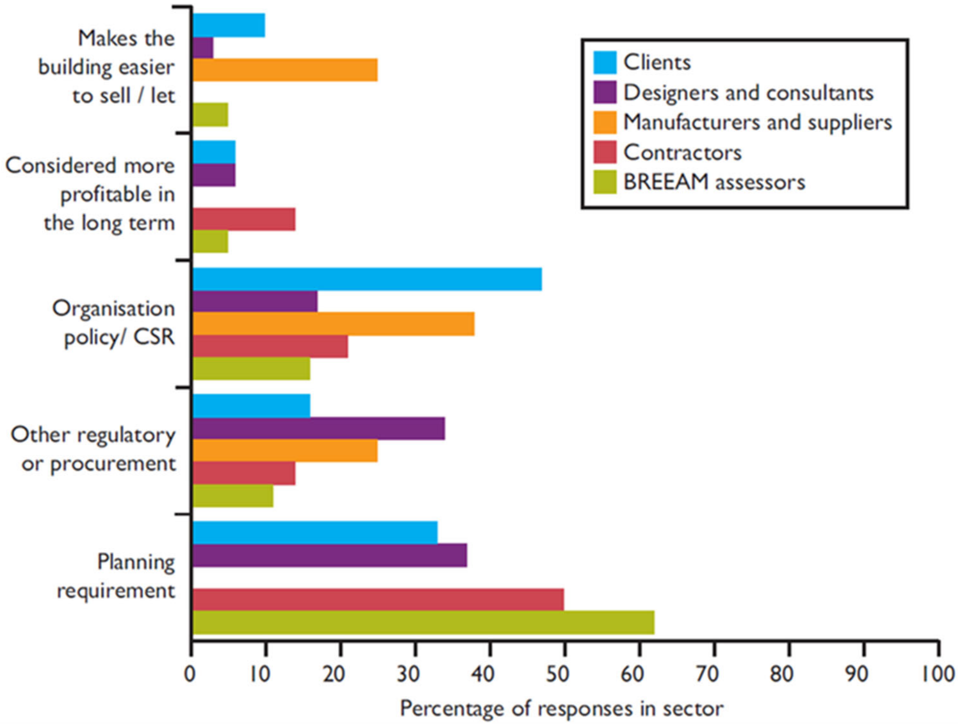

Figure 2.6.2 – "Main Motivation" for using a BREEAM assessment by stakeholder (Parker 2012)

In this scenario, triple bottom line benefits will not always accrue to the same parties as the costs, and vice versa. This may produce tension if the financial viability of a project is championed mainly by its promoters (internal to the construction process), whilst the social and environmental viability is driven by government or end users by means of planning laws, regulations or contracts (external to the construction process). Elkington (1987) challenges this view by suggesting that operations may benefit from taking social and environmental concerns "on board" (making them internal to the construction process). The effect is however likely to be somewhat less than perfect in reality, both because it relies on consumers and employees being perfectly informed and also because not all operations will be sufficiently sensitive to public opinion to counteract commercial pressures. Used correctly, a BSAS gives construction project teams the means to conduct a triple bottom line evaluation using their detailed knowledge of the project, and bring these decisions into the daylight for onwards communication to external players. It is clear, however, that commercial tensions may fundamentally disrupt this process. Construction teams are likely to be motivated to provide certification at minimum cost not only to the project as a whole, but also to their individual organisations. Potential therefore exists for BSAS to be manipulated by construction project teams and this is supported by a survey of BREEAM users conducted by Parker (2012), which reports that 88% of respondents sometimes, frequently or always “target credits which do not add value to the project”.

2.7 Assessment methodology

Given the complex socio-political context described above, the methodology by which BSAS are implemented arguably has great potential to influence their efficacy as well as their content. Subjective selection of indicators for use in schemes gives each BSAS a starting “viewpoint”, however selection and validation of credits within that scheme may be just as significant in determining their impact on performance outcomes. When considering the application of BSAS, a requirement for simple results, based on detailed objective analysis, gives rise to a number of practical issues, not least of which is transparency. The broad scope of “comprehensive assessment” dictates that BSAS utilise a large number of indicators. Many of the criteria are themselves also both complex and technical in nature; for example the assessor’s manual for BREEAM 2011 comprises 406 pages (BRE, 2013), and requires reference to many other technical publications. Furthermore, the scoring for different credits is commonly weighted so that credits in one category may contribute more to the final result than those in another (Ding, 2008; Beradi 2011). This complexity may be seen as necessary and commensurate with the ambition of the task at hand, however it also gives rise to a situation whereby no single stakeholder is realistically capable of understanding the full calculation, giving rise to the final result. This is not an unusual situation in modern construction that already relies widely on a team approach, with specialists often coming together to produce a final product that may not be fully understood by any one player. It does however call into question the degree to which those advocating or responding to these schemes are realistically able to appreciate what is being assessed.

The results of an assessment may be presented in a variety of ways, with varying levels of detail depending upon the intended recipient (Becker, 2004). Schemes often break credits down into categories, and this may allow some further analysis of results, additionally some schemes such as CASBEE and CEPAS express results in a way that allows differentiation between performance or human factors, and environmental impacts (Cole, 2005). To be meaningful, however, this information requires that the reader is fully conversant with the detail of the scheme, including the administrative burden attached to various credits. As previously discussed, the fact that a credit has not been achieved may simply mean that the administrative burden was considered too high, rather than that it was unachievable. This detailed knowledge is unlikely to be held by any party other than those actively involved in obtaining assessments, i.e. a member of a design team, or well-informed client. Beyond this select group, parties are likely to be reliant simply upon the rating itself, which may be a number of stars (Green Star), silver, gold, platinum (LEED), or pass, good, very good, excellent, outstanding (BREEAM). This headline result may be expressed on a numeric scale, such as a percentage of possible points scored and may be further broken down into various categories. In general though, it is arguably very difficult to appreciate assessment schemes at the meso level which would perhaps, benefit the most influential stakeholders (i.e. those commissioning and using buildings). This analysis further supports a picture of disengagement between the scheme and those who most fundamentally support it, with potential for the scheme to effectively operate as a black box (Alwaer and Kirk, 2012), without the benefit of feedback from its advocates and users.

Given the emphasis placed on certification by users and the complex commercial arena within which they operate, credibility and verification could be viewed as fundamental requirements for any successful BSAS although these aspects can generate conflict at a practical level. Credibility requires that indicators are evaluated in a robust way. Indicators may therefore be selected by scheme operators for the ease with which they can be evaluated and verified (for example using an existing tool or methodology), rather than because they are the most representative. Linked to this, verification for new build and refurbishment projects tends to focus on design compliance, both because it is far simpler to determine than actual performance over time and also because it allows compliance to be established at an appropriate time for conclusion of statutory, contractual and financial project matters. As a result, and given the previously discussed lack of inherent provision or demand for POE, it is unusual for the performance of the building in use to be compared to design stage predictions (Alwaer and Kirk, 2012; Cole, 2005). Verification also suggests an administrative burden, both for the scheme operator, and for the scheme users, which must ultimately translate into financial administration costs that have no direct benefit to the project. In practice, this administrative burden will manifest itself in registration and certification fees needed to meet the costs of the scheme operator, along with professional costs incurred by the project team in producing evidence of compliance. In most schemes, a third party assessor is also required, to provide verification on behalf of the scheme operator, attracting additional fees (BRE, 2013; USGBC, 2017a).

Additionally, and more subtly, the administrative burden attached to achieving compliance for a particular credit may significantly influence the choice of credits attempted, leading to a situation whereby sustainability gains are targeted by users according to their ease of attainment, rather than their value to that particular project or user (Hakkinen, 2012). Certain criteria within an assessment may lend themselves more readily to inclusion in existing design briefs and specifications than others. Thus if a certain generic workmanship standard may contribute to achieving a particular credit, then it is a simple matter for a design consultant to incorporate it into their base specification. Conversely, where criteria can only be achieved using a project specific design solution the relevant designer must incorporate solutions as the design develops. These may involve unexpected design time and from the building user or promoter's point of view there is also a danger that the scheme requirements (unless they themselves are intimately acquainted with them) may form a hidden parallel specification. There is potential tension in this case for designers, who must either consult their clients very closely, or risk incorporating features into the project that the client may not ultimately support. Designers and contractors may face similar challenges in relation to material selection; for example, most schemes include requirements for responsible sourcing of materials and encourage the use of materials with low life cycle impacts in terms of greenhouse gases and other pollution. This provides incentive for suppliers or component manufacturers to accommodate these requirements into their products and has the potential to manipulate markets so that more responsible material sourcing becomes the industry norm (Cole 2005). However, this is a somewhat immature market area (Beradi, 2011) and environmental certification may be far easier to obtain for some products than for others, hence favouring certain materials or products regardless of their wider suitability. In this case there is a similar danger where addressing scheme criteria detracts from making good basic design decisions. So, although assessment may drive specification change in a positive way, it is also possible in the complex interactions of a design process that the easiest path to compliance may in fact be one which least engages with the needs of the building end user. Favouring instead the procedural and construction issues that interfere least with the original design intent (Beradi, 2011).

In addition to the practical difficulties that may be involved in complying with certain credits there will also be a financial consideration. Many environmental assessment schemes ignore economics within their criteria, however the financial implications of achieving a rating may go well beyond the administrative costs already discussed. In some instances, it may be possible for the sustainability of buildings to be improved at zero or even negative cost. More commonly, schemes reward design changes for which there is no simple economic argument, and henceforth act to manipulate the underlying economics of construction. For many schemes this market transformation is a stated aim (Lee *et al*., 2002), and may be effected in a number of different ways. In some cases scheme requirements may simply balance capital and operating costs, for example by encouraging increased use of insulation which will pay for itself many times over in reduced on-going fuel costs. Alternatively, requirements may act to increase standards to bring about social or environmental benefits, for example by encouraging planting schemes to benefit local wildlife. Finally, it may encourage the use of innovative or specialised products in the hope that this will reduce future costs by bringing economies of scale to bear. The increase in project costs linked to these factors has been openly discussed by scheme operators (BRE and Cyrill Sweett, 2005). However, these estimates belie a rather complex situation, as the various discreet improvements rewarded by the scheme will also each have greater or lesser synergy with the practical requirements of the various parties. This situation may be further complicated by contractual arrangements, particularly where credit selection changes during the design process (for example certain credits may require additional design time, where others may attract additional construction cost). As such, although in theory designers will aim to satisfy those requirements that most provide the greatest cost/benefit for the end user, a situation may also develop whereby requirements are targeted based on the simple capital cost to the project, or even to particular parties.

That some credits are more difficult or expensive to achieve than others is perhaps inevitable, but it would be unwise to ignore this issue, as credits which are not attempted because they are too expensive can produce no benefit. In LEED, for example, research by Beradi (2011) identifies compliance rates varying very significantly between categories, from the lowest at 38% for “Energy and atmosphere”, to the highest at 66% for “Innovation and design process”. Therefore, it is possible to crudely surmise that the scheme is effecting almost twice as much change in terms of the construction process, than in climate change, and it would be of interest to discover the extent to which this may be driven by scheme users seeking to minimise compliance costs. Lee *et al*. (2002) suggest that credits could be weighted according to cost and difficulty to combat this effect. However, this would represent a significant change of emphasis from the current picture of assessment contributing to sustainability improvements, to one where market transformation becomes the primary aim.

The administrative burden associated with obtaining a rating and the pressures that practical considerations may have on the way that scheme requirements are approached has already been discussed. Added to this, however, it is worth briefly discussing the practicalities of obtaining a rating. There is broad agreement that early consideration of scheme requirements is beneficial (Ding, 2008; Hakkinen, 2012), but many assessment schemes are paper based (Cole, 2005) and predominantly passive. The requirements of BREEAM, for example, are contained in a manual format and given that such fundamental decisions such as the location of the site are assessed, these requirements must be understood in its entirety at the outset if the maximum rating is to be achieved. Alwaer and Kirk (2012) suggest “a key function of sustainability assessment should be to distinguish objectively between the performance of different courses of action”. Hakkinen (2012) similarly highlights a need for design tools, and Ding (2008) likewise suggests that assessment methods concerned with new build or refurbishment projects are “most useful during the design phase”. Paper manuals may additionally not sit well with normal design practice, which can be rather linear in nature and often proceeds by tackling issues in order of importance, returning to review earlier decisions only reluctantly (Barlow, 2011). The professional team involved at this early stage must therefore be fully conversant with the scheme, or must employ somebody who is. Similarly, at project completion, validation of results generally occurs all at once when all features are in place, providing potential for last minute disappointment if requirements have been misunderstood or incorrectly implemented, or if evidence has not been collected correctly. The paper manual format has been much emulated and is still widely employed, however web based technology is also available (Cole, 2005) with Green Globes for example operating as an online process (Green Building Initiative, 2014). It remains to be seen whether this may be employed to mitigate the problems described above. Perhaps allowing methods to be employed in a more interactive manner, even as a design tool. Regardless of format, there does, in any case, appear to be an argument for aligning certification for new construction more closely with the design process, for example by adopting a series of stage approvals rather than a single final evaluation. Barlow (2011) explores this idea by aligning particular BREEAM credits with particular Royal Institute of British Architects (RIBA) design stages. As it stands, this approach does not yet appear to have been adopted by any mainstream scheme operator. The nature of a criteria based assessment also generally dictates a checklist approach (Bell and Morse, 2003). Meeting these requirements results in credits being awarded which contribute to a final total and in turn dictate the rating achieved. Certain requirements may be mandatory, but generally speaking the user is free to select those credits which most appeal to them, and ignore those most problematic. This “balanced scorecard" approach is a significant strength of these schemes as it means that projects which may have inherently unsustainable features could still engage with the scheme and achieve a rating by improving other aspects of their design or operation (Barlow, 2011). It also allows scheme operators to include the criteria they want to without unduly restricting their customer base. On the other hand, where methods are used in an active fashion, there is a potential for design itself to follow a checklist approach; indeed, if a building is to achieve a top rating under a scheme then the design team must, arguably, proceed in this manner. This is perhaps no accident, with Cole (2005) noting that the building industry is notoriously risk averse and prefers "simple, unambiguous messages regarding what to do, rather than why it should be done". Schemes can therefore perhaps be seen to provide an industry definition of what constitutes a "green" building (Cole, 2005), albeit this may be incompatible with achieving a pathway towards a sustainable built environment as described by Guy and Moore (2004). A particular problem with this approach is that designing to satisfy a list of criteria merely ensures alignment with the limited viewpoint of the scheme and may ignore important features that it was simply not felt practical to include. Additionally, schemes are typically dominated by threshold criteria, which reward attainment of a minimum standard, often with no credit given for further achievement (Becker, 2004). Perhaps more importantly, designing to a checklist may impact both the quality and creativity of design. Innovative buildings may find it difficult to achieve ratings where schemes focus on mitigation rather than adaptation (Cole, 2005; Birkeland, 2008). In light of this, Oehlkers (2008) notes in relation to LEED that the scheme was not meant to hold back eco conscious designers but rather to transform the conventional building.

2.8 Conceptual framework

The literature review has provided reason to challenge the theoretical basis for using criteria-based, design stage assessment to determine sustainability. It also brings into question the practical effectiveness of BSAS in producing measurable improvements in use and the accuracy of design stage predictions of performance in general. Post occupancy evaluation is not inherent to any of the schemes identified. Furthermore it appears that for many stakeholders certification is their primary aim, with building performance being a secondary consideration. It is also apparent that schemes are open to gaming by key construction team members including designers and speculative developers for whom BSAS criteria must vie with a range of commercial considerations. As such, the true value of these assessments to policy makers is highly uncertain. Given the current widespread and increasing reliance on BSAS to measure and demonstrate sustainability in buildings, further research targeting this knowledge gap is essential.

As summarised in Figure 2.8.1, BSAS aim to improve building sustainability by influencing design and construction using a checklist of indicators. A certificate or rating is then awarded based upon an assessment of compliance with this checklist (in the case of BREEAM certification may be awarded at “Design” and/or “Post Completion” stage). In practice, there are however a number of significant factors which may work to frustrate this process. On a technical level, the use of indicators is by its very nature an imprecise means of predicting performance. Further increasing uncertainty is demonstrated when allowing project teams a choice of indicators and requiring them to produce their own evidence to demonstrate compliance. Overarching these practical difficulties, commercial pressure may act as a powerful incentive for gaming by project teams, whilst a lack of post occupancy evaluation prevents the use of feedback to measure and improve performance on an empirical basis.

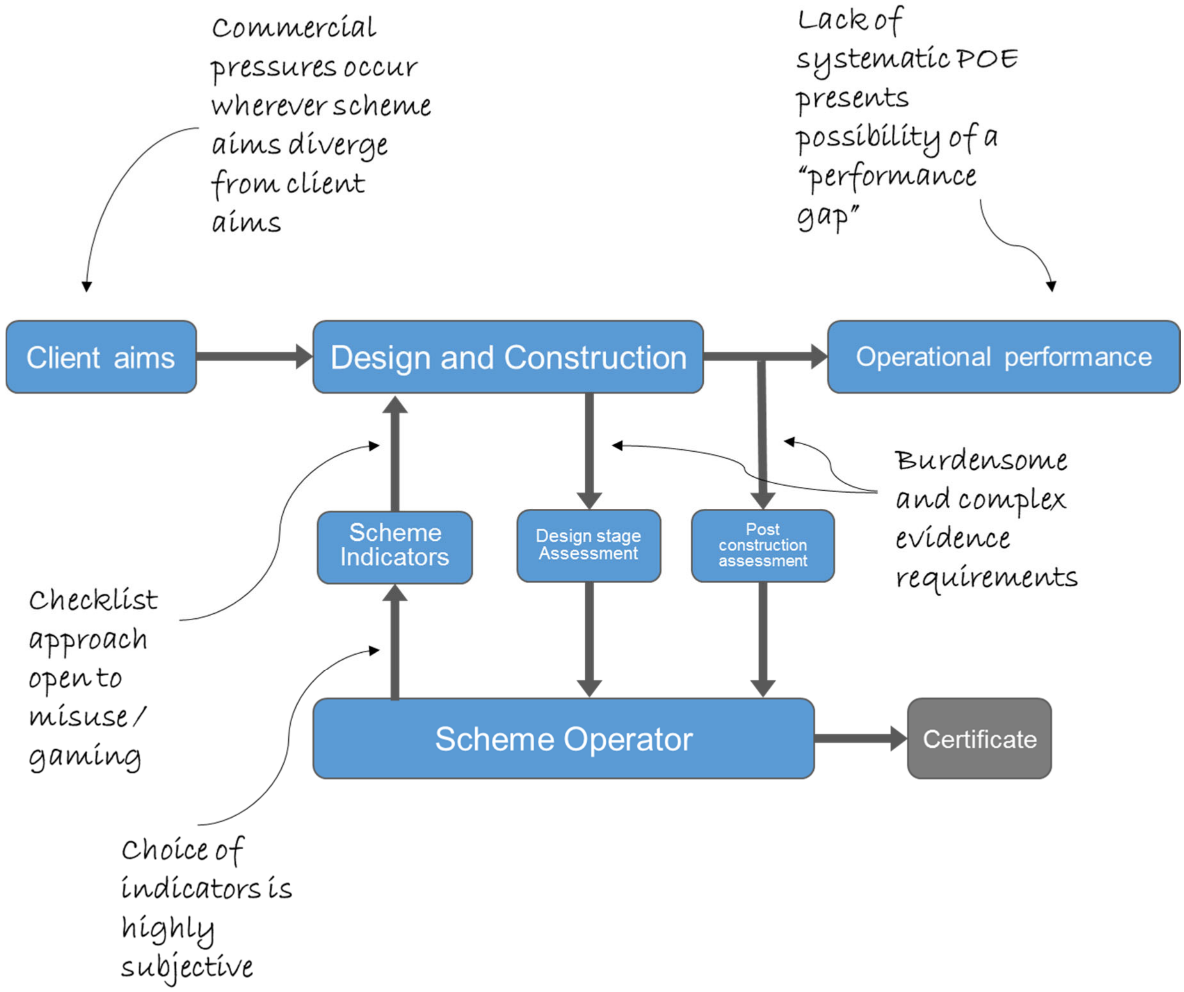

Figure 2.8.1 – Conceptual framework indicating the theoretical limitations of building sustainability assessment schemes

A study is therefore required which examines the extent to which these theoretical difficulties may be contributing to the empirical shortcomings observed by researchers including Scofield (2008), Monfared and Sharples (2011) and Turner and Arif (2012). This will require a detailed investigation of the key processes indicated; that is, an assessment of the indicators used and an understanding of how they are applied and evidenced in practice. To provide context for these activities, it is also desirable to measure the impact of these activities on the performance of the building in use. The knowledge gap, research aim and research objectives may therefore be summarised as follows:

Knowledge gap

- The design and construction stage interventions promoted by BSAS do not appear to be a reliable means of improving overall building performance and whilst a number of general theoretical weaknesses have been identified within these methodologies, the particular factors limiting their effectiveness are currently poorly understood.

Research aim

- To increase evidence of the relationship between building sustainability assessment schemes and building performance.

Research objectives

1. To assess BSAS content, by examining the operational effect of applying individual criteria in certified buildings.
2. To assess BSAS methodology, by examining the manner in which individual criteria have been applied during the design and construction of certified buildings
3. To assess whether a BSAS rating is a useful sustainability differentiator, by comparing the in-use performance of certified buildings with established benchmarks.
4. To generate recommendations for increasing the efficacy of BSAS, based upon an improved understanding of the link between content, methodology and building performance.

Addressing the knowledge gap and resulting research aim will require close examination of certified, occupied buildings. The research objectives require both that the overall performance in use of those certified buildings is measured, and that the realisation and operational effects of individual criteria are examined. Combined analysis of these will allow an assessment to be made of both whether and why certification produces a more sustainable building.

CHAPTER 3 – METHODOLOGY

This chapter describes and justifies the research design, including epistemology, theoretical perspective, methodology and methods. A reflective description of the data collection process is then given, followed by a review of the ethical considerations.

3.1 Research Design

3.1.1 Theoretical perspectives

This study is concerned with the impact that applying a sustainability assessment process to a building at design stage has on its in-use performance. The research aim and objectives require an examination of the assessment process, its direct effects on the physical manifestation of a building and the cumulative result of these multiple effects on particular aspects of building performance. A positivist perspective has been adopted and the research aims and objectives will be addressed through empirical enquiry (Gray, 2014). It is the tangible elements of the process and outcomes that will form the core of the analysis, the overarching aim of the research being one of improving measurable outcomes. An interpretivist stance was rejected and the study does not seek to examine the value or meaning attributed to assessment, sustainability or building performance. Therefore, although the influence of human behaviour on both the assessment process and the performance of buildings is acknowledged, these will be treated as a contextual factor for the purposes of this research. This approach is in line with key research that has informed the research aims (Bordass *et al*., 2001; Scofield, 2009; Monfared and Sharples, 2011; Menezes *et al*., 2012; Turner and Arif, 2012; Johnston *et al*., 2016) and is considered appropriate for extending it. Failure to fully consider the influence of culture and society is, nevertheless, a limitation. A particular consequence of this limitation is that the degree to which the study results might be impacted by variations in culture across regions or countries has not been assessed.

3.1.2 Methodology

As set out in Chapter 2, the literature review suggests that the application of BSAS standards is failing to produce the expected sustainability improvements in buildings. Analysis of the literature has also generated a number of theories as to why this might be the case i.e.

1. The use of indicators weakens the potential for assessment to influence building performance
2. The checklist approach adopted by BSAS is open to misuse/gaming by design teams
3. The choice of target credits may be influenced by the administrative burden of the evidence requirements
4. Commercial pressures may dictate the choice of credits, particularly where scheme aims diverge from client aims
5. The lack of systematic POE presents the possibility of a “performance gap”

Testing these theories deductively would require an experimental approach. An established means of achieving this would be to construct a hypothesis relating to each theory and test it statistically using quantitative data (Gray, 2014). This methodology has the potential to produce robust results, but requires access to suitable data. Unfortunately the data required to examine the effectiveness of a useful range of individual assessment criteria is not typically collected or reported, either by building occupants or researchers. Indeed, a failure to incorporate POE into BSAS has itself been identified in Chapter 2 as an important theoretical limitation. It is also a characteristic of these schemes that buildings are awarded a very simplistic “certification”, without public dissemination of the procedure or detailed scoring supporting the result (Alwaer and Kirk, 2012). Furthermore, both assessment and building performance data may be commercially or reputationally sensitive, making it less likely to be shared, even where it is collected. This lack of existence and dissemination of data has undoubtedly contributed to the existence of the identified knowledge gap and is not easily surmountable. To achieve the research aim it has therefore been necessary to consider combining experimentation with alternative, qualitative approaches (Gray, 2014). The suitability of a number of potential qualitative methodologies have been considered as summarised in Table 3.1.1.

Table 3.1.1 – Summary of available qualitative methodologies

Methodology	Features	Suitability
Case study	May incorporate a range of research methods Requires a high degree of access/co-operation May be longitudinal or cross-sectional	High
Ethnography	Examines cultural influences on behaviour Requires researcher "participation" Suitable for longitudinal studies	Low
Phenomenology	Examines human experience Requires in-depth study of individuals Typically used as an inductive process	Low
Grounded theory	Generates theory from empirical data Can employ qualitative or quantitative data Typically concerned with participant behaviour	Low
Action research	Requires researcher "participation" Researcher is an agent of change Data is generated through participant experiences	High
Heuristic enquiry	Typically focussed on a personal problem Understanding is derived using self-enquiry Limited potential for generalisation	Low

As discussed above, although human behavioural characteristic have potential bearing on particular aspects of both assessment process and building performance, it is the quantitative result of assessment that is the core area of interest. As such, detailed investigation of individual's behaviour and attitude are considered to be peripheral to this research. For this reason, potential methodologies such as ethnography, phenomenology, grounded theory and heuristic enquiry are considered to have a low level of applicability to the study. Of the methodologies identified above, only action research and case studies are discussed in further detail.

Action research

Action research has been successfully used as a means of examination of the energy performance gap in housing (Johnston et a.l, 2016). Researchers have carried out close observation of construction process and incited controlled changes, with a view to achieving greater understanding of the mechanisms involved in achieving improved results. Such an approach would appear to have great potential both to increase understanding of BSAS process and to test theories relating to how it might be improved. The researcher would ideally participate (or form a suitable arrangement with existing participants) in the design and assessment of the building. The researcher would then monitor (and perhaps intervene) in the construction of the building, and carry out POE following occupation. Such a project would however require a considerable time commitment. From inception a building might typically take a year or more to design and a further year to construct. At least one further year would then ideally be required to allow performance data to accrue (Preiser and Vischer, 2003). A minimum three year data collection process would therefore be needed, with the additional risk of this being extended due to unforeseen delays to design, construction or occupation. Such timescales are unfortunately inconsistent with the practical requirements of this project.

Case studies

Case studies are an investigation of a contemporary phenomenon in its real life context (Yin, 1984) and allow for highly detailed examination and analysis. When applied to a whole building, they are capable of generating large volumes of data, often within a well understood and well defined setting (Thomas, 2011). Case studies have been employed in key supporting literature used to generate the research aim. The Probe studies (Bordass *et al*., 2001a) in particular, make use of case studies that include POE of individual buildings to identify specific performance shortfalls, combined with detailed analysis of the building as a whole. These multiple sources of evidence are then used as a basis to comment on more general underlying problems with building design and operation. Given the lack of access to existing data, case studies arguably provide the only practical means of gathering robust primary data with which to address the chosen research objectives. Case studies may additionally be applied in a cross-sectional manner, allowing data to be collected at a point in time (Schell, 1992) and thereby limiting the required data collection period. These two factors make this technique highly suitable for this project and were key factors in its selection. There are however a number of limitations inherent in the approach. The method can be resource intensive, due to the need to collect and analyse multiple sources of primary and secondary data. Resource requirements therefore limit the number of case studies that can be practically studied. Meanwhile, case study selection is also critical to the representativeness of the data produced. Selection of case studies is often necessarily purposeful, and may therefore be based on practical considerations such as location and ease of access, as well as their representativeness. This may be viewed as a positive factor, allowing high quality reliable data to be obtained (Thomas, 2011). However, because case study data is context dependant, care must be taken when generalising (Schell, 1992; Thomas, 2011). It is therefore understood that any assertions resulting from case study data must be founded on high quality data in a well understood context, rather than statistical analysis (Rose and Manley, 2011; Yin, 2014).

3.1.3 Case study design - Theoretical considerations

Addressing the research aim requires that both an assessment and its subject building are examined, in order to better understand their interrelationship. Research objectives 1 and 2 are concerned with the effects and means of applying an assessment to a particular building. These require both access to assessment scheme report documentation and detailed knowledge of the physical manifestation of the associated buildings. Research objective 3 requires that data be collected relating to pertinent elements of building performance. Research objective 4 relies on triangulating the qualitative and quantitative data to comment on the significance of limitations identified from the literature and to propose mitigation measures relating to these. As such, a predominantly "explanatory" case study approach has been used to test existing explanations as to why BSAS are failing to reliably ensure improved sustainability performance. Notwithstanding this, case study data may also be used both to describe and test theories (Schell, 1997) and although not a primary aim, there is potential for the data collected to also identify further reasons for poor performance (a "descriptive" output).

As discussed above, collection of detailed data through unrestricted access is a key strength of the case study approach, whilst obtaining such access is a noted challenge. A leading requirement for case study selection in this instance was therefore that access be available for collection of high quality primary building performance data. It was also desirable that case study buildings be recently constructed, to provide insight into the most up to date assessment methods possible. Multiple case studies were desirable, for a number of reasons. Multiple case studies increase the depth of data where case studies are similar, or broaden the data where they significantly differ. Comparing data from different settings increases certainty and the potential for replication and generalisation, whilst examining different sets of data limits project risk by avoiding relying exclusively on one setting (Yin, 2014). Multiple case studies also mitigate an important problem associated with case studies; that gaining a detailed understanding in a single context may lead a researcher to overestimate their overall understanding of an issue (Guthrie, 2010). Four case studies were used for this project, representing a compromise between the breadth and depth of information desired, the need to cross reference data across settings, and the resources available. Each case study comprises a recently constructed building and its associated sustainability assessment and these were purposefully selected in conjunction with a university estates management team. The assessment scheme applied to the study buildings was BREEAM in every cases; the use of multiple schemes was rejected on the grounds that this would have unacceptably increased the scope of the project. The use of alternative established schemes such as LEED or CASBEE was also rejected, primarily because their use in the UK is so limited that obtaining access to multiple buildings with certification under these schemes, within realistic travel distances for data collection, would have been extremely challenging. The national and international relevance of BREEAM is discussed in detail in Section 3.1.4 below, whilst the detailed characteristics of the buildings themselves are discussed in Section 4.1.

3.1.4 BREEAM

As discussed above, for primarily practical reasons, the selected case study buildings have all been assessed using the BREEAM scheme, this being the most used scheme in the UK by some margin (Figure 3.1.1). BREEAM is, additionally, considered a good proxy for BSAS in general, for a number of reasons. It has substantial and expanding UK uptake (Figure 3.1.2) and is internationally significant in terms of certification numbers (Figure 3.1.3). BREEAM also offers a "global" version (BRE Global, 2016) and has additionally been specifically franchised to 8 other countries including the USA, Germany and Spain. Only LEED currently has a greater global reach and whilst theoretically suitable, its low uptake in the UK would have made availability of case studies extremely limited.

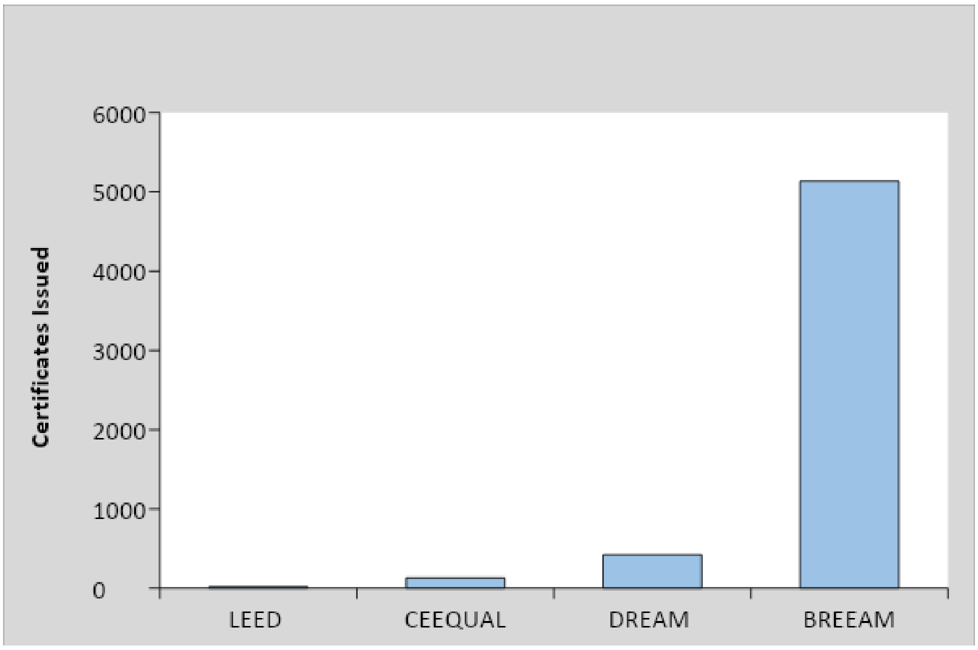

Figure 3.1.1 – Total number of UK certificates issued by scheme (Aug 2012)

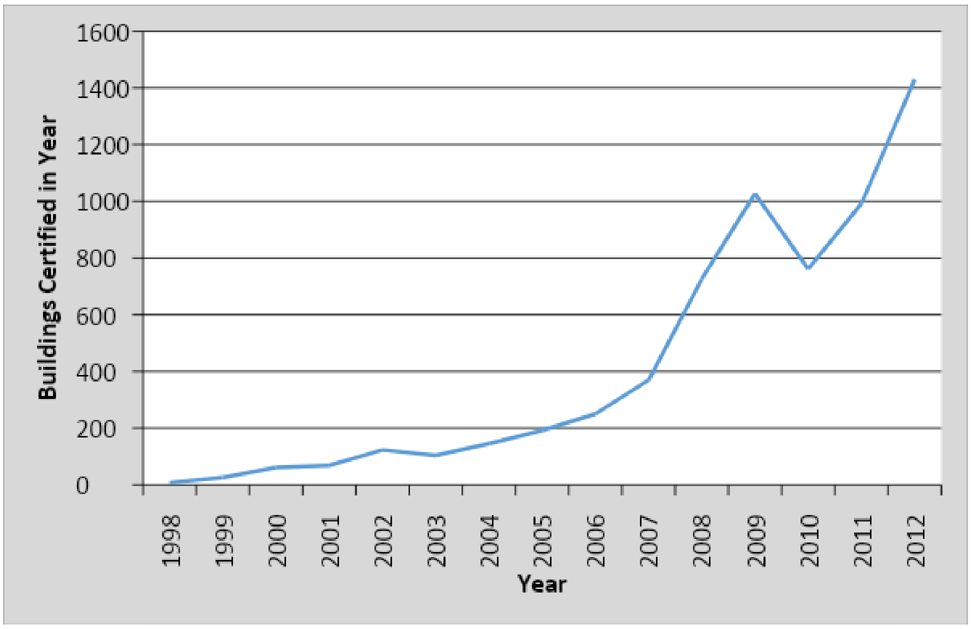

Figure 3.1.2 – Number of UK BREEAM certificates awarded by year (BRE, 2012)

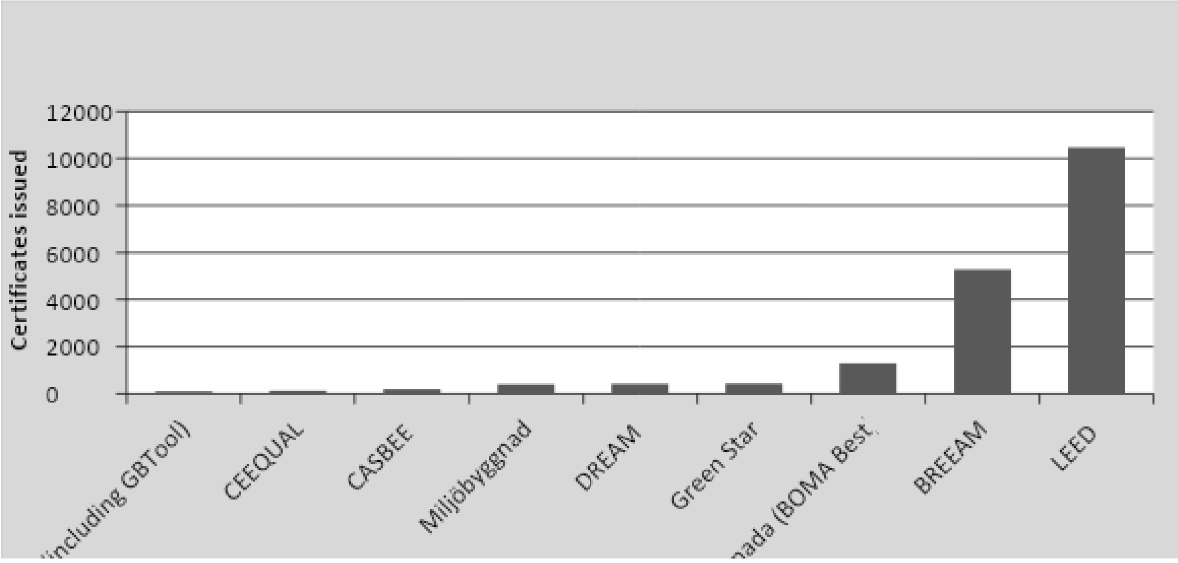

Figure 3.1.3 – Total number of certificates issued worldwide by scheme (Aug 2012)

Numerically, BREEAM is highly representative of sustainability assessment in the UK where this study is based, and is likely to remain so for some time. Along with LEED, it is also an important scheme internationally. As discussed in Chapter 2, BREEAM is further acknowledged as being the original BSAS and has both inspired and retained similarities with many other schemes. Despite these recommendations, it is acknowledged that there are numerous differences between BREEAM and its competitors, both in terms of configuration and ambition. An analysis of BREEAM cannot therefore necessarily be considered representative of other schemes in detailed terms. It is expected however that it will provide substantial insight into both the use of criteria based schemes in general, and the general effectiveness of using design stage specification to produce sustainability benefits in use.

It should be noted that the BREEAM scheme has undergone a number of updates since its inception, and the particular version of the scheme to be studied must therefore also be considered and justified. Occupied buildings holding a BREEAM 2011 or BREEAM 2014 certificate were not widely available when the fieldwork was conducted (Spring 2013), due to the time delay inherent in obtaining certification and a desire to study buildings which had been in occupation for at least one year. Instead, the buildings considered held certification under BREEAM 2006 and BREEAM 2008. The particular differences between these and later schemes are discussed in detail in section 3.1.4 and are considered minimal; the changes being primarily a ramping up of standards in response to increases in minimum statutory requirements, with both the general approach and the specific structure of individual criteria being largely unchanged. An analysis of the general effectiveness of BREEAM 2006 and 2008 is therefore considered to be highly representative of all manifestations, up to and including the current versions.

3.1.5 Data requirements

BSAS offer a comprehensive sustainability rating, constructed using a large number of discreet and disparate indicators (Brandon and Lombardi, 2011). The construction of this rating is complex and, crucially, lacks a unifying metric of measurement. Because of this, measuring the extent to which the rating differentiates a building from standard practice in quantitative terms is highly problematic. To address the research objectives, an alternative approach is therefore required. The configuration of BREEAM described in detail in section 4.2 is broadly similar to many other BSAS. It consists of a dimensionless scoring mechanism, based upon compliance with criteria and credits, grouped into categories and added to give an overall rating. As noted above, the lack of a verifiable metric for the overall rating makes comparison of rated and non-rated buildings in terms of their BREEAM score meaningless. In order to produce a measurement framework to support the research objectives, a thorough, bottom up analysis of the scheme contents was therefore required, in order to understand what differences might be expected to be observed between a rated and non-rated building.

3.1.5.1 Research objectives 1 and 2

Examination of the impacts of assessment on a building in use firstly required that the case study buildings be examined to confirm whether the design interventions for which the building achieved credits are evident. Secondly, the case studies needed to reveal whether those design interventions which are evident have produced a sustainability benefit. Achieving these objectives provides essential context for the quantitative data examination through research objective 3, contributing in turn to the ability to suggest improvements as required to satisfy research objective 4. These contextual information requirements were based upon techniques used successfully for the Probe Studies (Bordass *et al.*, 2001b), with the significant additional requirement that the BREEAM documentation be examined in detail. The following techniques were therefore employed:

- Review of building design information
- Walk through surveys of occupied buildings
- Formal and informal interviews with buildings and facilities managers
- Review of BREEAM reports

Considered together, these have produced a detailed picture of which elements of the BREEAM scheme were applied and evidenced in each of the case study buildings, and the extent to which this influenced the as-built design.

3.1.5.2 Research objective 3

Research objective 3 is concerned with quantitative, in-use, sustainability and will be addressed through building performance evaluation (BPE). As discussed in Chapter 2 BSAS are concerned with multiple performance metrics; the BREEAM scheme versions used to assess the case study buildings include a total of 110 different assessment issues and some analysis was therefore required to establish which elements of building performance should and could be measured. To establish the data requirements, both the stated aim and the criteria for each scheme credit were examined in detail, in order that the assessment theme (or themes) could be identified. Collating these themes for each BREEAM category reveals the full scope of themes assessed and therefore the material differences that might be expected to result from scoring credits within that category (refer appendix A). Combining all themes sets out the differentiation that should be evident for a building complying with the scheme as a whole. Analysis of appendix A reveals that 63 distinct themes were identified, some of which appear in multiple categories. This analysis provides us with a list of building characteristics against which a building with a 100% BREEAM rating should outperform equivalent non-rated buildings. Full realisation of research objective 3 would require that performance in each of these areas be both measured, and compared to a suitable benchmark. Table 3.1.1 therefore lists the 63 identified themes, and identifies a potential data collection method for each. The viability of each of these data collection methods is discussed in turn, below.

Table 3.1.2 – BREEAM assessment themes with corresponding potential data collection requirements (themes shown in brackets were not assessed for any of the selected case study buildings)

Themes (63)	Potential data collection method
Construction stage site impacts (environmental and social) Embodied carbon of construction materials Pollution associated with construction materials Monitoring and minimising construction waste Use of recycled aggregates for construction Brownfield development Contamination remediation Maintaining / improving site biodiversity (Foundation design) (Re-use of building elements) (Using a BREEAM consultant)	Design and construction stage data collection methods
Pedestrian and cyclist safety Incidence and fear of crime Legionella Flood risk (Safe and effective fume cupboards) (Refrigerant global warming potential)	Statistical analysis of event incidence
Energy efficiency of building services CO_2 emissions (regulated energy) Monitoring of energy use *Renewable energy* (Energy efficiency of building fabric) (Energy efficiency of domestic appliances) (Energy efficiency of IT equipment)	Energy consumption monitoring
Water efficiency in-use Monitoring of water use Water leak detection/mitigation Water for irrigation (Water re-use) (Water for vehicle cleaning)	Water consumption monitoring
Mechanical ventilation Daylighting View out Artificial lighting Natural ventilation Thermal comfort Acoustics (External pollutants)	Building user studies survey
Promotion of sustainable construction Public transport provision and information Proximity to amenities Cyclist facilities Car parking	Building user transport survey
Building functionality Building aesthetics Traffic impact Community relations Building maintenance requirements Recycling of building waste (in use) NO_x emissions Light pollution Noise pollution CO_2 levels Volatile organic compounds *(*Cost effective maintenance and operation) (Accessibility) (Chilled drinking water) (External amenity space) (Compaction of recyclable building waste (in use)) (Composting of building waste (in use)) (Tenant's floor finishes) (External amenity space) (External educational space)	Specialised data collection methods required

Design and construction stage data collection methods

Eleven themes have been identified which relate to the manner in which the building is designed and/or constructed, or the nature of materials embodied within the structure. These themes do not lend themselves to post occupancy evaluation, as they are not readily measurable within the completed building. Inclusion of these themes within the scope of the project would require the use of a longitudinal study monitoring the design and construction of the building, in addition to measuring its performance in use. Such a study would require a data collection period of at least 3-4 years, which was not feasible within the timescales of this project. These themes were not therefore suitable for assessment.

Statistical analysis of event incidence

Six themes relate to reduction of risk for relatively uncommon events, such as on-site injuries to pedestrians and cyclists, flooding of local watercourses, and accidental escape of refrigerant gases. A case study approach does not lend itself to examination of these themes, which would instead require relevant data for a large number of BREEAM certified buildings. As in-use data is not routinely recorded or collected as part of the BREEAM process, this would need to be gathered by the project team. This would be a significant undertaking, and may also be hindered by the sensitivity of the information, which generally relates to negative incidents. As such, assessment of these issues was not considered to be feasible within the timescale and resources of the project.

Energy consumption monitoring

Seven themes relate to energy consumption within the building in-use. Energy consumption monitoring is considered compatible with the proposed case study approach, subject to the metering arrangements in place within the occupied buildings. A range of energy consumption data benchmarks is also in existence, making these themes suitable for assessment. .

Water consumption monitoring

Six themes relate to water consumption within the building in-use. Water consumption monitoring is considered compatible with the proposed case study approach, subject to the metering arrangements in place within the occupied buildings. A range of water consumption data benchmarks is also in existence, making these themes suitable for assessment. .

Building user survey

Eight themes relate to the internal environmental quality of the building. BREEAM addresses these themes under the wider category of “Health and Wellbeing” and it is therefore implicit that the overarching reason for improving the internal environment is intended to be for the subjective benefit of building users. A post occupancy survey of building users was therefore identified as an appropriate means of data collection. As described in further detail in section 3.2.2, the use of a standardised survey method additionally provides benchmark data, making these themes suitable for detailed assessment within the study.

Building user transport survey

Five themes might be addressed through the use of a building user transport survey. However, variations in the road and public transport environment surrounding individual buildings are likely to be highly influential in any results. As such, although useful national benchmark information is available in relation to transport behaviour, meaningful comparison with this would require the examination of a data from a large cross section of BREEAM certified buildings. As previously noted, such data is not routinely collected, and would be beyond the scope of the project to assemble. As such, these themes were not considered suitable for assessment as part of this study.

Specialised data collection methods

A further 20 themes have been identified, which would each require an additional stand-alone data collection method to be mobilised. These themes are not suitable for assessment within this study, because they each require substantial additional resources, whilst returning data in relation to just one BREEAM issue.

Non-uptake of BREEAM issues

In addition to the difficulty of assessing and benchmarking certain themes described above, the configuration of the scheme additionally means that only a proportion are tackled for each building. A building achieving a “very good” rating under BREEAM need only attempt a proportion of the available credits. Collecting data in relation to all themes is therefore unlikely unless a large number of buildings are studied. In practice, a significant number of BREEAM issues were not targeted for any of the case study buildings, and as a result no assessment was made of the effect in relation to these. Twenty themes are identified as relating to these issues and are indicated in brackets in Table 3.1.5. This limitation is unavoidable, being inherent to both the case study approach, and the assessment methodology. The impact on the study results is however minimal, as a large number of issues remained to be assessed. The impact of this feature of the assessment on its results is however potentially significant, and is discussed in detail in Chapter 4.

Post occupancy evaluation

Based on the analysis presented above, building energy monitoring, building water monitoring, and a building user survey were applied to the case study buildings. These were expected to provide performance data for comparison with recognised benchmarks in relation to 14 key themes as follows:

- Energy efficiency of building services
- CO_2 emissions (regulated energy)
- Monitoring of energy use
- Water efficiency in-use

- Monitoring of water use
- Water leak detection/mitigation
- Water for irrigation
- Mechanical ventilation
- Daylighting
- View out
- Artificial lighting
- Natural ventilation
- Thermal comfort
- Acoustics

This data will therefore provide a basis for evaluating the degree to which BREEAM certification is an effective differentiator of performance in 14 of 62 themes identified within the BREEAM assessment scheme. These themes account for 26% of available credits, concentrated in the Energy, Water and Health and Wellbeing categories. Whilst incomplete, a detailed examination of these three key categories, conducted across multiple buildings and against recognised benchmarks will make a substantial contribution to furthering research objective 3.

3.1.5.3 Research Objective 4

Research objective 4 is concerned with examining the link between scheme content, methodology and building performance. A framework for such an examination is presented in Figure 3.1.4. This framework considers the efficacy of a particular BSAS criterion at 5 levels as follows:

- Level 1 (Selection) - The credit is targeted by the user
- Level 2 (Compliance) – The credit produces a design change
- Level 3 (Delivery) – The credit produces a performance benefit for the building
- Level 4 (Tactical) – The credit produces a wider sustainability benefit
- Level 5 (Strategic) – The credit contributes to the stated aim(s) of the BSAS

Adopting this framework, it follows that selection of a credit is a pre-requisite for producing a design change, which is in turn a pre-requisite for improving building performance, and so on. In effect, scheme criteria must pass over a series of hurdles before they will be effective within the stated aims of the BSAS.

BREEAM credit Hea 01 is used as an example to illustrate this proposal. The stated aim of the credit is “to give building users sufficient access to daylight”. If the credit is not targeted, or if no change is effected in the completed building then no improvement in daylight levels can be attributed to the influence of the scheme. If however the intended change *is* achieved and evidenced in the completed building, then this evidence contributes to certification. At this point the BSAS process is complete and it is deemed that application of the criteria has improved the daylighting within the building. This improvement is however assumed, and is not tested through the normal application of BREEAM. Furthermore, the scheme provides no evidence that improved daylighting has produced a measurable building performance benefit, will contribute to the wider sustainability of society, or contribute to achieving the proffered benefit of the assessment scheme. As indicated in Figure 3.1.4, this research project is concerned primarily with furthering understanding of criteria impact at level 3. As noted in Chapter 2, research (Haroglu, 2013) suggests that BSAS are relatively effective at producing design change, but that there has been little objective examination of whether these design changes produce their intended benefits. An exploratory case study used in conjunction with this framework provides a means of examining these links and presenting an assessment as to whether implementation of particular criteria have produced their intended effects in particular cases. Comparison of more or less effective criteria will be used to identify strengths and weaknesses with the scheme methodology and content, and hence produce recommendations for improvements.

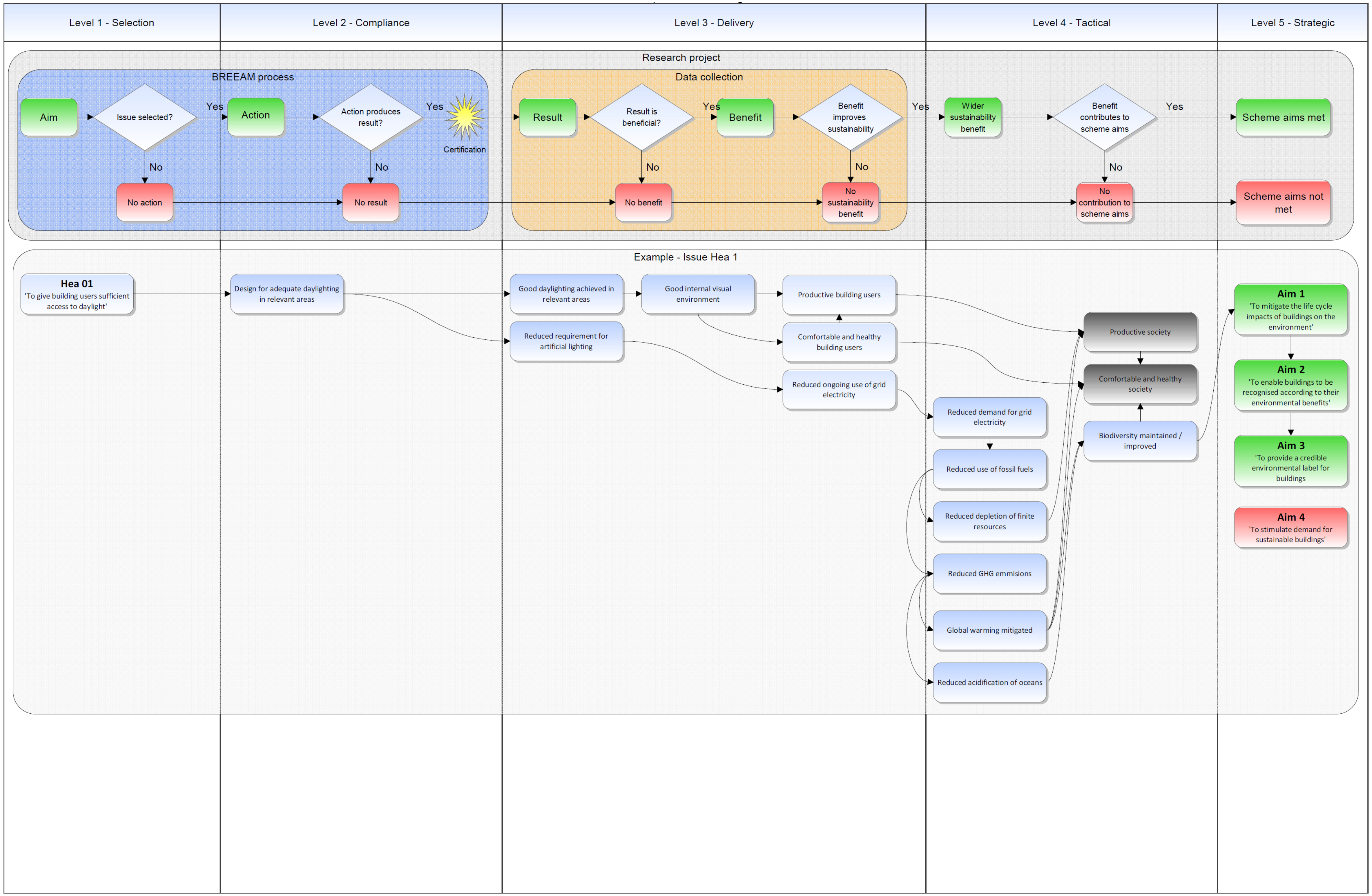

Figure 3.1.4 - Framework for assessing the efficacy of BSAS credits and associated criteria

3.2 – Practical application and reflections

3.2.1 Justification for selection of the case study buildings

The use of a case study approach and its design are justified and discussed in sections 3.1.2 and 3.1.3 respectively. Purposeful selection of case studies has been identified as both a potential weakness and a potential strength of the approach and an explanation of this process therefore follows. Selection of buildings owned by the university in which the researcher was based was considered advantageous in terms of arranging access, which is a key constraint for case study research. Buildings were also required which had been in occupation for at least one full year and which held the most recent BREEAM certification possible. This further reinforced the desire to use university buildings, as a number of recently constructed buildings were available, all of which had achieved BREEAM certification. Having identified a number of buildings meeting these essential requirements, the following secondary aspects were considered:

- Location
- Situation
- Use
- Rating
- Size

The general location of the buildings available was the East Anglia Region of the UK. Using buildings in a similar location was convenient in practical terms and ensured that environmental conditions were broadly similar, allowing for example direct comparisons to be made in terms of energy consumption for heating and cooling. Although broadly representative of many areas of the UK, this region is relatively densely populated, low lying and dry, and these factors were considered where relevant. The particular situation of the buildings is more variable. As described in detail in Chapter 4, two buildings are in city centre locations, whilst two are on sub-urban campuses. This variation has allowed some interesting comparisons to be made, however it must also be acknowledged that rural situations were not represented.

Being university owned, the use of the buildings is broadly similar, consisting primarily of teaching, research and office space. Making use of different building types such as industrial units, hospitals or prisons would have extended the range of the research, however it would also have reduced the depth of data and made it far more difficult to draw comparisons between buildings. Overall, it is considered that the variation in use across the selected buildings is adequate to represent a wide range of higher education buildings, but that generalisation to other building types should be carried out with caution. This project should therefore be considered primarily an evaluation of BREEAM as applied to university buildings, although it is likely that many similar issues may apply across different building types.

In terms of BREEAM rating, all buildings achieved a “very good” standard. This results directly from university policy in force at the time of construction that required this as a minimum standard. As discussed in Section 3.1.3, “very good” is the most widely achieved certificate and is therefore relatively representative of assessments generally. Representativeness could have been improved by including one or more buildings with an excellent rating, as this is also a commonly achieved certificate. Using buildings with higher ratings would probably also have increased the range of issues for which credits were achieved, and therefore the scope of the analysis, and this might be considered for any future work. The particular BREEAM score and rating certified for the four case study buildings is summarised in Table 3.2.1. Note that whilst BREEAM allows for both design stage and post-construction stage assessment, these may be achieved independently of one another. Two of the case study buildings obtained design stage certificates, one obtained only a post-construction stage certificate, and one obtained both. This variation appears to be reasonably typical of the wider picture, as discussed in section 4.2.

Table 3.2.1 – Summary of scheme type and ratings achieved for the case study buildings

Case study	Assessment scheme	Design stage rating / certificate	Post-construction stage rating / certificate
Building A	BREEAM 2008 Bespoke	59% “Very Good”	57% “Very Good”
Building B	BREEAM 2008 Bespoke	Not awarded	61% “Very Good”
Building C	BREEAM 2008 Education	59% “Very Good”	Not awarded
Building D	BREEAM 2006 Bespoke	58% “Very Good”	Not awarded

Of the variables considered above, size is arguably the only one in which significant variation is apparent across the buildings, with floor areas ranging from 450m^2 to

7500m^2. This range is believed to represent the full extent of buildings within the portfolio of this particular university and may therefore be expected to be reasonably representative of university buildings generally. As discussed above, in the context of the available resources, covering a broad range of higher education buildings was in this case considered preferable to attempting to cover all buildings to which the BREEAM scheme may be applied.

The general characteristics listed above were those that materially informed the choice of case studies. Other less fundamental differences between the buildings are discussed at length in Chapter 4.

3.2.2 Case study design (practical application)

The practical application of the case studies was configured to provide data pursuant to the research objectives as described in 3.1.5 and summarised in Figure 3.2.1. A full reflective description of the data collection techniques applied is set out below.

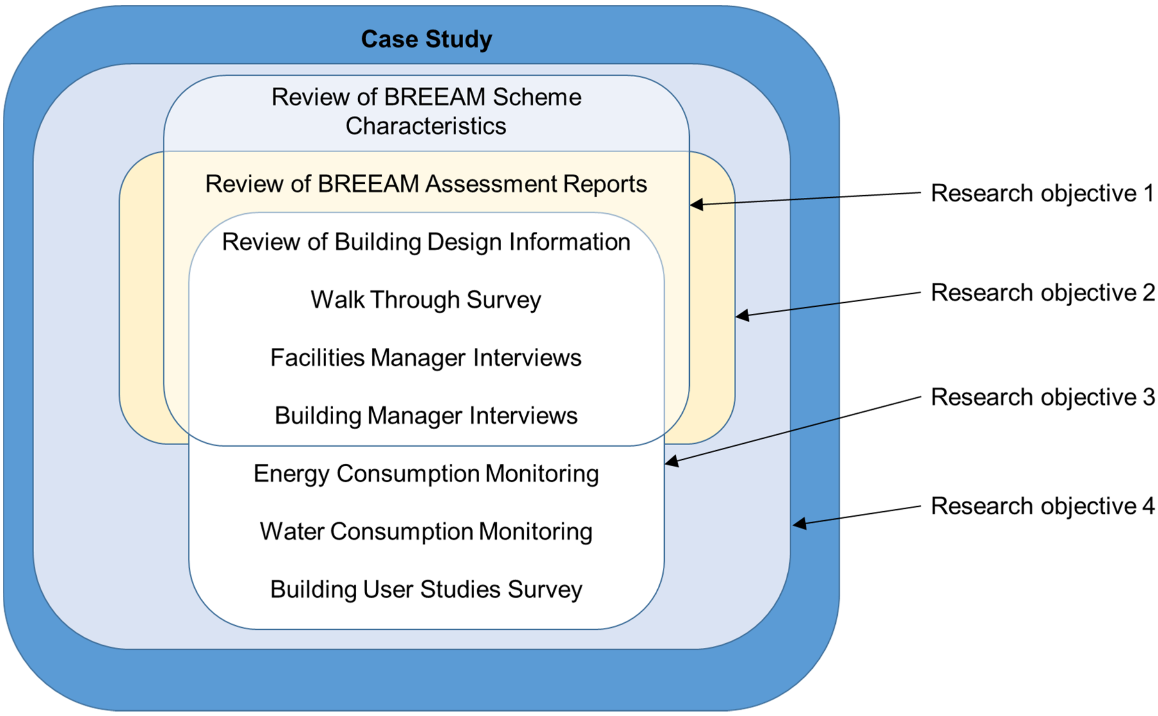

Figure 3.2.1 – Summary of data collection methods used to address research objectives

Review of BREEAM Scheme Characteristics

A full review was carried out of the BREEAM scheme content, application process and outcomes, as presented in Section 4.2. In addition to the review of literature described in Chapter 2, the data presented is based on a combination of publicly available scheme information (BRE, 2006; BRE, 2008a; BRE, 2008b) and a comprehensive set of outcome data disclosed to the researcher by the BRE (BRE, 2012)

Review of BREEAM assessment reports

A successful BREEAM assessment results in a certificate being issued by the scheme operator. This certificate includes the following information:

- Building name and address
- The overall BREEAM score
- The overall BREEAM rating
- The scheme version

The certificates for the case study buildings were obtained from the University Estates department and in the case of Building C, a copy was also displayed in the building foyer. The certificates do not however provide any breakdown of the building score in terms of scoring across particular sections, or within individual issues. To obtain a detailed record of the assessment it was necessary to source a copy of the submissions made to the scheme operator by the BREEAM assessors. These proved quite difficult to obtain in practice. Only one of these reports had been held on file by the University. A further report was obtained via the main contractor, and the remaining two came direct from the BREEAM assessor. In one case it was necessary to trace the BREEAM assessor to his new place of work to obtain the report, as no records had been held by his previous employer. The difficulty experienced in obtaining these reports has wider methodological significance for this area of research, as it is apparent that any larger scale analysis of the application of the BREEAM scheme would likely be significantly hampered by the focus of end users on certification, rather than process. The reports obtained appear to follow a standard template for Buildings A, B and C and include the BRE logo, whilst that obtained for Building D appeared to use an in-house style. All provided similar information as follows:

- Summary of certification information including overall score and relevant stakeholders
- General information about the BREEAM scheme
- General information about the BREEAM scoring and rating system
- Project team and building details
- Summary of the building's assessment performance (by section)
- Detailed assessment of building performance (by individual credit)

Each also included reference to appendices including "BREEAM Assessment Tool and Calculator Print-Outs", however these were missing from all reports excepting that for Building A.

The level of information obtained was therefore generally good, however a number of ambiguities were noted. The general descriptions of the buildings contained within the reports were often inaccurate. This was particularly the case in terms of the building services strategies. The reasons for this are unknown, but were remedied in practice by visual verification of details wherever possible, backed up by reference to as-built drawings and/or discussions with facilities management staff. The floor areas described within the reports were also often considerably at variance with those from other sources. As a result the floor areas of all buildings were measured from as-built drawings. This ensured that appropriate areas were used for analysis based on the observed use of the building, and also that an appropriate and consistent measurement method was used (typically gross internal floor area (GIFA)). Finally there are a number of arithmetical errors in the scoring summary shown in the report for Building D, however the scoring within the detailed sections, and the overall score for certification did appear to be correct.

Review of Building Design Information

The study is concerned with the effect of BSAS on buildings in use, and a full systematic review of design information was not therefore considered necessary. Nevertheless, as-built architectural drawings were obtained for all buildings. These provided useful contextual information relating to the general construction buildings, were helpful in planning the building occupant surveys and provided particular information used for analysis of results, such as floor areas.

Walk through survey

A walk through survey was conducted for each building. This typically took place on the same day as the Building User Survey, although further visits were also carried out as required, to clarify particular issues. Notes and photographs were used to confirm/record the situation of the building (including the use of adjacent areas) and the external configuration, lighting, condition and materials used. Internally, the following specific information was recorded for every accessible room:

- Room function
- Wall, floor and ceiling finishes
- Furniture and equipment
- Heating/cooling sources, controls and current operation
- Ventilation sources, controls and current operation
- Daylighting sources, blinds/shading types and controls
- Artificial lighting type, controls and operation
- Acoustic conditions and control measures

Collection of this information for all rooms was relatively time consuming, but is considered an essential part of the post occupancy evaluation. These observations provided some useful context for consideration of specific issues, particularly relating to the building servicing strategies, much of which differed from that described in the BREEAM reports. The understanding of the use of the rooms provided by the observations, although limited by being collected at a point in time, was also useful in better understanding building user survey results and comments collected in those same areas.

Facilities manager interviews

In addition to the experience of building occupants, the experience of facilities management staff is considered of great interest in evaluating the effectiveness of a building in use. The BREEAM criteria themselves include remarkably little direct reference to facilities management, and this is perhaps indicative of its focus on the design and construction phase. Nevertheless a great many of the design features promoted by the scheme require ongoing professional input to maintain their effectiveness. This is particularly the case for building services, where an appropriate level of technical support may be pivotal in the success of more complex systems (Bordass *et al.*, 2001a). Additionally facilities management act as an interface between the building and its non-technical users, are therefore in a unique position to evaluate both its day to day performance and its longer term viability.

In practice, the level of engagement achieved with facilities management staff was variable. For Buildings B and C it was not possible to arrange interviews. In the case of Building C this was due to staff availability, however for Building B the reason given was a lack of involvement in the building. Specifically, for Building B, the hospital facilities management team appeared to believe that the first point of contact for facilities management issues for the building was the University, although the University facilities management team believed the opposite to be true. For Buildings A and D however the day to day management is carried out by the University facilities management team, and these individuals contributed a significant amount of time to assisting with the study. This included a three hour long round table discussion relating to particular aspects of the BREEAM assessments, attended by the Assistant Director of Building Services, Maintenance Manager, Environment Manager, Sustainability Engineer and Clerk of Works. A structured approach was taken with the researcher first explaining the aim of each BREEAM “issue” before asking contributors to numerically rate both the importance of the aim to them as professionals and the extent to which it had been met on each of the case study buildings. In practice, the time allowed for only a small proportion of issues to be discussed and no structured analysis of the results has therefore been possible. The approach did however prove very successful in generating discussion and the detailed insight that was gained arguably could not have been obtained in any other way. Extending this exploratory investigation to cover all issues on all buildings would potentially have been extremely rewarding, however as noted above it was very time consuming in practice. Some refinement of this technique would perhaps therefore be helpful for future investigations. Pertinent information obtained during the discussions is presented informally within the analysis of relevant BREEAM issues, throughout Chapter 4.

Building manager interviews

In addition to the facilities management teams, three of the four buildings also had a nominated building manager. These individuals were senior administrative or academic staff whose role included a liaison function with facilities management. In contrast with facilities management staff these individuals were based full time in the building, and had in every case been present since initial occupation. The building managers were asked to comment in relation to a range of factors relevant to particular BREEAM issues. The discussions were therefore exploratory and targeted primarily at providing context for the technical investigations. Open-ended questioning was combined with an informal conversational approach. In some cases, no significant new insight was gained, however for one particular building it became clear that the building manager's experience of the building services contrasted considerably with the impression provided by facilities management. In this case facilities management had reported that their input into the building since its occupation had been extremely minimal, and that they had responded to occasional minor problems reported by the occupants but were not closely involved in the day to day running. The building manager however described a serious problem with the heating for the building that had been ongoing since first occupation, and was still to be properly resolved after three years. A number of other significant services related issues were also described, including problems with the lift, lighting and the hearing induction loop. In addition to this, following a discussion with the researcher regarding overheating, it transpired that the building occupants were unaware that the building was fitted with additional natural ventilation in the form of windcatchers.

Energy consumption monitoring

Energy monitoring is commonly used in POE and was appropriate for this project, given that BREEAM has significant content related to reducing building energy consumption and its related CO_2 emissions. As discussed in detail in Chapter 4, the case study buildings were powered by various combinations of mains gas, mains electricity and, in one instance, photovoltaic panels. Energy consumption was also moderated in particular cases by the use of building level combined heat and power plant, and air source heat pumps. Utility meters were in place in all buildings to measure overall consumption of gas and electricity, and at least one full year's data was obtained, in all cases. A single reading was generally obtained for the building as a whole. Data was obtained from facilities management teams and was based either on monthly manual meter reads (Buildings B and C) or pulsed readings collected by the BMS at 15 or 30 minute intervals (Buildings A and D). Additionally Building D is believed to export electricity generated by its photovoltaic panels to the grid, although no meter data was available to quantify this. The data obtained for the buildings is described and analysed in detail in Chapter 4.

Sub metering of particular energy uses within a building is also commonly employed in commercial buildings, and is promoted by BREEAM. For the case study buildings, however, although electricity sub-metering was believed to be installed in several of the case study buildings, it was in all cases either non-functional, or unmonitored. Electricity consumption data relating to particular uses such as lighting or lifts would have been useful in analysing the success of certain issues. Carrying out early intervention to commission existing sub-meters, or to install temporary sub-metering would therefore be an improvement for consideration, if this research was to be extended or replicated.

In addition to analysing actual energy consumption, reference has also been made to the Energy Performance Certificate (EPC) for each building, and to the Display Energy Certificate (DEC). The EPC includes predictive greenhouse gas emissions data based upon design information, and the emissions rate predicted by the EPC forms the basis for awarding a number of BREEAM credits. The emissions rate is expressed as kilograms of CO_2 per square metre of total useful floor area, per annum ($kgCO_2/m^2$.year). Note that total useful floor area equates to gross internal area as defined by the Royal Institute of Chartered Surveyors (RICS, 2015). This “Building Emission Rate” (BER) is calculated using modelling software approved for use under UK building regulations, and accounts for regulated energy use’ only, as used by fixed internal and external lighting systems, heating, hot water, air conditioning and mechanical ventilation (NBS, 2014). Note that the software makes use of design values for the thermal performance for the building fabric, but excludes emissions relating to other unregulated energy use, such as power for equipment, processes and general plug loads. The EPC’s for Buildings A, B and D were obtained either from the University or from the UK government online register (Department for Communities and Local Government, 2017). No EPC appears to have been registered for Building C, despite this being a mandatory requirement of Building Regulations.

A building DEC includes energy consumption data expressed as kilowatt hours per square metre of total useful floor area (kWh/m^2.year). It also indicates the total CO_2 emissions for the building, presented in graphical form. The energy data includes both regulated and unregulated use, and is obtained from metered readings where these are available, or estimates where they are not. The CO_2 emissions are calculated based upon the energy data and therefore also include both regulated and unregulated use. It is a statutory requirement to obtain and display a DEC for public buildings greater than 500m^2 in floor area (DCLG, 2015) however there is currently no requirement that the building meet any particular energy or emissions standard. DEC data is not used by BREEAM, however as discussed in Chapter 4 it does provide a useful point of reference when assessing building energy use. The DEC certificates for buildings A, C and D were obtained from the UK government online register (DCLG, 2017). Building B requires no DEC, as it has a floor area of less than 500m^2.

It should be noted that whilst the data associated with the EPC and DEC certificates obtained for the building provides useful contextual information, the ratings themselves are of limited value. Both EPC's and DEC's generate a numerical rating for the building, which are dimensionless and are presented in similar ways in both cases, being banded from A-G. They are however calculated in quite different ways, and are not comparable. For EPC's, the asset ratings is calculated by the following formula (DCLG, 2008):

$$\text{EPC Asset rating} = 50 * \frac{\text{BER}}{\text{SER}}$$

Where BER (building emission rate) represents the design emissions for the building and SER (standard emission rate) represents the design emissions for a similar "notional" building designed to meet the 2002 version of the Building Regulations. For DEC's the operational rating is calculated as follows (DCLG, 2015):

$$\text{DEC Asset rating} = 100 * \frac{\text{Actual CO2 emissions}}{\text{Average CO2 emissions}}$$

Where 'Average CO_2 emissions' for a particular building function are taken from benchmarks for existing buildings, produced by CIBSE (2009). The DEC asset rating is therefore the buildings CO_2 emissions expressed as a percentage of those for a typical existing buildings of similar use.

Water consumption monitoring

Water consumption monitoring was desirable as BREEAM has significant content relating to reducing water use. Water used in the case study buildings is understood to be exclusively derived from mains supply; no form of water harvesting or recycling was apparent either in building designs or the buildings in use. Consumption data was obtained from facilities management teams and was provided in the form of manual monthly readings for Buildings B and C. No readings were however available for Buildings A or D, due to faulty meters. In the case of Building A the fiscal utility meter had been faulty since installation, in the case of Building D it was the University's own meter for the building which had, again, been faulty since installation. The data obtained is described and analysed in Chapter 4. As for energy, BREEAM also promotes the use of sub-metering for water consumption, however no sub-meters are understood to have be installed in the case study buildings.

Building Use Studies survey

Analysis of the BREEAM scheme (Appendix A) identified that the requirements of a significant proportion of BREEAM issues might be expected to produce effects and benefits intended to improve conditions for building users. This is particularly the case within the health and wellbeing section, where the expected benefit is often explicit. It is also implicit for a number of other issues across the remaining sections, including management, energy, materials, land use and ecology, and pollution. The particular potential benefits include issues relating to thermal comfort, air quality, lighting, acoustics and views out, as well as safety issues relating to contamination, pedestrian safety and fear of crime.

To assess the success of these issues it was considered necessary to engage with building users. Users for the case study buildings may be divided into those who are based in the buildings, and those who visit them to use particular facilities. The former are generally employees of the organisations occupying the buildings, whilst the latter will include students and conference delegates, as well as occasional visitors. Of these two groups it was decided that those based in the building would be the both the easiest to access and the most representative. Individuals based in a building are, in general, likely to spend a greater proportion of their time in the building, and to experience it in different climatic conditions throughout the whole year. Any potential complacency in terms of their environment is therefore offset by a more thorough understanding. As the benefits expected to result from the issues in question are subjective in themselves, it was considered appropriate to make use of subjective data to test them. It was however desirable to be able to benchmark the results against other buildings, and for this reason an established survey methodology was adopted.

The Building Use Studies (BUS) methodology (Arup, 2017) has been in use in its current form since 1990. It consists of a survey aimed primarily at desk based workers in an office environment, and generates quantitative as well as qualitative data. Respondents are invited to rate various particular aspects of their work environment on a seven point Likert-type rating scale, including thermal comfort, air quality, acoustics and lighting. They are also asked to rate the effect that their work environment has on their overall comfort, health and productivity, as well as describing their typical journey to and from the building. The ratings generate mean scores for the building, which can be benchmarked against a rolling dataset containing the 50 most recent surveys. Dependent upon the specific scale type, the scheme operator flags mean building responses based on a traffic light system, as follows:

1) Likert scale for which 7 represents ideal conditions

- Red – Significantly below both the study mean and the scale midpoint
- Amber - Significantly below either the study mean or the scale midpoint
- Green – Significantly above both the study mean and the scale midpoint

2) Likert scale for which 1 represents ideal conditions

- Red – Significantly above both the study mean and the scale midpoint
- Amber – Significantly above either the study mean or the scale midpoint
- Green - Significantly below both the study mean and the scale midpoint

3) Likert scale for which 3 represents ideal conditions

- Red – Further departed from the scale midpoint than the study mean
- Amber – Significantly departs from the scale midpoint but betters the study mean
- Green – Does not significantly depart from the scale midpoint

Opportunity is also provided to make qualitative comments, including suggestions for improvements. This methodology was considered to be manageable in that a single researcher can typically carry out a full building survey in a single day. It is also manageable for respondents, who may complete the form within as little as five minutes. Finally, the survey produces numerical responses which may be quantitatively analysed, as well as allowing for richer qualitative statements for a number of sections (Arup, 2017; Turpin-Brookes, 2006). A copy of the survey is appended (Appendix B)

The BUS methodology was used under licence, and as such was conducted in full, and in accordance with the instructions and suggestions provided. The survey does include a number of questions not directly relevant to this study, for example questions are asked in relation to provision of desk space and storage. These comprise around 15% of the overall questionnaire. This was undesirable from an ethical point of view, as answering these questions does not directly contribute to the study. It was however only through the use of a standard questionnaire that responses could be benchmarked, and omitting these questions would have both invalidated the survey licence, and distorted the benchmark data for future users. As suggested by the licensee, the surveys were distributed to staff in person, in paper form. Because of the small number of staff in Building B, the survey date was arranged specifically to ensure that all staff were present. For the remaining buildings the surveys were carried out on either Tuesdays or Wednesdays; these being recommended by the licensee as days for which maximum attendance is likely in office buildings in general. Given that the case study buildings were in use by educational establishments, consideration was also given to term times, with both academic holiday periods and exam periods being avoided. A number of passes were made through the building across the day, to maximise coverage, this being particularly helpful in Buildings C and D, where a large proportion of staff were engaged in teaching and therefore away from their desks for part of the day. In each case, following the visit, a web version of the survey was distributed by email, in an attempt to capture those that were not present in the building on the day.

As discussed above, the target survey population consisted of those who were based in the building on a permanent or contract basis. In each case a list of names was provided by the building managers to allow the sampling frame to be established (Gray, 2014). Due to the relatively small numbers it was desirable to sample the entire population, initially through the paper surveys for those present on the day, and subsequently via email for those who were not. Table 3.2.2 details the size of the sample frame and the response rates for the various buildings.

Table 3.2.2 - Sampling and response data for the BUS survey

Building	Total staff	Staff present	Paper survey response	Web version response	Overall response rate (%)
Building A	21	16	13	2	71%
Building B	4	4	4	0	100%
Building C	34	23	20	5	74%
Building D	107	31	25	5	28%

Figure 3.2.1 shows that the majority of responses came through the initial paper survey, for which the response rate based on the number of person present in the buildings on the day of the survey was between 81-100%, for individual buildings. In terms of sampling this produced a substantial bias towards those who were present on the day, particularly for Building D where only 28% of those theoretically based in the building were surveyed. It is notable in this regard that the Business School makes up a large proportion of the “permanent” occupants and that this has a large proportion of visiting and associate lecturers. A bias towards those staff present on a typical working day may therefore be viewed in a positive light in this instance, given that the intention was to capture the opinions of those with significant experience of the building. In fact the respondents that were captured spent a mean of 33 hours per week in their buildings. Additionally 63% of respondents overall stated that they had been based in their building for at least one full year.

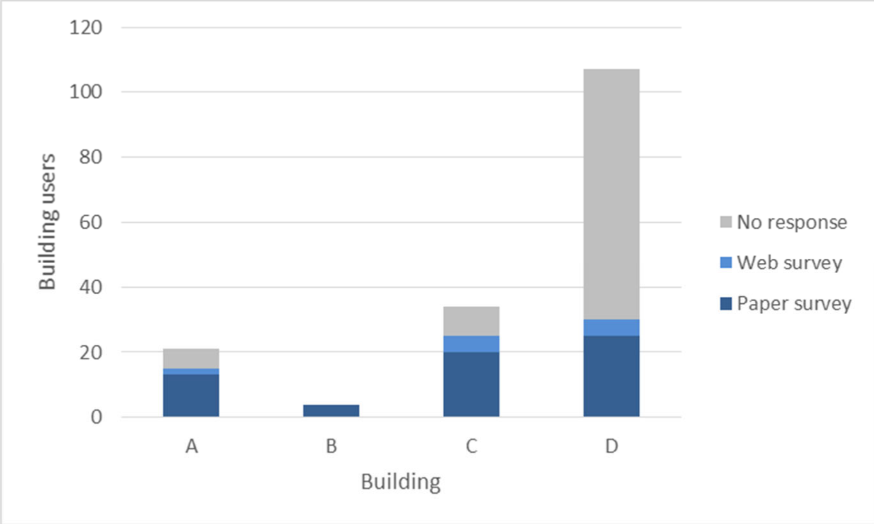

Figure 3.2.2 – Response data for the BUS survey by building

It should be noted that the samples are relatively small in absolute terms, particularly for Building B. This is perhaps an inevitable consequence of excluding students from assessment in buildings where a significant proportion of space is given over to teaching activity. Care must therefore be taken in analysing the results, although for this study a smaller number of high quality responses was considered more appropriate than a larger number of lower quality ones. Finally it should be noted that although benchmarking increases potential for statistical analysis, the material details of the other buildings in the set were not divulged. The representativeness of the data cannot therefore be accurately assessed, and comparisons with buildings in general should be viewed accordingly.

In practice the survey methodology was straightforward to carry out and the quality of responses was generally high. A number of respondents did complain however that the survey was too long, and it appeared to the researcher that it often typically took considerably longer than the stated minimum of 5 minutes to complete. The layout of the form also appears to have caused difficulties for some respondents. For example one particular set of questions relating to control of services is grouped in in a corner of the page, and was attempted by less than 50% of respondents. Overall however the survey was invaluable in evaluating a large number of highly relevant factors, in a user friendly, structured, and resource-efficient manner.

In addition to using survey data to describe the performance of the case study buildings, it was also possible to interrogate the data to establish possible relationships between performance metrics. Combining data from across the four buildings produced 74 sets of responses. Testing these relationships statistically allowed examination of the link between effect and benefit, and has provided significant additional insight when analysing certain of the cause and effect relationships.

The BUS survey has provided data for a large number of variables relating to the internal environments of the case study buildings. For the purposes of this analysis this was treated as quantifiable, interval, data (Gray, 2014). It is acknowledged that the variables are subjective to a significant degree, and that responses to the numerical scale are therefore also open to interpretation by users. Despite this, it is considered that the configuration of the scoring system is robust enough to yield useful statistical results, and this is certainly the intention of its designers (Cohen *et al*., 2001). Additionally it should be noted that in this particular exercise we are comparing the response of each individual across multiple variables, not comparing the responses of one individual with another. As such it is expected that the effects of subjectivity in terms of scale will be minimised. Pearson's product-moment correlation is commonly used to establish whether there is a statistically significant linear correlation between any two variables where interval data is available (Field, 2013; Gray, 2014). This level of analysis is considered appropriate to both the aim of the study and the quantity of data available. It should be noted however that this analysis will not reveal any curvilinear relationships between variables. Additionally it assumes normally distributed data in all cases.

Pearson's product-moment correlation produces a correlation co-efficient ranging from +1.0 for a perfect positive correlation, to -1.0 for a perfect negative correlation. Between these two values the correlation is imperfect, however the strength may be assessed as shown in Table 3.2.3.

Table 3.2.3 – Strength of association based upon the value of a coefficient (adapted from Gray, 2014)

(+/-) 0.10-0.29	Small
(+/-) 0.30-0.49	Medium
(+/-) 0.50-1.00	Large

The significance of this relationship, that is the chance that this correlation occurred by chance, must also be evaluated. Both the correlation coefficient and the significance level have been calculated for a number of variables relevant to the BREEAM assessment process. The BUS survey produced interval data for 48 variables. Of these variables the following are not considered to be measured by BREEAM and have therefore been excluded:

- Cleaning (how do you rate the cleaning?)
- Availability of meeting rooms
- Suitability of storage arrangements
- Furniture (how do you rate the usability of the furniture at your desk or normal work area?)
- Space at desk (do you have enough space at your desk or normal work area?)

For the purposes of this analysis, it was additionally necessary to exclude those variables where a midpoint indicates an ideal situation, for example where temperature is rated from "too cold" to "too hot". This resulted in the following variable being excluded:

- Temperature in winter/summer (too hot-too cold)
- Air in winter/summer (still-draughty)
- Air in winter/summer (dry-humid)
- Noise from colleagues/other people/other inside/outside (too little-too much)
- Natural light (too little-too much)
- Artificial light (too little-too much)

Where questions were configured such that a high score indicated a negative the sign of the scoring was manually reversed, in particular:

- Temperature in winter/summer (stable-varies through the day)
- Air in winter/summer (odourless-stuffy)
- Air in winter/summer (fresh-stuffy)
- Glare from sun and sky (none-too much)
- Glare from artificial lights (none-too much)

These remaining 30 variables were analysed for correlation, using SPSS (Statistical Package for the Social Sciences) software. 100% of the "large", and over 96% of the "medium" correlations are statistically significant, indicating that the sample size was generally large enough to capture these relationships. Note that the non-significant medium correlations identified relate in all cases to the effectiveness of facilities management support, a question which only 36 out of the 77 respondents answered. Of the “small” correlations, however, less than 10% are statistically significant. This suggests that more responses would be required to usefully examine these weaker relationships. The results obtained are discussed in detail in section 4.5.2.

Principal component analysis was considered, to analyse whether comfort, health or productivity could be positively identified as latent variables. The data set of 77 participants was however rather small for these purposes, there being an expectation that 10-15 participants per variable may be required to produce good results (Field, 2013). Additionally there were a significant number of missing values within responses, which reduced the data to just 24 complete sets for listwise comparison. Running an initial analysis using SPSS served to identify a number of variables with very limited correlation to the wider data set, in particular:

- Temperature stability (both summer and winter)
- Control over services
- Odourlessness of air (both summer and winter)
- Freshness of air in winter

The analysis was re-run without these variables, and whilst the Kaiser-Meyer-Olkin measure of sampling adequacy of 0.768 suggested a good sampling adequacy overall, sampling adequacy for the individual variables was below 0.5 in most cases. Excluding all of these variables would have rendered the output meaningless and the exercise was therefore abandoned.

3.2.3 Benchmarking

In order to comment on the measured building performance it was necessary to consider and select appropriate benchmarks for energy consumption, water consumption and internal environmental quality.

Both energy consumption and CO_2 emissions relating to building operation are considered within the BREEAM scoring mechanism, and it is therefore appropriate to analyse the performance of the case study buildings in terms of both. It would be possible to compare observed energy use to the Building Regulations standards applied to the buildings, however Building Regulations specify performance in terms of regulated energy use for a building with notional occupancy characteristics. As illustrated in Figure 3.2.3, actual energy use additionally includes unregulated consumption, for example plug loads, and may also vary according to the specific characteristics of the building, for example occupancy times. The observed energy consumption will instead therefore be considered in terms of established benchmarks for total energy consumption, as described below.

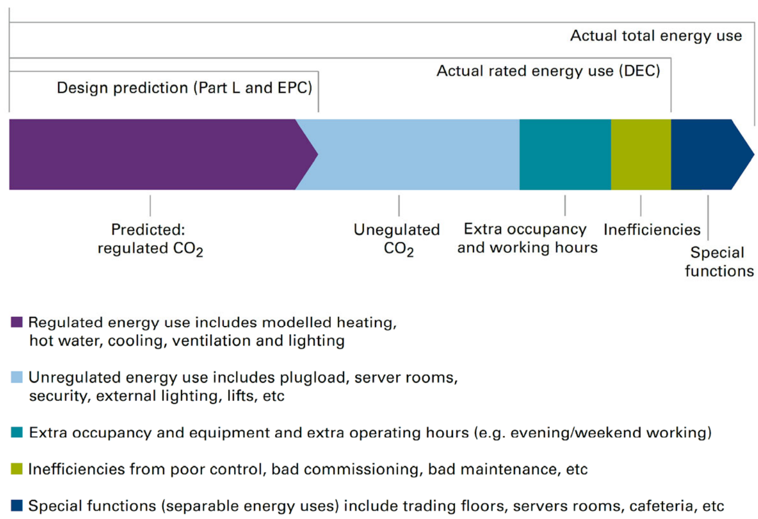

Figure 3.2.3 – Relationship between design predictions and actual energy use (RIBA, 2017)

CIBSE Guide F (CIBSE, 2012) includes energy use benchmarks for different categories of buildings. Benchmarks are expressed for “good practice”, and “typical practice”, separated between fossil fuels and electricity, with the guide suggesting that “good practice” may be considered an upper limit for new buildings. The source for the benchmarks relating to higher education buildings is the Higher Education Funding Council (1996). The data is based upon a survey of buildings in use at the time of publication of the report, and is therefore likely to represent a standard of building fabric and services performance considerably inferior to that of the case study buildings. Energy performance standards for regulated energy use in new buildings have increased considerably in the UK during the period following publication; the maximum elemental wall u-value allowable for new buildings of a wall was, for example, reduced by 33% between 1995 and 2002 (HMSO, 1995; NBS, 2002) and the overall modelled regulated energy performance of new buildings was further reduced by 40% between 2002 and 2010 (NBS, 2010). Conversely, although limited data is available to substantiate this, unregulated energy use, particularly related to plug loads and information technology in buildings is believed to have increased considerably over the same period (CIBSE, 2012). Additionally it has not been possible to obtain a copy of the original report, making an evaluation of the methodology impossible. Notwithstanding these significant limitations, these benchmarks remain in current use and form the basis of DEC evaluations as described below. Some relevant benchmarks from CIBSE Guide F are summarised in Table 3.2.4, however due to the range of uses observed in the case studies, including a significant amount of circulation space, no attempt has been made to convert these to an overall building level benchmarks.

Table 3.2.4 – Summary of CIBSE Guide F benchmark values

	Good practice		Typical practice	
	Fossil fuels (kWh/m^2.yr)	Electricity (kWh/m^2.yr)	Fossil fuels (kWh/m^2.yr)	Electricity (kWh/m^2.yr)
Higher education [1]				
Lecture room (arts)	100	67	120	76
Lecture room (science)	110	113	132	129
Science laboratory	110	155	132	175
Offices [2]				
Air conditioned (standard)	97	128	178	226
Naturally vented (open plan)	79	54	151	85

[1] Based upon gross floor area

[2] Based upon treated floor area (excludes unheated spaces)

CIBSE TM46 2008 (CIBSE, 2008) describes the methodology for calculating the energy use benchmarks which appear on DEC's. These benchmarks are based on the data presented in CIBSE Guide F, however the building categories are somewhat simplified. Provision is also included for benchmarks for specific buildings to be adjusted for local weather, and/or exceptionally long occupancy periods. As noted above the benchmarks are based upon historic information, and whilst considered appropriate for comparing existing buildings for statutory purposes, they do not take account of recent increases in design standards relating to regulated energy use, or of any behavioural changes over time relating to unregulated power consumption. A summary of benchmark data (without any building specific adjustments) is shown in Table 3.2.5. Figures are shown for both the "University Campus" and "General Office" categories, in order to highlight the significant differences between them.

Table 3.2.5 – Summary of relevant CIBSE TM46 benchmark data

	University campus ($kWh/m^2.yr$)	General office ($kWh/m^2.yr$)
Energy (electricity)	80	95
Energy (fossil fuel)	240	120
Energy (total)	320	215

The Energy Consumption Guide 19 (Action energy, 2003) sets out benchmark energy and CO_2 performance data for offices. It is cited in literature relating to post occupancy evaluation (Bordass *et al*., 2001; Menezes *et al*., 2012) and is additionally reproduced in CIBSE Guide F. Reference data is presented for 4 categories of buildings; "naturally ventilated, cellular", "naturally ventilated, open plan", "air-conditioned, standard" and "air conditioned, prestige". Benchmark data is further broken down into "typical" and "good practice" for each building type, and apportioned according to various uses. A building specific benchmark can therefore be calculated for both "typical" and "good practice", depending upon the proportion of a building best described by each category, and further tailored by its particular facilities. The data presented is based upon buildings in use at the time of publication and is therefore somewhat dated. It is also configured specifically for offices, which represents only a part of the use of the case study buildings. Nevertheless, this detailed and well defined data arguably provides some useful additional context for the case study data. Table 3.2.6 sets out the base benchmark data.

Table 3.2.6 – Summary of Energy Consumption Guide 19 benchmark data for office buildings

Energy consumption (kWh/m^2.yr)	Naturally Ventilated Open Plan		Air Conditioned Standard		Air Conditioned Prestige	
	Good practice	Typical practice	Good practice	Typical practice	Good practice	Typical practice
Heating and hot water	79	151	97	178	107	210
Cooling	1	2	14	31	21	41
Humidification	0	0	8	18	12	23
Fans pumps controls	4	8	30	60	36	67
Lighting	22	38	27	54	29	60
Office Equipment	20	27	23	31	23	32
Catering, gas	0	0	0	0	7	9
Catering, elec	3	5	5	6	13	15
Other electricity	4	5	7	8	13	15
Computer room	0	0	14	18	87	105
Total fossil fuel	79	151	97	178	114	210
Total electricity	54	85	128	226	234	358
Total energy	133	236	225	404	348	568

The Carbon Buzz project (RIBA, 2017) is a web platform which collects in-use energy consumption data for existing buildings. Data is uploaded by building users and made available anonymously, in area weighted form, to others. It is possible to aggregate this data and thereby obtain a benchmark for a particular building type. As a data source the website has the significant advantage of reflecting current levels of unregulated energy use, having been first launched in 2008. It does not however provide any indication of the age of the buildings surveyed, or the thermal efficiency of their fabric or building services. The data input process is additionally un-moderated, there is no sampling strategy, and the reliability of individual contributions is impossible to verify. Generating benchmark data using Carbon Buzz also proved to be quite problematic in practice, due to the limitations placed on analysing the data. It appears to be impossible for example to aggregate energy use by fuel type, despite this being split for individual entries. Also, although a range of building types are catered for in terms of inputting data, it is not possible to filter results in the same detail. Hence although "university campus building" is a building category, results can only be filtered to the level of "education" buildings, which includes a range of other categories including schools. For this reason, results for both “education” and “office” have been extracted, on the basis that the case study buildings are arguably as similar to offices as they are to schools. Additionally, both the education and office data sets included significant outlying results. For example the education data set included a CO_2 result of 697,935 kg/m^2.yr as against an average of around 79kg/m^2.yr. As results are presented graphically in the form of a bar chart there is no ready means to modify the data to exclude these. Additionally the outliers distort the scale of the graph, and in the case of the value for CO_2 noted above this effect was so extreme that it was impossible to distinguish the other values. Finally it should be noted that although there is provision for filtering results for other features such as size and ventilation strategy, these filters appeared to have little or no effect in practice, suggesting that this data has not been provided for all buildings. Details of the benchmarks generated using Carbon Buzz are summarised in Table 3.2.7.

Table 3.2.7 – Summary of input and output data for carbon buzz benchmarks

	EDUCATION BENCHMARK	OFFICE BENCHMARK
FILTERS		
Date accessed	09/01/15	09/01/15
Data to search	All	All
Completion date	All	All
Floor area	All	All
Data quality	All	All
Building use	Single and mixed use	Single and mixed use
Sector (inc)	Education	Office
Type of data available	Actual energy data	Actual energy data
Internal environment	All	All
Data to show	Measured by fuel	Measured by fuel
Number of results	177	128
Mean energy use (kWh/m^2·yr)	230	256
Mean CO_2 emission (kg/m^2.yr)	Not legible	Not legible

Data collected by the Higher Education Funding Council for England (HEFCE) for 2012-2013 (Higher Education Statistics for the UK, 2013) includes values for floor area and energy use by fuel type, for 158 higher education establishments. This data has been used to calculate an average overall annual consumption by floor area, split into grid electricity and fossil fuels. Note that this data includes both residential and non-residential university buildings. Table 3.2.8 shows results for both the average across all institutions, and for the university associated with the case study buildings.

Table 3.2.8 – Energy use data for HEFCE institutions 2012-2013

	Grid electricity (kWh/m^2.yr)	Fossil fuels (kWh/m^2.yr)
HEFCE – Average all institutions	104	167
HEFCE – Case study university	119	121

Water consumption benchmarks

Predicted water use is considered within the BREEAM scoring mechanism and it is therefore appropriate to analyse the performance of the case study buildings in this respect. The metered water consumption described above will therefore be compared to a number of benchmarks as described below. Benchmark data for water use in buildings is often stated per person, however occupancy is difficult to define in many building types, and this is particularly the case for the case study buildings. Consumption by floor area provides a practical alternative in this instance, with this approach also being supported by the literature (Construction Industry Research and Information Association, 2006). The benchmark data from the sources discussed below is summarised in Table 3.2.9.

Table 3.2.9 – Benchmark data for water consumption

Source	Benchmark ($m^3/m^2.yr$)
CIRIA 2006 – Typical office	0.6
CIRIA 2006 – Best practice office	0.4
Watermark report 2003 – Typical higher education	0.62
Watermark report 2003 – Best practice higher education	0.40
HEFC 2014 – Average for all HEFC universities	0.74
HEFC 2014 – Average for case study university	0.33

Water key performance indicators and benchmarks for offices and hotels (CIRIA, 2006) includes water consumption benchmarks for offices, based upon data obtained from UK water supply companies for 222 existing large offices in 2002-2003. Although relevant only to office areas, the report includes a detailed discussion of water benchmarking techniques and includes thorough statistical analysis of results. Of particular interest is the finding that for office buildings, water consumption showed an extremely strong correlation with floor area, with simple linear regression indicating correlation $R^2 = 0.9875$.

The Watermark Report (Office of Government Commerce, 2003) was produced for the UK government and evaluates water use based upon consumption data obtained from government buildings. Benchmarks are presented for 15 categories of building, including higher and further education (based upon 127 buildings).

Data collected by the Higher Education Funding Council for 2012-2013 (HESA, 2013) includes values for non-domestic floor area and non-domestic water use, for 158 higher education establishments. This data has been used to calculate an average overall yearly water consumption by floor area.

3.3 Ethical considerations

3.3.1 Ethical principles

Ethical principles applicable to research may be categorised as falling within four main areas as follows (Gray, 2014):

- Avoid harm to participants
- Ensure informed consent of participants
- Respect the privacy of participants
- Avoid the use of deception

The chosen research methodology requires interaction with a number of participant organisations and individuals, and a strategy is therefore required to ensure that their needs are adequately considered. The research design requires that surveys be carried out with building occupants, and that building managers and facilities managers are interviewed. All three groups will comprise employees of the organisation operating the building (there is no requirement to interact with students). Permission was obtained to invite these individuals to participate from the university estates manager, and from the senior staff member within each building. By liaising with senior administrative staff within each building it was further possible to establish that building occupants were in all cases at least 18 years old, and did not include vulnerable groups of people.

Avoiding harm to participants

Whilst the research design does not present any potential to cause physical harm to participants, the risk of causing mental distress required consideration. Building occupants were asked to comment in detail on their work environment, which brings with it the possibility of consequential criticism or victimisation from others within their organisation. Building managers and facilities managers were asked to comment on operational matters relating to their work which, similarly, may open them to criticism or victimisation from others. In either case, both the risk and severity of harm were considered to be small, and were further reduced by ensuring that responses are effectively anonymised and securely stored. Survey participants were not therefore asked to give their names, whilst the identity of building managers and facilities managers were coded by job title at the point of data collection. The identity of the case study buildings was similarly coded, and no details have been recorded regarding their names or specific locations. Following collection, data has been stored on the university server, being password protected and therefore accessible only to the research team. The research findings are not expected to be such that disclosing the identity of any of the organisations involved in the research is either necessary or useful, as the research is focussed on the application of Building Sustainability Assessment Schemes themselves.

Overall, such risk as does exist of reputational harm to participating individuals or organisations is considered to be limited and manageable through appropriate data collection and handling, and judicious presentation of findings. Whilst not participating directly, the potential for reputational damage to organisations operating BSAS (and BREEAM in particular) will also be similarly considered. In the latter case particularly, the quality of the research will be key to ensuring that any risk is balanced by the potential for improvement in the application and effectiveness of BSAS, the benefit of which might reasonably be expected to accrue to these same organisations (Gray 2014).

Informed consent

Informed consent was obtained from all individuals participating in the research. As there was no need to engage with young or vulnerable participants, the use of printed participant information sheets and associated consent forms was considered appropriate. These were supplemented by providing opportunity for discussion with the researcher in person (before and during data collection), and by subsequently leaving the researcher’s email and telephone contact details with participants.

Participant information sheets were configured to be concise and easy to understand, and included core essential information, as follows:

- The aims of the research and who is conducting it
- Who is being asked to participate and what will be required of them
- That participation is voluntary and that there is a right of withdrawal
- How the collected data will be stored and anonymised

Participant privacy

Privacy was protected through making it clear through the informed consent process described above, that participation in the research was voluntary, that responses to individual questions were voluntary, and that participants had a right of withdrawal at any time. As described above, all data was anonymised and requests for personal data were limited to gender and age range. Where survey forms were emailed to participants, “work” email addresses were used as provided by their employers. Contact details were not linked to the data collected, or retained by the researcher.

Deception

There was no requirement to employ deception within the research design. The research aim and methods were clearly and fully described to participants as part of the informed consent process.

3.3.2 Institutional Ethics Approval

The project was granted approval by the Anglian Ruskin University Faculty of Science and Technology Research Ethics Panel on 18th April 2013.

CHAPTER 4 - RESULTS

This chapter contains a description of the case study buildings, including their location, function, layout and building services arrangements. The structure of the BREEAM scheme assessment which has been applied to them is also summarised, following which the buildings' performance in terms of energy use, water use and internal environmental quality is described. Finally the effect that each BREEAM criterion has had on the buildings is examined by cross referencing the scheme assessment reports with the physical manifestation of the buildings and their performance in use.

4.1 – Description of Case Study Buildings

This section set out a detailed picture of the physical manifestation of the case study buildings. This has been produced by means of a desktop study (including review of architectural design drawings), supplemented where needed by walk through surveys, building manager interviews and facilities manager interviews.

4.1.1 General building characteristics

The case study buildings are all recently constructed and have a higher education function, with links to a single university. Buildings A and D are owned and operated by the university, although they are located on different campuses. Building B operates as a joint venture between the university and a hospital university trust, and is located on the hospital site. Building C is a joint venture with a further education college, and is located on the college campus.

The buildings are located across four sites within a 40km radius, in the East Anglia region of the UK. The buildings were all procured on a design and build basis, with the university estates and facilities department assuming the role of project client in each case. The day to day operation and maintenance of the buildings is however a local function. Buildings A and D are maintained by the university estates department, Building B is maintained under a private contract managed by the hospital estates team, and Building C is maintained by the on-site college facilities management team.

All four buildings sit within urban or suburban areas. Buildings C and D directly adjoin their respective town/city centres whilst Buildings A and B are further removed. Key general information relating to the buildings is summarised in Table 4.1.1. Note that building floor areas have been calculated from design drawings and are based upon gross internal floor area (GIFA) using the Royal Institute of Chartered Surveyors (RICS) definition (RICS, 2015). The as-built configuration of the buildings was found to closely reflect the drawings in all cases, although an independent dimensional survey was not carried out.

Table 4.1.1 - General characteristics of the case study buildings

	Building A	Building B	Building C	Building D
Setting	Suburban university campus	Suburban hospital site	Urban College Campus	Urban university campus
Date of first occupation	Feb 2011	Mar 2011	Apr 2012	June 2011
Number of storeys	3	2	3	4
GIFA	2235m^2	472m^2	2192m^2	7356m^2
Procurement route	Design and Build	Design and Build	Design and Build	Design and Build
Owner	University	University / Hospital Trust	University / College	University
Occupier	University / Research Group	University / Hospital Trust	College	University
Day to day maintenance	University Estates	Hospital Facilities Management	College Facilities Management	University Estates

4.1.2 Building function and facilities

Whilst the buildings all have a higher education function, their facilities vary somewhat. Building A provides undergraduate teaching facilities in the form of two large (200 and 400 seat) lecture theatres. The remaining space is utilised for research and postgraduate teaching and the building contains a significant area of laboratory space. Building B is used for postgraduate lecture and seminar based teaching, and for laboratory based practical skills training. This teaching is typically delivered in the form of part or all day events. Building C is primarily an undergraduate teaching building, containing a single large (105 seat) lecture theatre, a number of classrooms and associated office space. Building D contains six large and medium sized lecture theatres (100-400 seat capacity) as well as numerous smaller classrooms. The building is used for small conferences and seminars as well as for undergraduate teaching. There is additionally a large open access IT space within the building, which serves the campus as a whole. The office space is occupied primarily by the business school and supports both teaching and research activity. Buildings A, C and D all contain small commercial café outlets, while Building D also has a medium sized (94m^2) commercial kitchen. All buildings contain domestic scale kitchen/tea point facilities for staff, as well as sanitary conveniences.

The use of space in the buildings is illustrated in Figure 4.1.1, based upon net room areas. Teaching space include lecture theatres, classrooms and open access IT suites, whilst office space includes areas such as meeting rooms. Laboratory space is that used for practical academic applications, whether for teaching or research purposes. The proportion of service space is in all cases significant, ranging from 36% in Building A to 49% in Building C. The latter areas are often discounted by the BREEAM scheme, which makes use of the term "occupied areas" in its assessment. Occupied area is defined as "A room or space within the assessed building that is likely to be occupied for 30 minutes or more by a building user" (BRE, 2008a). Figure 4.1.2 therefore also shows the allocation of space for these "occupied areas", which excludes circulation and general service areas, but includes the commercial kitchen in Building D. Figures 4.1.1 and 4.1.2 demonstrate that the four buildings, whilst all having a "university" usage, display considerable variation in the manner in which they are used by that university.

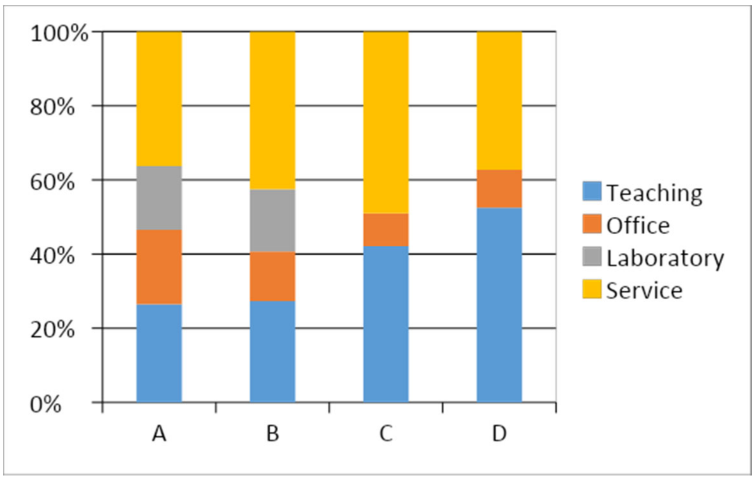

Figure 4.1.1 Use of space by percentage of total GIFA for case study buildings

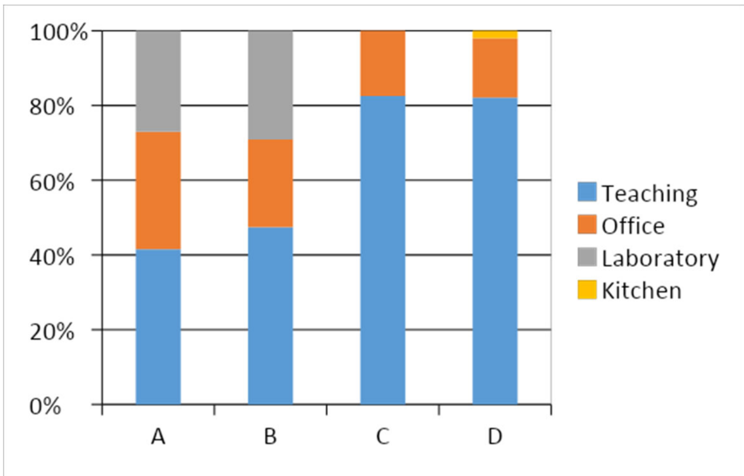

Figure 4.1.2 Use of "occupied areas" by percentage of total GIFA for case study buildings

4.1.3 Building setting, configuration and construction

Building A

Building A is a medium sized three storey building. It is situated in a quiet setting on the edge of a 9 hectare university campus, approximately 1.5km from the nearby city centre. It is detached and sits in its own modestly sized landscaped area. The building is broadly cuboid in shape and is of medium weight construction. The building structure is of steel with a concrete ground floor and composite steel and concrete upper floors. For the upper floors the building envelope comprises insulated render, fixed to a lightweight frame, with a concrete blockwork inner leaf. At ground floor, external walls are insulated cavity blockwork, painted externally and plaster finished internally. Glazed areas are formed using double glazed aluminium windows, doors and curtain walling. The lecture theatres are accessible from both the ground and first floors. The ground floor also contains the café and administrative office areas. The research office and laboratory spaces are located on the upper floors. A semi-enclosed plant area is located on the roof. The ground floor plan is shown in Figure 4.1.3 and key construction information is summarised in Table 4.1.2.

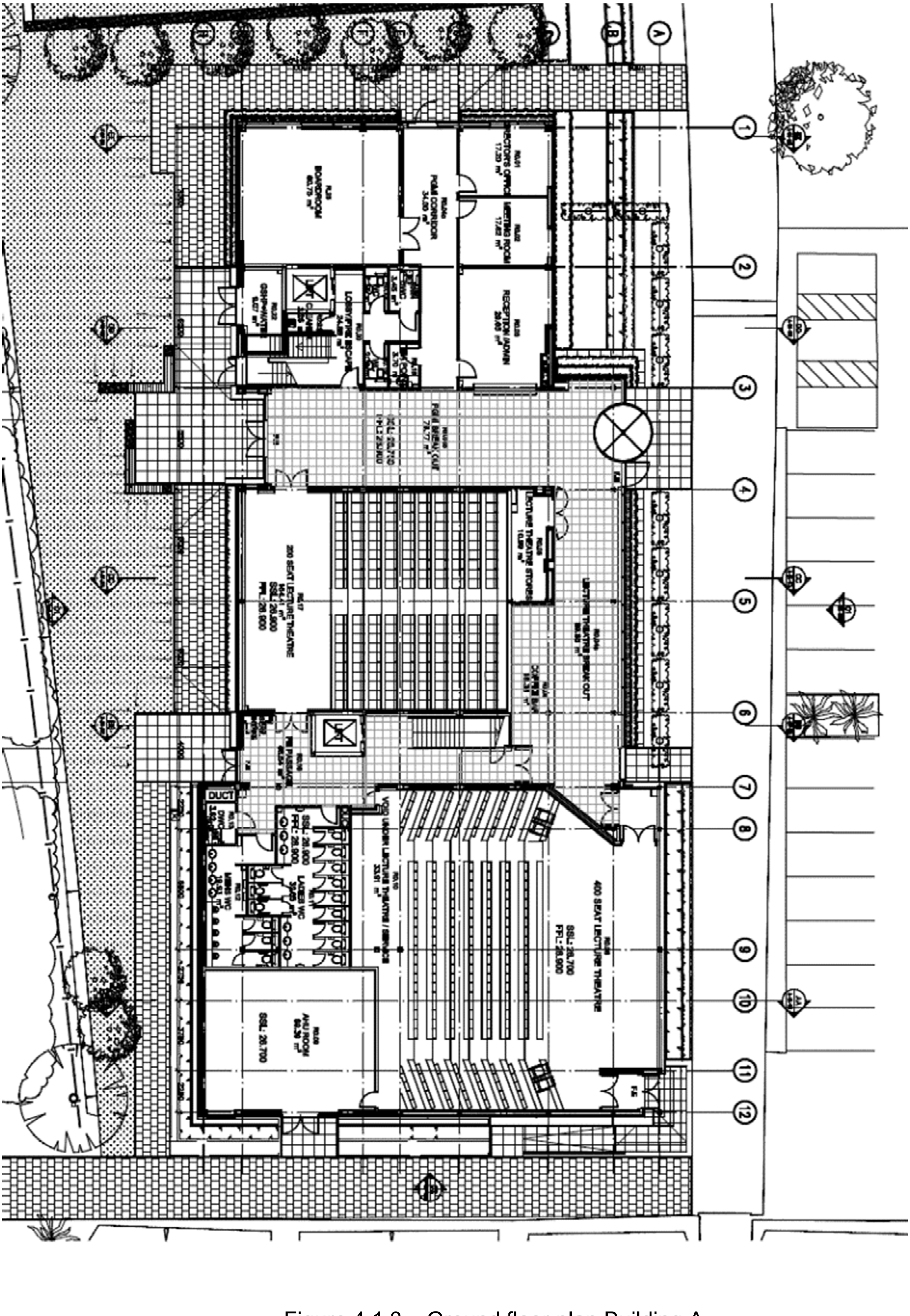

Figure 4.1.3 – Ground floor plan Building A

Table 4.1.2 – Summary of building construction and finishes for Building A

BUILDING A	
BUILDING ELEMENT	DESCRIPTION
Foundations	Piled
Structural Frame	Steel (braced)
Ground Floor	In-situ concrete
Upper Floors	Composite
Roof – Plant Area	Mineral membrane / concrete pavers on composite deck
Roof – Other areas	Mineral membrane on lightweight deck
External Walls (ground floor)	Cavity blockwork. Painted externally with planting on stainless steel trellis
External Walls (upper floors)	System render on metal subframe / Blockwork inner leaf
Glazing	Aluminium glazing system with opening lights / Full height glazing to main entrance / Ribbon windows elsewhere / Brise soleil to south elevation
Entrance Doors	Automatic revolving doors + un-lobbied automatic sliding door to front. Manual doors to side and rear.
Internal wall finishes	Painted plaster generally / Part height glazed partitions used in 2nd floor office area.
Floor finishes	Stone/ceramic tile to entrance area / Carpet tiles to teaching and office areas.
Ceilings	Painted plasterboard to lecture theatres / Acoustic plasterboard to circulation areas / Grid ceiling to office and service areas.

Building B

Building B is a small two storey building, situated in a quiet location on the edge of a 14 hectare hospital campus. The campus is around 3km from the town centre and sits within a predominantly residential area. The building is detached and sits in a small landscaped site which also includes two disabled parking bays, a bin store and a cycle shelter. The building is broadly cuboid in shape and is of light to medium weight construction. The building structure is of steel with a concrete ground floor and pre-cast concrete upper floors. The building envelope is of lightweight aluminium faced insulated panels, with lightweight steel framing internally. Glazed areas are of double glazed aluminium windows, doors and curtain walling. The ground floor contains the main lecture theatre with adjoining technician's room, along with an open plan area containing the entrance foyer, a seminar/seating area and the administration office. The laboratories are situated on the first floor, along with a further seminar room and two cellular offices. The ground floor plan is shown in Figure 4.1.4 and key construction information is summarised in Table 4.1.3.

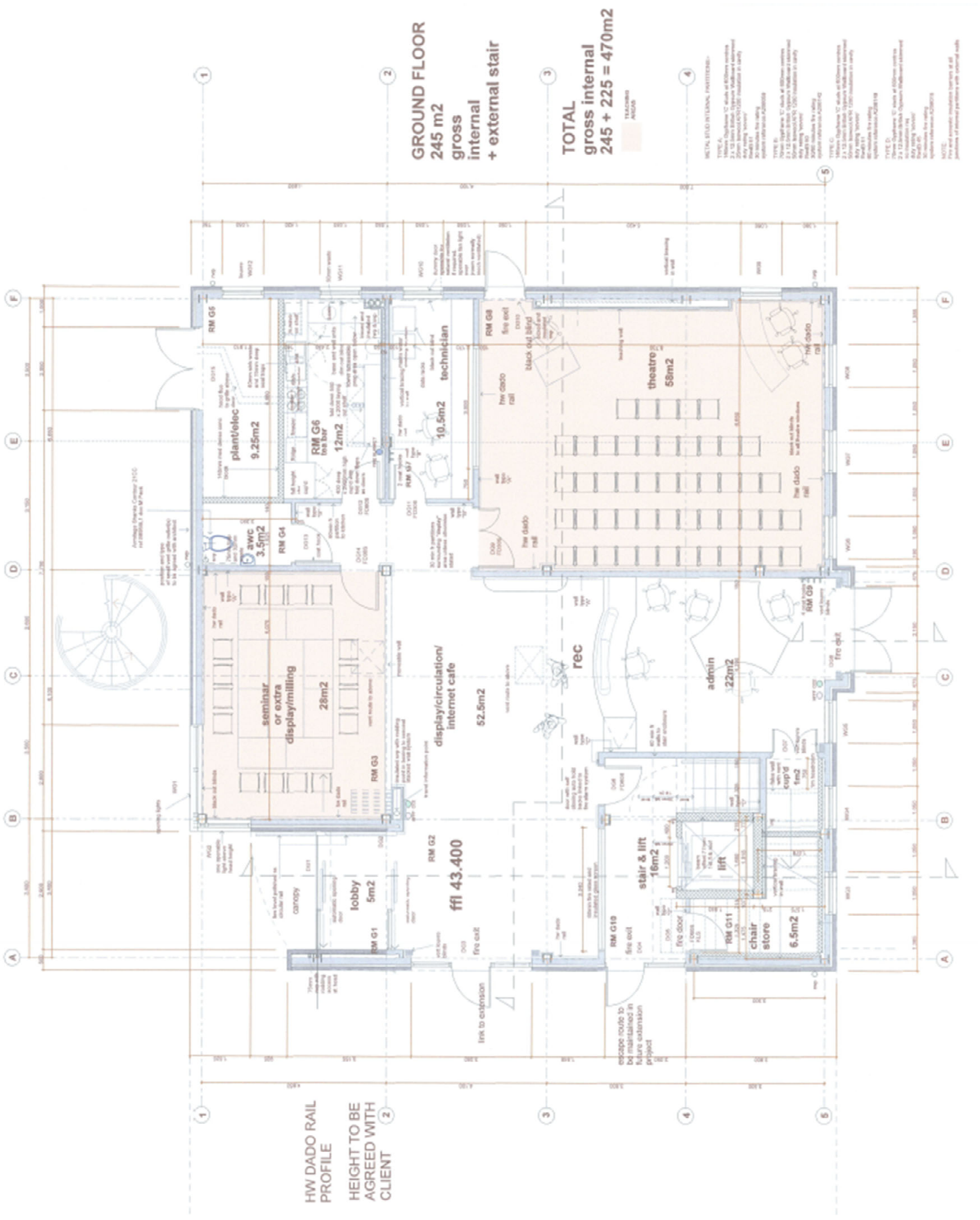

Figure 4.1.4 – Ground floor plan Building B

Table 4.1.3 – Summary of building construction and finishes for Building B

BUILDING B	
BUILDING ELEMENT	DESCRIPTION
Foundations	Unknown
Structural Frame	Steel
Ground Floor	In-situ concrete
Upper Floors	Precast concrete
Roof	Metal standing seam / timber structure
External Walls	Insulated composite panel / lightweight steel frame inner leaf.
Glazing	Aluminium glazing system with opening lights.
Entrance Doors	Automatic lobbied sliding doors to main entrance / Manual doors to side and rear.
Internal wall finishes	Painted plaster / Sliding partition between laboratories.
Floor finishes	Stone/ceramic tile to lobby and stairwell / Vinyl to laboratories / Carpet tiles elsewhere.
Ceilings	Grid ceiling throughout.

Building C

Building C is a medium sized three storey building, situated on a further education (FE) college campus, close to a main road and less than 100m from the nearby town centre. The building is detached and sits on a tightly constrained site facing the main college car park, which was re-constructed as part of the project and is included in the BREEAM assessment. Further temporary car parking exists to the rear. A large cycle shelter is also indicated on drawings, however this had not been constructed and the area was vacant at the time of the researcher's visits. The building is broadly cuboid in shape and is of relatively heavy weight construction. The building structure is of concrete and steel, incorporating concrete shear walls. It has a concrete ground floor and pre-cast concrete upper floors. The building envelope is a combination of standing seam metal cladding on a lightweight frame to the rear and facing brickwork to the ends, whilst the front (north) elevation is predominantly glazed. Glazed areas are of double glazed aluminium windows, doors and curtain walling. The building houses a large lecture theatre accessible at first and second floor. The entrance foyer is large with a café, open stairs and a triple height atrium space. Classrooms and office spaces are situated on all floors. The ground floor plan is shown in Figure 4.1.5 and key construction information is summarised in Table 4.1.4

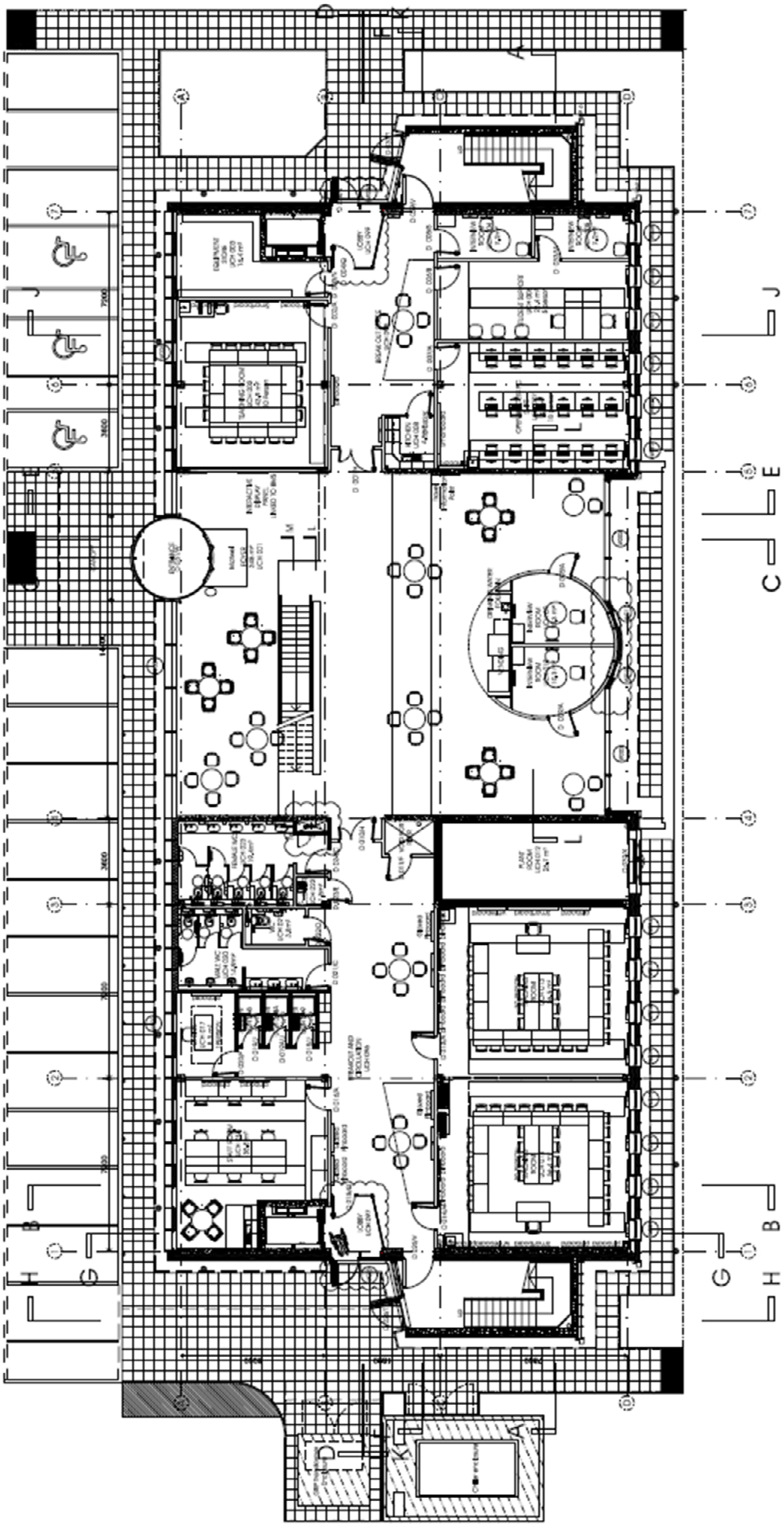

Figure 4.1.5 - Ground floor plan Building C

Table 4.1.4 – Summary of building construction and finishes for Building C

BUILDING C	
BUILDING ELEMENT	DESCRIPTION
Foundations	Unknown
Structural Frame	In-situ concrete (shear wall)
Ground Floor	In-situ concrete
Upper Floors	Precast concrete
Roof	Metal standing seam / concrete deck
External Walls	Metal standing seam to rear / Facing brick to ends
Glazing	Aluminium glazing system with opening lights / Full height curtain walling to front elevation / Punched windows with brise soleil to rear (south) elevation
Entrance Doors	Automatic lobbied sliding doors to main entrance / Manual doors to side and rear
Internal wall finishes	Painted plaster / Sliding partition between laboratories
Floor finishes	Stone/ceramic tile to lobby and stairwell / Vinyl to laboratories / Carpet tiles elsewhere
Ceilings	Grid ceiling throughout

Building D

Building D is a large four storey building, situated on a compact city centre university campus site. The building shape is relatively complex, wrapping around to form a large central courtyard and incorporating four circular “pods”. The building also adjoins and links through to a number of other pre-existing buildings. The building is heavy weight, with the building structure and floors being of in-situ concrete. The building envelope incorporates a range of finishes including facing brickwork, standing seam metal cladding, timber cladding and ceramic tiles. The inner leaf of the external walls and partitions are generally of concrete blockwork. Glazed areas are of double glazed aluminium windows, doors and curtain walling. The ground floor of the building contains the large lecture theatres, along with generous circulation space, a small office, the café and the commercial kitchen. The second and third floors are given over to teaching space, which includes the large open access IT suite. The upper floor contains a large open plan office space, along with smaller offices, meeting rooms and classrooms. The high level roof houses plant and photovoltaic panels. Lower level roof areas are generally accessible balconies with additionally a small area of (inaccessible) green roof. The ground floor plan is shown in Figure 4.1.6 and key construction information is summarised in Table 4.1.5

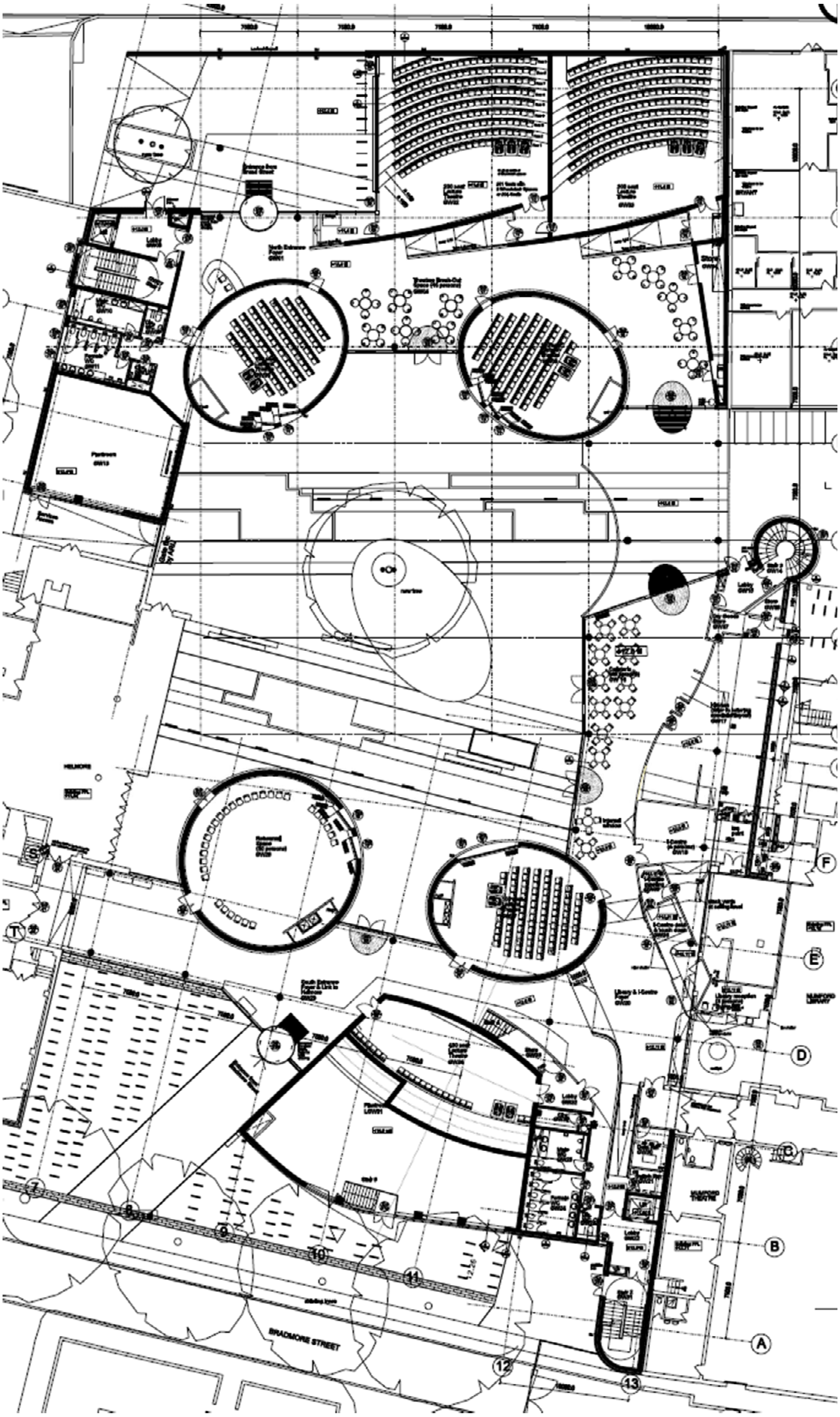

Figure 4.1.6 – Ground floor plan Building D

Table 4.1.5 – Summary of building construction and finishes for Building D

BUILDING D	
BUILDING ELEMENT	DESCRIPTION
Foundations	Unknown
Structural Frame	In-situ concrete
Ground Floor	In-situ concrete
Upper Floors	In-situ concrete
Roof	Single ply membrane / concrete deck / Small area of extensive green roof
External Walls	Facing brick with feature areas of metal, timber and ceramic tile cladding.
Glazing	Aluminium curtain walling system incorporating opening windows and automatic ventilation louvres / Full height glazing, ribbon windows and punched windows used / Brise soleil to upper floors on south and west elevations.
Entrance Doors	Automatic lobbied sliding doors to main entrances / Automatic/manual doors elsewhere
Internal wall finishes	Painted plaster generally / Feature timber cladding / Ceramic tile to pods
Floor finishes	Stone/ceramic tile to Gf circulation areas / Carpet tiles elsewhere
Ceilings	Exposed concrete soffit throughout

4.1.4 Building environmental services

A general overview of key building services features is provided below.

Energy sources for heating and cooling

Information regarding energy sources is based upon design information and discussions with members of the facilities management teams. Buildings A, C and D make use of mains gas and electricity, whilst Building B uses electricity only. Building D additionally generates electricity on site via a sizeable solar PV array. The heat load in Buildings A and C is understood to be served primarily by a gas boiler, although the mechanical ventilation system in Building A is also able to provide heat by means of air source heat pumps (these being powered by mains electricity, but also drawing a portion of renewable energy from the air). Having no gas supply, Building B makes use of air source heat pumps as its primary heat source. Building D has a gas fired combined heat and power (CHP) system installed, designed to run in conjunction with a supplementary gas boiler. The mechanical ventilation fans and cooling systems (where present) for all buildings are powered by electricity.

Heating, ventilation and cooling strategy

The observed heating cooling and ventilation strategies in use in the buildings as described above are summarised in Figure 4.1.7 and 4.1.8, based on gross GIFA and "occupied areas" respectively. These comparisons illustrate the significant differences in ventilation and cooling provision employed across the four buildings.

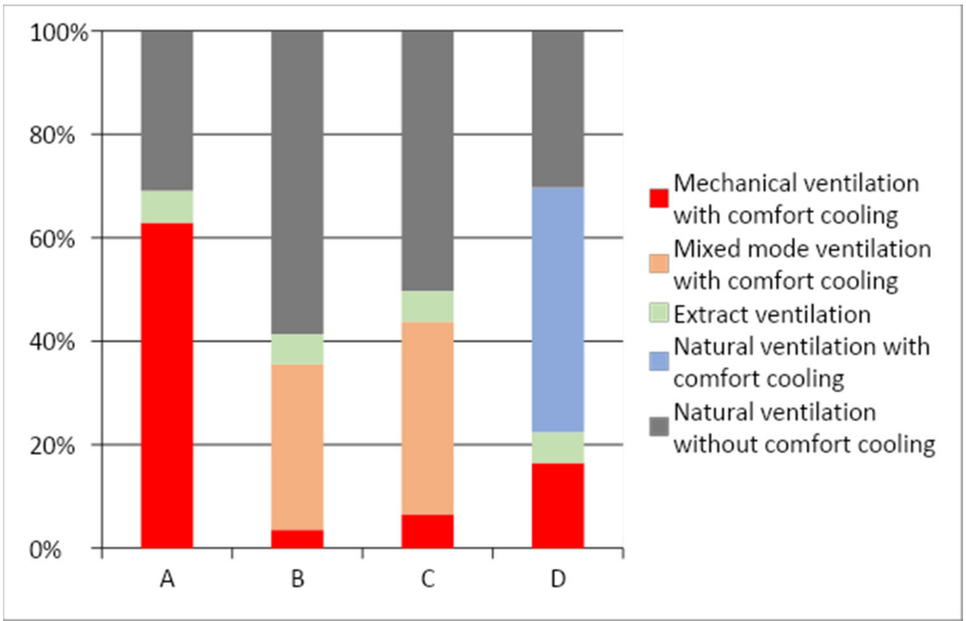

Figure 4.1.7 – Ventilation and cooling strategy by floor area

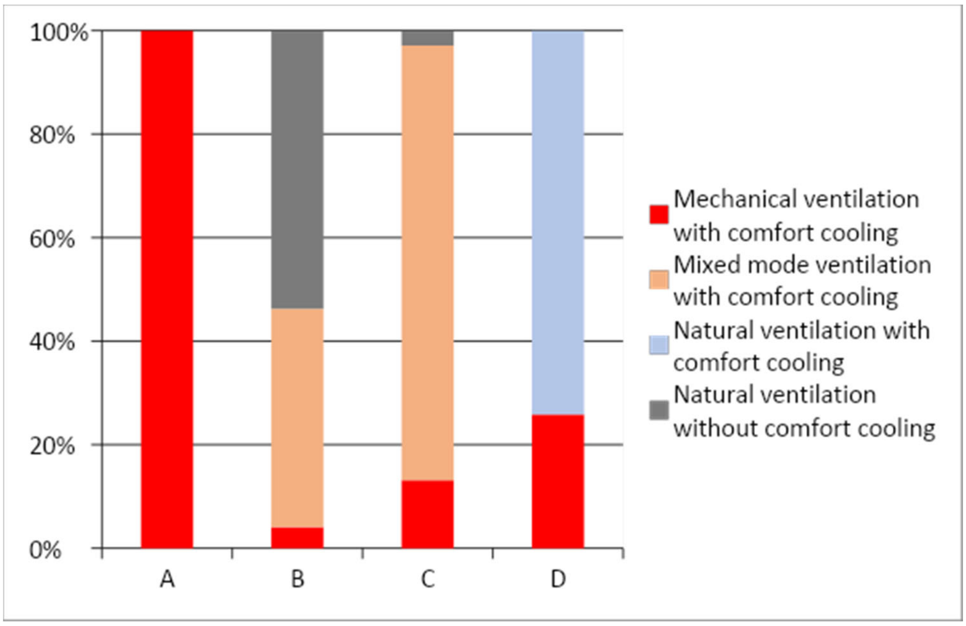

Figure 4.1.8 – Ventilation and cooling strategy by "occupied" floor area

Extract only ventilation is provided to wet areas such as WC's and showers in all buildings. The extent of additional mechanical ventilation provision varies considerably, however. Of the four buildings, Building A is most reliant on mechanical ventilation. The lecture theatres are heated and cooled using stand-alone heating ventilation and cooling (HVAC) systems incorporating chilled water cooling. Offices and laboratories are also heated and cooled via a mechanical ventilation system, with cooling provided by reverse cycle air source heat pumps. Supplementary heating is provided by radiators in certain rooms. The ground floor entrance area and stairwells are naturally ventilated by means of opening windows (automatically controlled by the BMS in the entrance foyer) and heated by radiators. Mechanically ventilated areas are also provided with manual opening windows, however notices have been posted on these asking occupants not to open them. All radiators are fitted with manual thermostatic radiator valves (TRV's), whilst the temperature of the mechanical ventilation system within the offices is designed to be locally adjustable in the range 19-23°C, by means of wall mounted digital controllers.

In Building B some confusion surrounds the heating, ventilation and cooling strategy. The BREEAM report states that the building is naturally ventilated with cooling provided to the hub room only. The building user guide produced by the university facilities management team states that mechanical heating ventilation and cooling is provided to the lecture theatre, hub room, technician room and one of the laboratories. Inspection of the building reveals however that mechanical ventilation has been installed to the majority of the ground floor, including the open plan area containing the seminar room, foyer and administration office. The additional provision was evidenced by grilles in the ceiling along with a digital controller in the seminar room, which also indicated that the system was operating. On the first floor there was no evidence of mechanical ventilation, however the laboratories and seminar room were provided with windcatchers in addition to opening windows. Control panels were evident for the windcatchers, however there was no positive indication that they were operational. It should be noted that the building manager was unaware of the existence of either the mechanical ventilation in the foyer area, or the windcatchers at first floor, and was instead making use of opening windows to ventilate these areas. The building has no gas supply and space heating is generated by air source heat pumps, and delivered both by an underfloor heating system, and via the mechanical ventilation system where present. Local temperature control is provided for both the underfloor heating system and the mechanical ventilation.

In Building C there is also some confusion regarding the servicing strategy. The BREEAM report states that the building is naturally ventilated with cooling provided to "localised specialist areas only eg server rooms". The building user guide supports this, stating that the building is heated by radiator and trench heating and is "generally naturally ventilated", with no mention made of mechanical cooling. Inspection reveals however that mechanical ventilation is actually provided to the majority of rooms, and that a temperature control dial is also installed in each of these rooms. Additional heating is provided by means of trench heating to north facing rooms, and radiators to south facing rooms and circulation areas. Radiators have been provided with TRV controls, which appeared to be linked to the BMS in classrooms (manual elsewhere). The large lecture theatre is provided with a stand-alone mechanical heating ventilation and cooling system. It should be noted however that manually opening windows were also provided to most rooms, and were in widespread use on the days of the researcher's visits, suggesting a mixed mode ventilation strategy. Several automatically opening windows were also in evidence to the south elevation of the entrance foyer, and in two cellular offices at ground floor.

Building D is provided with HVAC for its medium and large teaching spaces, but relies on natural ventilation elsewhere. This natural ventilation is provided by a combination of manually opened windows and automatically opening louvers. Trench heating is provided for the majority of areas, with radiators also used in some stairwells and lobbies. Chilled beams provide comfort cooling to the naturally ventilated classrooms and offices. The heating, cooling and ventilation louvers are centrally controlled by means of the BMS, however local override switches are provided for some ventilation louvers. The building is of concrete frame construction and features exposed soffits designed to moderate peak summer temperatures through mobilisation of thermal mass.

Lighting

The majority of "occupied" spaces within the case study buildings are provided with glazing which provides significant potential for natural lighting. Exceptions to this are the large (200+ seat) lecture theatres in Buildings A, C and D (5 in total), which are either windowless or have a single small window at high level. The 4 medium sized (100 seat) lecture theatres in Building D also have reduced window provision (less than 5% of floor area), as does the dance space, whilst the ground floor office and the commercial kitchen have no external lighting whatsoever; for the office and kitchen the configuration of the building makes provision of external windows impossible, however for the lecture theatres the reduced level of natural lighting appears to be a specific design intention.

Artificial lighting within the buildings is generally achieved by means of ceiling mounted fittings making use of either compact fluorescent or strip fluorescent bulbs. In Building D these are incorporated into the chilled beam array where present. The larger lecture theatres are typically also provided with secondary lighting arrays such as wall washers and/or low level lighting. Light switching arrangements are a combination of manual switches and proximity sensors, and are discussed in detail in section 4.3. External lighting is generally achieved by means of building mounted fittings, with Building C additionally featuring extensive bollard and column lighting to the car park area.

Hot and cold water services / wastewater

Water and wastewater services are provided in the case study buildings to serve toilet areas and kitchens. In Building C showers are also provided. A range of water efficiency measures were evident across the buildings. Buildings B and C make use of dual flush toilets, Buildings A and D are fitted with waterless urinals and Buildings A, B and C have washbasin taps controlled by electronic proximity sensors. The buildings are served by incoming mains water and outgoing mains drainage. Hot water is understood to be generated primarily by means of gas fired boilers in Buildings A, C and D, and by electricity in Building B. No rainwater or greywater harvesting is in use in the buildings.

Acoustics

Buildings A and B are situated in relatively quiet campus locations. Building C is however situated close to an urban dual carriageway and also has a large car park directly to its front. Building D is situated on a campus, but fronts on to a large and busy courtyard which forms the main external social space for the site. Resistance to break-in noise is in all cases provided by the building fabric and therefore has potential to be significantly compromised in those building areas reliant on natural ventilation.

Noise transfer between rooms is also mitigated by the building fabric. The construction of internal partitions is understood to be predominantly lightweight (stud partitions) in Buildings A and B, and medium to heavy weight (concrete blockwork or in-situ reinforced concrete) in Buildings C and D. Building C also makes use of sliding room dividers in several locations.

Acoustic reverberation time (and therefore speech intelligibility) are controlled in certain areas of Building D by acoustic panels suspended from ceilings. This provision is understood to be required in response to the widespread use of exposed concrete ceilings in the building. In the remaining buildings ceiling tiles are more normally used, with dedicated acoustic panelling being used only in large lecture theatres and certain circulation areas.

4.2 Review of BREEAM scheme characteristics

The case study buildings were assessed using the BREEAM scheme. A description of BREEAM assessment structure, scoring and ratings therefore follows. This information has been obtained by direct reference to the BREEAM assessor manuals relating to each scheme version (BRE, 2006; BRE, 2008; BRE, 2011; BRE, 2014). The scheme description focuses on BREEAM 2008, as this is most relevant to the case study buildings, however the differences between BREEAM 2008 and other versions are also discussed.

When assessed under the BREEAM 2008 scheme a building is awarded a “rating benchmark” depending upon the total % score accrued as follows:

Unclassified	<30%
Pass	≥30%
Good	≥45%
Very Good	≥55%
Excellent	≥70%
Outstanding	≥85%

The overall assessment is spilt into nine “environmental sections” as follows, along with a tenth “innovation section”:

1) Management
2) Health and Wellbeing
3) Energy
4) Transport
5) Water
6) Materials
7) Waste
8) Land Use & Ecology
9) Pollution
10) Innovation

Each “section” is in turn split into a number of “issues” numbered as follows:

1) Management - Man 01-12
2) Health and Wellbeing - Hea 01-17
3) Energy - Ene 01-20
4) Transport - Tra 01-08
5) Water - Wat 01-06
6) Materials - Mat 01-07
7) Waste - Wst 01-05
8) Land Use and Ecology - LE 01-08
9) Pollution - Pol 01-08
10) Innovation - Inn 01-10

Each of these issues contains one or more “credits” and each credit has a number of corresponding “criteria”. Fulfilling the relevant criteria leads to a credit being gained. Credits are then weighted depending upon which section they are achieved in and the particular scheme version, to make a contribution to the total score, for example as shown in Table 4.2.1

Table 4.2.1 – Sectional weightings in BREEAM 2008 Education (BRE, 2008)

SECTION	Credits available	Section Weighting
Management	10	12%
Health &Wellbeing	14	15%
Energy	21	19%
Transport	10	8%
Water	6	6%
Materials	12	12.5%
Waste	7	7.5%
Land Use & Ecology	10	10%
Pollution	12	10%
Innovation	10	10%

When the appropriate criteria have been fulfilled, evidence must be submitted to a third party BREEAM assessor. The assessor is employed as part of the project team and has responsibility for checking compliance and collating evidence which is then submitted to BRE for final validation. Compliance may be demonstrated both at “design stage” (leading to an “interim certificate”) and at “post-construction stage” (leading to a “final certificate”). The design stage assessment is based upon design information, whilst at post-construction stage additional evidence is collated which is intended to demonstrate that features incorporated at design stage have been implemented at construction stage. This takes the form of either on-site inspection and a review of construction records. A certificate may be obtained at either or both stages.

At both design and post-construction stages, weighted credits are totalled to give a percentage score, which in turn determines the “rating” achieved. In practice however, the scoring mechanism is rather complicated; note for example that the maximum score achievable is actually 110%, as the 10% available for innovation is considered additional to the basic score accrued for the environmental sections. It is also apparent that credits have different value in different sections, not only because the sections are weighted overall, but also because there are different numbers of credits making up each section. In addition some credits apply only to certain building types, so that the number of credits in each section (and therefore their individual value) also varies depending on the use of the building, and even the particular facilities it may contain. The overall effect can be significant, for example for Building A (assessed under BREEAM 2008 Bespoke scheme) each credit in the Transport section contributed 0.62% to the overall score, whereas each credit in the waste section contributed 1.25%. Furthermore each issue is composed of a varying number of credits, and each credit is composed of a varying number of criteria. For example in the BREEAM 2008 Education scheme issue Man 01 contains two credits determined by a total of 10 criteria. Meanwhile, for issue Ene 01, 15 credits are determined by just three criteria. Finally, in terms of credit selection, users are free in general to choose using a “balanced scorecard” approach. There are however a small number of minimum standards relating to particular ratings. These are credits which must be complied with, for each rating level. The minimum standards for BREEAM 2008 are as shown in Table 4.2.2.

Table 4.2.2 – Minimum standards in BREEAM 2008 (BRE, 2008)

BREEAM Issue	BREEAM Rating / Minimum number of credits				
	PASS	GOOD	VERY GOOD	EXCELLENT	OUTSTANDING
Man 1 – Commissioning	1	1	1	1	2
Man 2 - Considerate Constructors	-	-	-	1	2
Man 4 - Building user guide	-	-	-	1	1
Man 9 - Publication of building information (BREEAM Education)	-	-	-	-	1
Man 10 - Development as a learning resource (BREEAM Education)	-	-	-	-	1
Hea 4 - High frequency lighting	1	1	1	1	1
Hea 12 - Microbial contamination	1	1	1	1	1
Ene 1 - Reduction of CO2 emissions	-	-	-	6	10
Ene 2 - Sub-metering of substantial energy uses	-	-	1	1	1
Ene 5 - Low or zero carbon technologies	-	-	-	1	1
Wat 1 - Water consumption	-	1	1	1	2
Wat 2 - Water meter	-	1	1	1	1
Wst 3 - Storage of recyclable waste	-	-	-	1	1
LE 4 - Mitigating ecological impact	-	-	1	1	1

Up until and including BREEAM 2008, schemes were sub-divided depending upon building type. The bespoke scheme used at this time additionally allowed assessors flexibility to determine which issues to apply to a particular building, and also allow an issue to be applied to part of a building on a pro-rata basis. Scoring within the bespoke versions is therefore further complicated, as there is scope for varying numbers of credits in each section and for the attainment of partial credits. When BREEAM 2008 was superseded by BREEAM 2011 a single scheme document was introduced which was applicable to all building types. This greatly reduced the training requirement for BREEAM assessors, who had previously been obliged to achieve accreditation for each building type individually. In terms of the assessments themselves however the change was not significant, as differences in the application of individual issues and criteria to particular building types remained, albeit contained within a single document.

BREEAM 2011 has in turn been superseded by BREEAM 2014, however neither of these versions arguably represents a significant change in substance or approach. Individual criteria have been altered in terms of detail, primarily to remain in advance of statutory standards (in particular the energy efficiency standards contained in Building Regulations). The scoring framework, certification process and document format have however remained largely unchanged, as have the many of the criteria themselves. Some structural difference is however evident between these schemes and the BREEAM 2006 version. In particular the sections are configured differently, as is the notation for the individual issues. Detailed analysis reveals however that the content of the clauses in this scheme is typically extremely similar, and in many cases identical. The primary effect of these differences occurs within the section weightings, which are significantly different, however the individual issues, although referenced in a different way, are generally directly interchangeable with those in BREEAM 2008. The similarities existing between these versions of BREEAM which relate to new construction work and major refurbishment work should not be confused with BREEAM In-use, which was first released in 2009 and is applicable to buildings already in occupation. This scheme does have significantly different parameters, purpose and application to the original scheme, and has not therefore considered relevant to this study. In particular BREEAM in-use is not currently used as a policy tool to influence the design and construction of new buildings.

The BRE publishes details of BREEAM certificates issued under BREEAM 2008 and later schemes (BRE, 2017b). Analysis of this data reveals that 5568 BREEAM certificates have been issued since the scheme's inception, of which 71% relate to buildings in the UK. The distribution of ratings is illustrated for all schemes, the bespoke scheme, and the higher education scheme, respectively (Figures 4.2.1 – 4.2.3). Note that "other" ratings consist of an amalgamation of "pass", "unclassified" and "acceptable". Overall, "very good" is the most commonly awarded rating, accounting for 58% of all certificates issued. A similar picture exists for certificates issued under the bespoke scheme. Within the higher education scheme "excellent" is the most awarded rating (48%) with "very good" representing 39% of certificates.

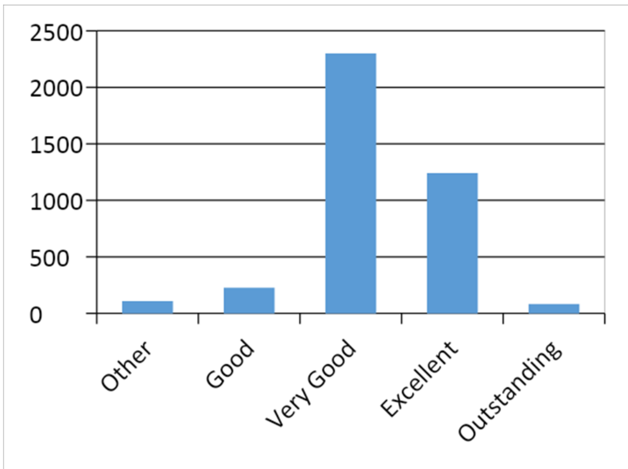

Figure 4.2.1 – BREEAM certificate ratings issued under BREEAM 2008 and later (all building types) (BRE, 2017)

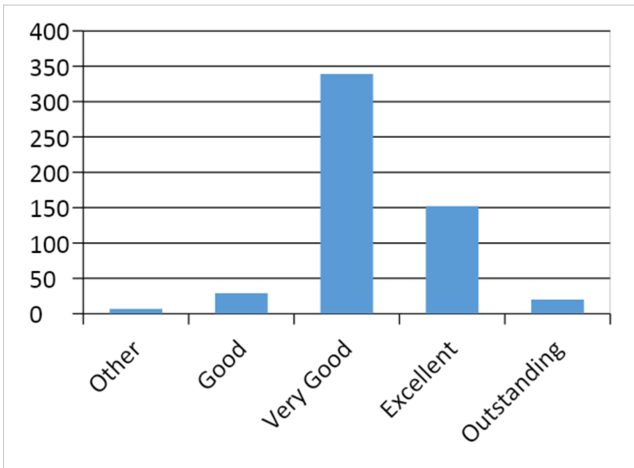

Figure 4.2.2 - BREEAM certificate ratings issued under BREEAM 2008 and later (‘bespoke’ assessments) (BRE, 2017)

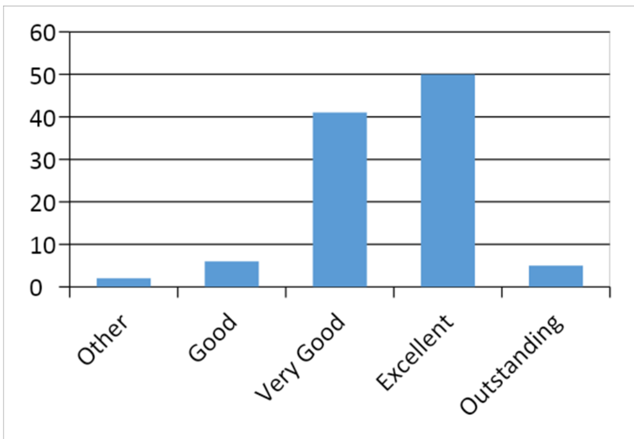

Figure 4.2.3 - BREEAM certificate ratings issued under BREEAM 2008 and later (‘higher education’’ assessments) (BRE, 2017)

As previously noted, a post construction assessment was introduced with BREEAM 2008 (note that this was also applied retrospectively to the Bespoke 2006 assessment used for Building D). The data provided on the Green Book Live website (BRE, 2017b) reveals however that a substantial number of projects do not go on to obtain this final certificate. Analysis of the information provided reveals that 43% of 'bespoke' assessments do not achieve a final certificate, whilst for higher education assessments the proportion is 68% (Figure 4.2.4).

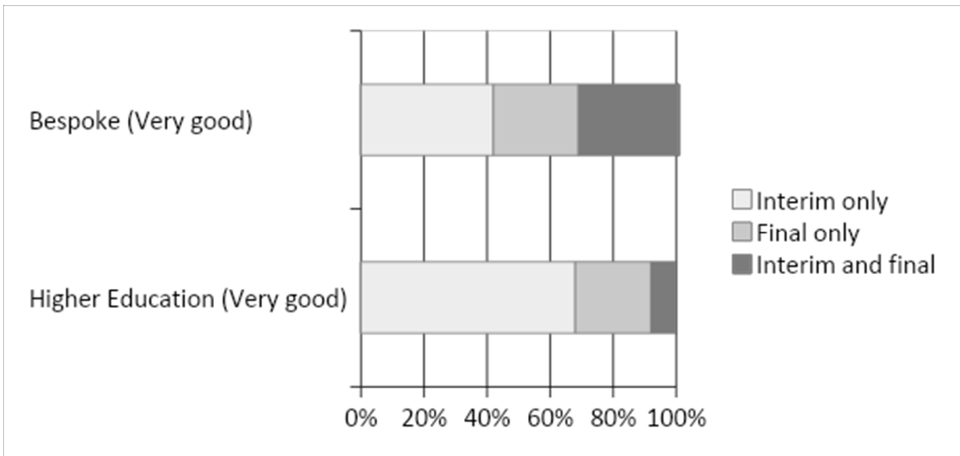

Figure 4.2.4 – BREEAM rated projects by certificate type (BRE, 2017).

4.3 - Energy

4.3.1 Introduction

As described in detail in Chapter 3, the energy performance of the case study buildings was quantified using meter readings. The impact of the BREEAM assessment on that performance, was then explored through close examination of the BREEAM reports, combined with design review, a walk through survey, building manager interviews and facilities manager interviews.

4.3.2 Energy performance of case study buildings

Energy certificate data

As discussed in Chapter 3, copies of the Energy Performance Certificate (EPC) and Display Energy Certificate (DEC) were obtained for the case study buildings. Note that due to its smaller size there is no statutory requirement for a DEC for Building B, and none has been produced. Additionally, although typically a Building Control requirement, no EPC appears to have been registered for Building C; the reason for this is unknown. Key relevant data from the remaining documents is summarised in Table 4.3.1.

Whilst noting the inconsistencies discussed above, it is possible to provide useful context for the metered energy consumption in the buildings by extracting the in-use energy consumption and CO_2 emissions from the DEC, and the CO_2 emissions resulting from regulated energy use predicted by the EPC. To allow for comparison with measured energy consumption, the DEC figures for consumption by floor area have been adjusted on the basis of measured as-built area. No such adjustment is required for the EPC figures, it being assumed that the calculated consumption by floor area would not vary significantly with a modest change in building size.

$$E_{[\text{DEC corrected}]} = E_{[\text{DEC stated by area}]} * A_{[\text{DEC stated}]} / A_{[\text{as-built}]}$$

Where E = Energy consumption, A = Area.

A similar calculation has been used to adjust CO_2 emissions stated on the DEC. Note that the CO_2 emissions for the DEC have been calculated from the energy data using the conversion factors show in Table 4.3.3 (Department for Communities and Local Government, 2008). The results are summarised in Table 4.3.4.

Table 4.3.1 – Summary of EPC and DEC data for case study buildings

	Building A	Building B	Building C	Building D
EPC				
Asset rating	42	39	No EPC available	45
Band	B	B		B
Main heating fuel	Natural Gas	Grid Electricity		Natural Gas
Building environment	Air conditioning	Natural Vent		Air conditioning
Total useful floor area (m^2)	2299	445		7502
BER ($kgCO_2/m^2$.year)	30.17	29.52		21.68
DEC				
Operational rating	79	No DEC available	71	90
Band	D		C	D
Renewal date	30/10/15		28/09/14	30/10/15
Previous operational rating	79		71	90
Previous operational rating	79			81
Main heating fuel	Natural Gas		Natural Gas	Natural Gas
Building environment	Natural Vent		Mixed Mode	Natural Vent
Total useful floor area (m^2)	2784		2291	7990
Energy use based upon	Actual		Actual	Actual
Annual energy use – heating (kWh/m^2.year)	128		129	131
Annual energy use - electricity (kWh/m^2.year)	68		81	114
Annual energy use - total (kWh/m2.year)	196		210	245

Table 4.3.2 – Floor areas for case study buildings obtained from various sources

Floor area (m^2)	Building A	Building B	Building C	Building D
EPC (TUFA)	2299	445	-	7502
DEC (TUFA)	2784	-	2291	7990
As-built drawings (TUFA)	2235	472	2192	7356

Note: TUFA = Total Useful Floor Area

Table 4.3.3 – Fuel conversion factors

Fuel	CO_2 conversion factor ($kgCO_2$/kWh)
Grid electricity	0.550
Natural gas	0.194

Table 4.3.4 – Energy consumption and CO2 emissions data obtained from energy certificates

Source	Building A	Building B	Building C	Building D
Energy (kWh/m^2/yr)				
DEC (Gas)	159	N/A	135	131
DEC (Electricity)	85	N/A	85	114
DEC (Total)	244	N/A	219	275
$C0_2$ (kg/m^2/yr)				
EPC (Total)	30	31	N/A	21
DEC (Gas)	31	N/A	26	25
DEC (Electricity)	47	N/A	47	63
DEC (Total)	78	N/A	73	88

Measured energy consumption data

As discussed above, metered gas and electricity consumption data was obtained for all buildings. Unfortunately the fiscal electricity meter for Building D serves multiple buildings and it was not initially possible to obtain measurements, although as described below, sub-metering was later installed for this building. The available data is summarised in Table 4.3.5, expressed in terms of yearly consumption per square metre of floor area. For consistency, the “as-built” treated floor areas listed in Table 4.3.2 have been used to calculate these figures. The monitoring period was 01/08/12 to 31/07/13. This period was selected as it represents a full year period for which data is available for Buildings A, B and C and during which time all buildings are understood to have been fully occupied and in normal use. Recorded degree days for heating (15.5°C) over this period were 2380 (BizEE, 2016), representing 97% of the 20 year running average provided for normalisation (Vesma, 2016). This indicates a broadly typical period in terms of heating load, and no normalisation of data has therefore been carried out. CO_2 emissions have been calculated using the fuel conversion factors in Table 4.3.3.

Table 4.3.5 – Metered energy consumption and associated emissions data (01/08/12-31/07/13)

Fuel	Building A	Building B	Building C	Building D
Energy consumption				
Gas (kWh/m^2/yr)	178	N/A	198	151
Electricity (kWh/m^2/yr)	191	199	90	Unknown
Total (kWh/m^2/yr)	369	199	288	Unknown
CO2 emissions				
Gas (kg/m^2/yr)	34	N/A	38	29
Electricity (kg/m^2/yr)	105	109	49	Unknown
Total (kg/m^2/yr)	140	109	88	Unknown

Figures 4.3.1-4.3.4 illustrate the monthly electricity and gas consumption pattern for each building. Data is presented for the core monitoring period, with data outside of this period also shown in grey where available, to provide context. Buildings A and C show a relatively even use of electricity through the year, with gas use varying seasonally. The lack of increase in electricity use in summer indicates that the mechanical cooling believed to be installed in these buildings may not be being used extensively. There is

however a general increase in electricity use in Building C year on year, with usage over the monitoring period being just 72% of that in the following year. Building B is electrically heated and displays a seasonal variation which suggesting that around half of energy use may be related to this. Gas use for Building D also shows the expected seasonal variation, but additionally includes a significant spike in February 2013 which is not apparent for the other buildings. The facilities management team were unable to offer a specific explanation for this, although they did cite various ongoing difficulties with correct operation of the CHP plant, which is gas-fired. As previously noted no electricity data is available for Building D, for this period.

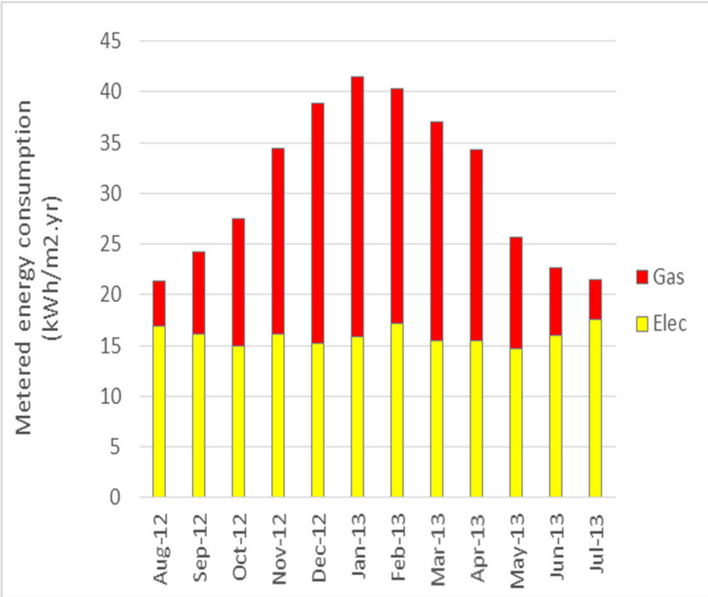

Figure 4.3.1 – Metered electricity and gas consumption for Building A

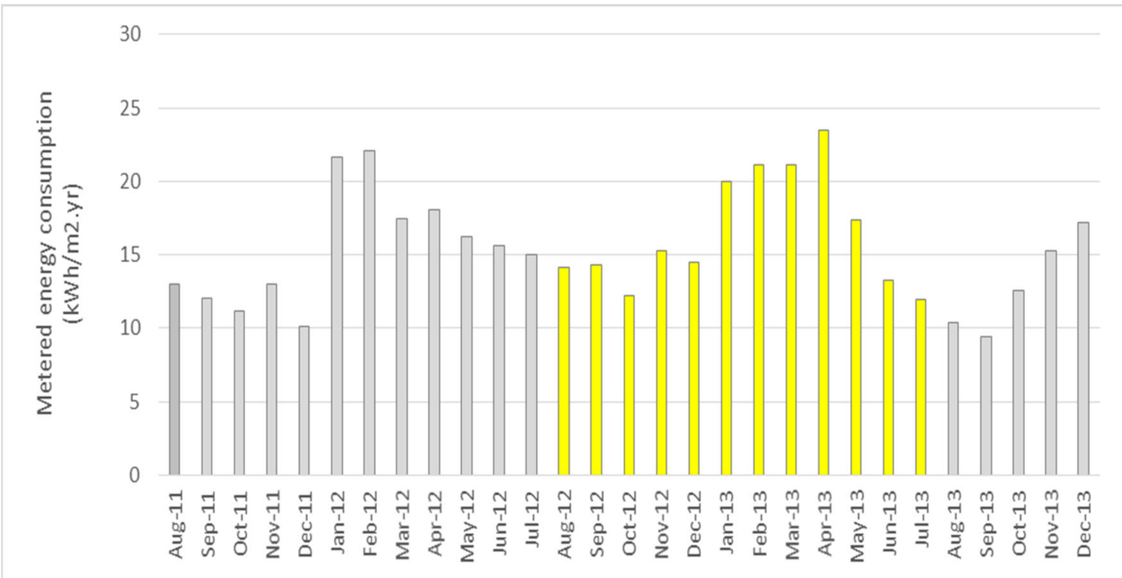

Figure 4.3.2 - Metered electricity consumption for Building B (no gas installed)

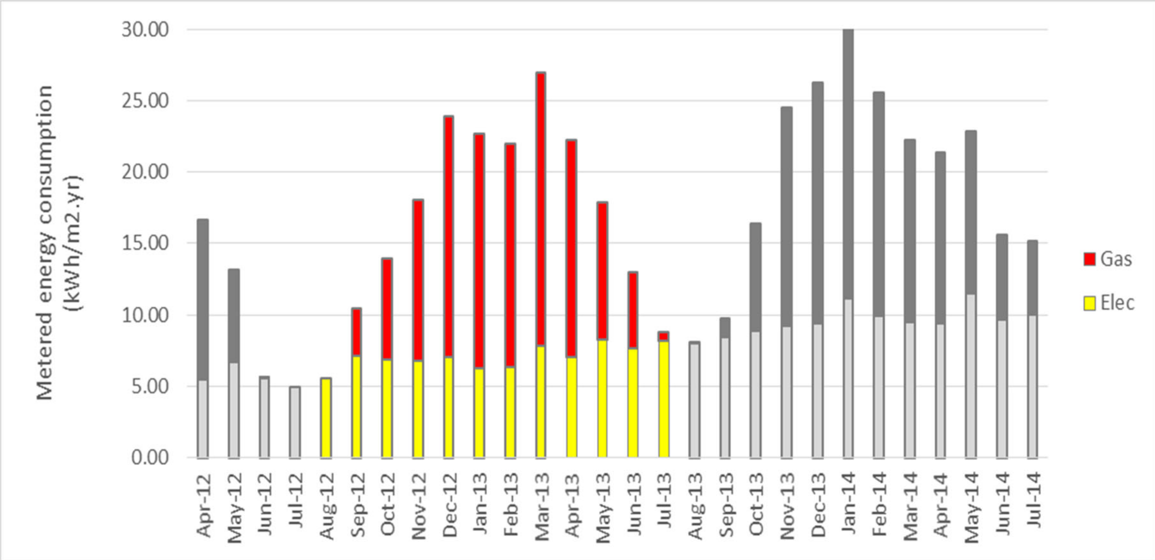

Figure 4.3.3 - Metered electricity and gas consumption for Building C

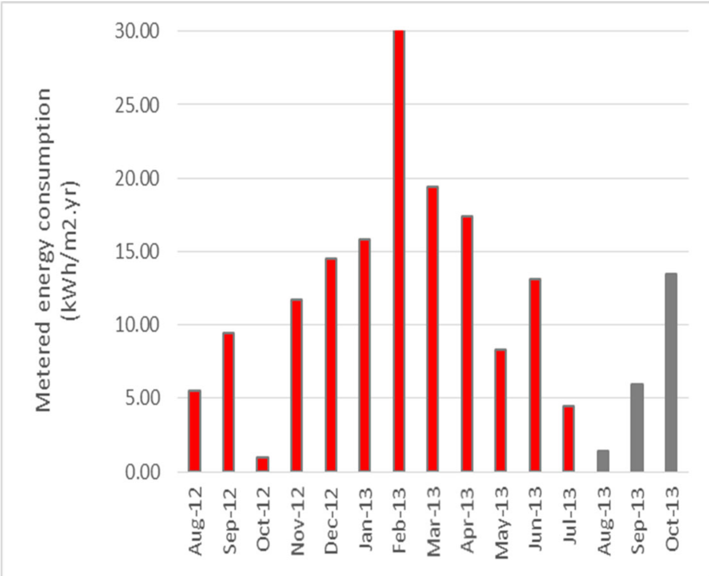

Figure 4.3.4- Metered gas consumption for Building D (no data available for electricity)

Building D – Measured Energy Consumption Data 2014

In 2014 an electrical sub-meter was installed and commissioned which allowed electrical consumption of Building D to be measured in isolation from the rest of the campus (Table 4.3.6). Recorded heating degree days (15.5°C) over this period were 1802 (BizEE, 2016), representing just 74% of the 20 year running average provided for normalisation (Vesma, 2016). Building D is however heated predominantly by gas; as such, although the monitoring period was substantially warmer than both the 20 year average and that used for the other buildings, no normalisation of electricity consumption data has been carried out. CO_2 emissions have been calculated using the fuel conversion factors in Table 4.3.3.

Table 4.3.6 – Metered electricity consumption and associated emissions data (Building D 01/01/14-31/12/14)

Fuel	Building D
Electricity (kWh/m^2/yr)	150
Electricity (kg/m^2/yr)	82

The use profile for the period is illustrated in Figure 4.3.5 and indicates a modest variation across the year, with the highest value being in July. This is perhaps unsurprising as the comfort cooling for the building is powered by electricity, with July representing both summer temperatures, and a much higher level of occupation than might be expected in August, when few students are present in the building.

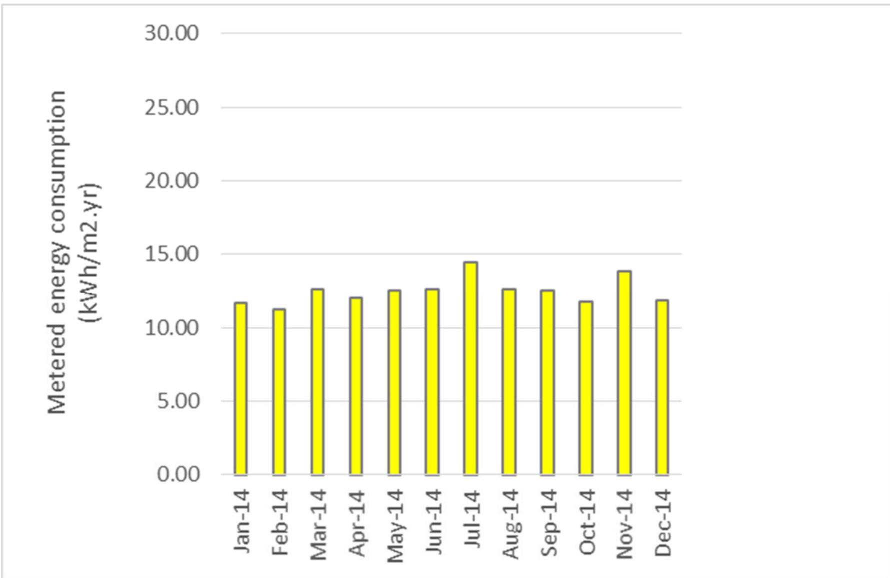

Figure 4.3.5 - Metered electricity consumption for Building D (2014)

Comparison of measured and DEC data

Comparing metered energy consumption with DEC data reveals close agreement only for Building C, where actual data has been used. Actual consumption for Buildings A and D is significantly higher than that reported for the DEC, particularly for electricity use in Building A. This appears to be due to the means of calculating the consumption used to generate the DEC's, which the estates management team confirmed is based upon area weighted data for the campus as a whole and is not therefore representative of any particular building. Given the observed discrepancies and the lack of clarity regarding information sources, the DEC energy consumption data will not be considered further. Metered consumption will instead be used to evaluate the performance of the buildings.

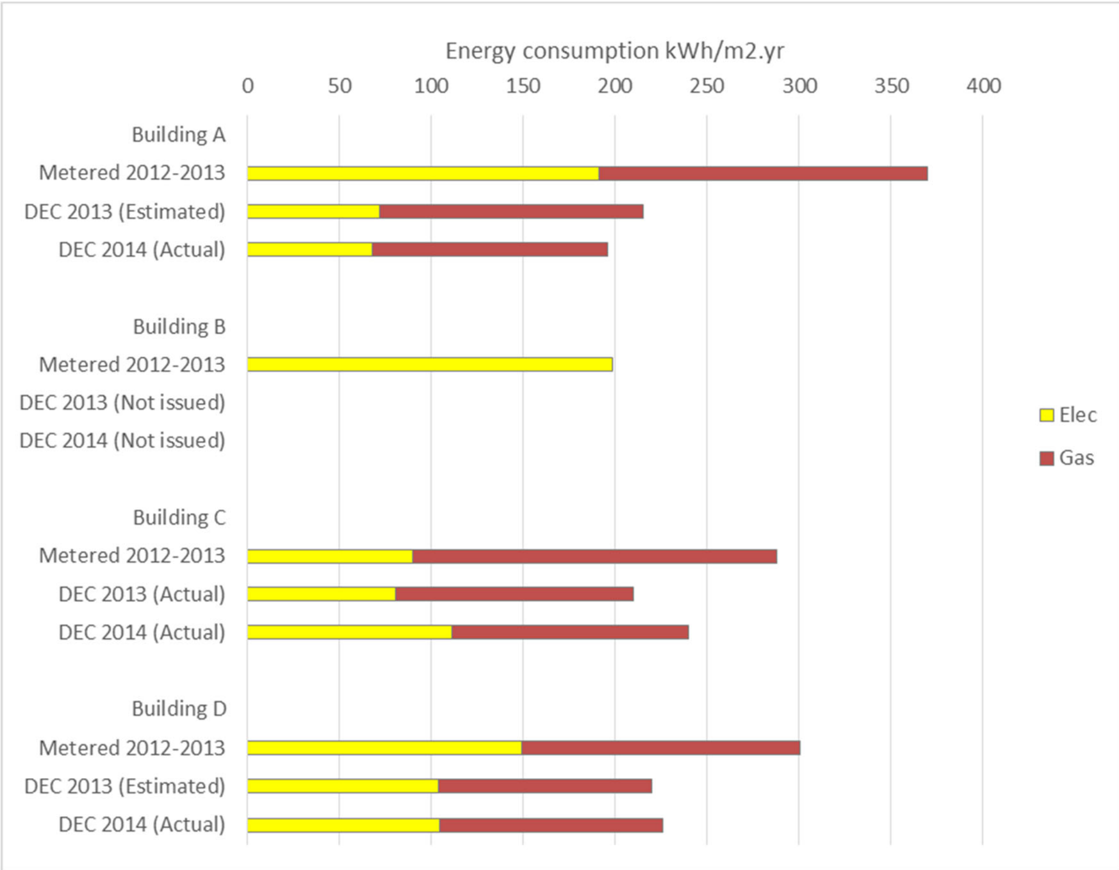

Figure 4.3.6 – Comparison of metered energy consumption with DEC data

Performance of buildings against energy and CO_2 emissions benchmarks

The energy consumption and carbon emissions benchmarks discussed in Chapter 3 are summarised in Table 4.3.7. Figures 4.3.7 and 4.3.8 compare the metered energy consumption and CO_2 emissions for the case study buildings with these benchmarks. In terms of existing buildings generally it can be seen that there is broad agreement between the energy consumption data collected by HEFCE and that collected by Carbon Buzz. Comparing the HEFCE data of 2012-2013 with the CIBSE TM46 benchmark for

University Campus buildings based on data from 1996, the HEFCE data is indicating greater electricity consumption, but only 50% of the gas use. This is perhaps unsurprising given that, as discussed Chapter 3, increases in building fabric and services efficiency standards over this time would be expected to considerably reduce heating load, whilst an increased density of computing equipment over the same period may be expected to increase electricity use. In terms of the ECG 19 benchmarks the average HEFCE building is showing a similar split between electricity and fossil fuels as a "typical" naturally ventilated office (approximately 35:65), with consumption overall being around 15% higher for the HEFCE data.

Table 4.3.7 – Summary of energy consumption and CO_2 emissions benchmark data

Benchmark	Electricity (kWh/m^2yr)	Fossil fuel ($kWh/m^2 yr$)	Total ($kWh/m^2 yr$)	CO_2 ($Kg/m^2.yr$)
CIBSE TM46 - University campus	80	240	320	91
CIBSE TM46 - General office	95	120	215	76
ECG 19 - NV open plan office (typical)	85	151	236	76
ECG 19 - NV open plan office (good practice)	54	79	133	45
ECD 19 - AC standard office (typical)	226	178	404	159
ECD 19 - AC standard office (good practice)	128	97	225	89
Carbon buzz - Education	Unknown	Unknown	230	Unknown
Carbon buzz - Office	Unknown	Unknown	256	Unknown

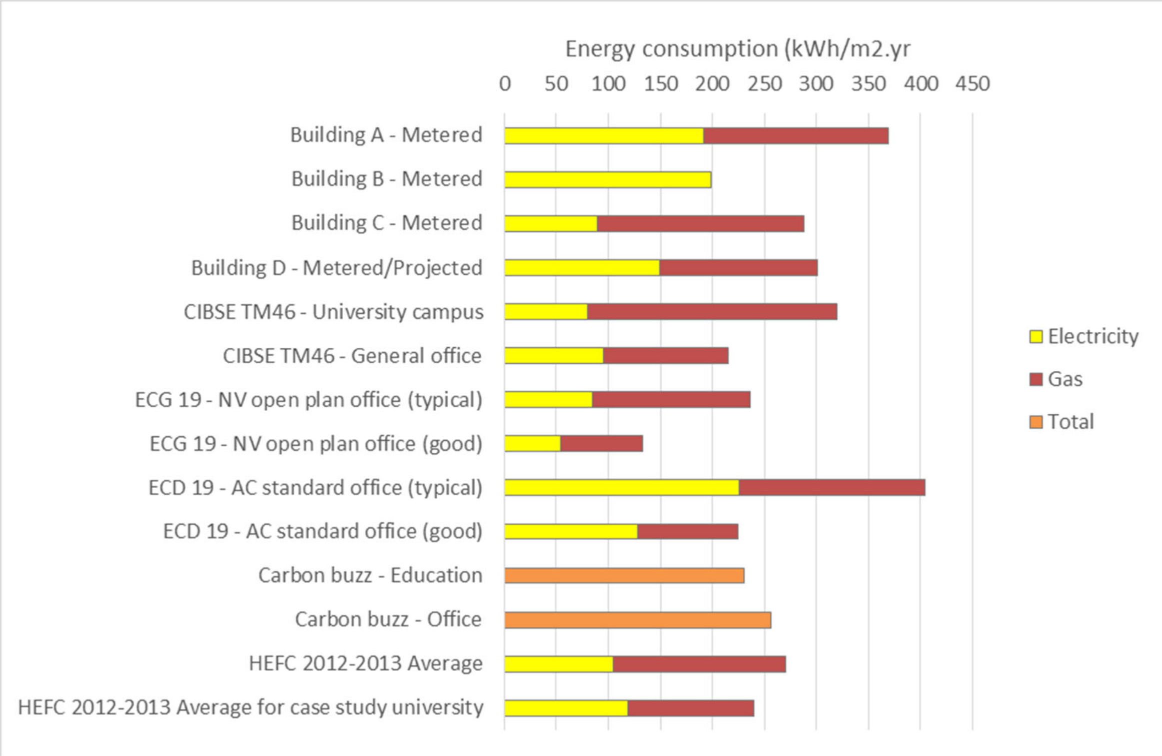

Figure 4.3.7 – Metered energy consumption for case study buildings compared with relevant benchmarks

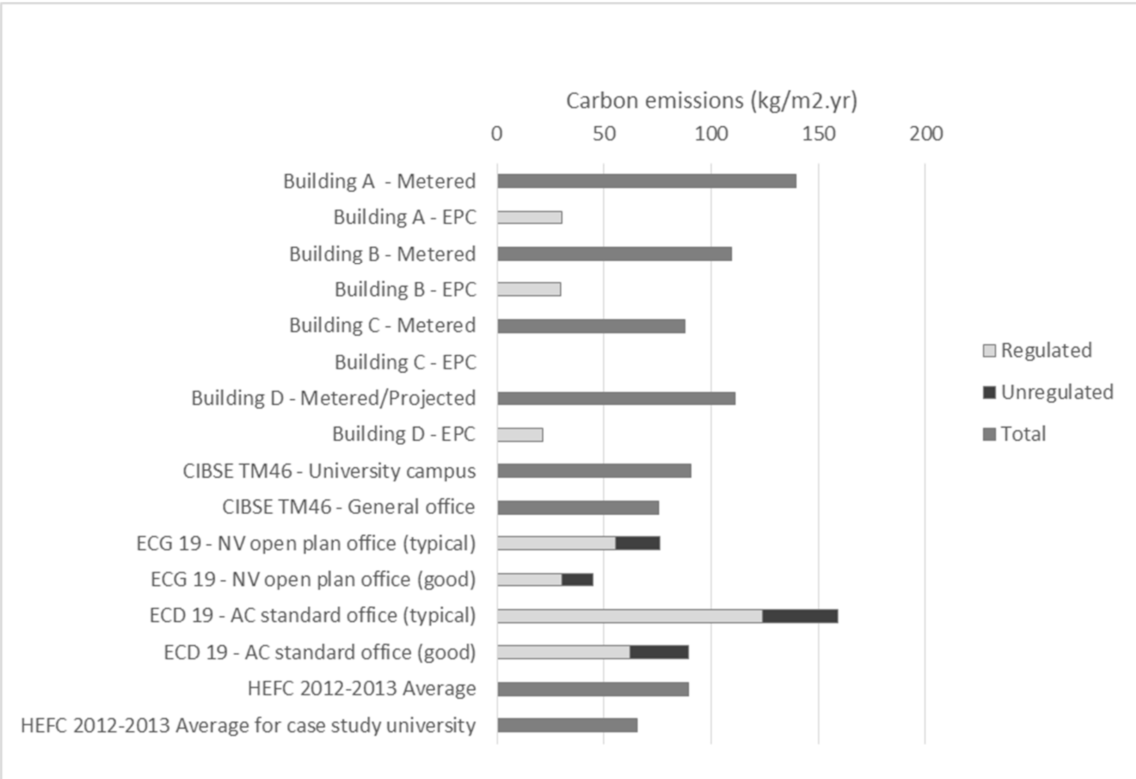

Figure 4.3.8 – Metered carbon emissions for case study buildings compared with EPC values and relevant benchmarks

Measured against the benchmarks, Buildings A, C and D can be seen to significantly exceed the HEFCE average in terms of overall energy use. In the case of Buildings A and D the underperformance appears to be largely in terms of electricity use (90% and 43% above average respectively). For Building A it is perhaps significant that this building has facility for locally controlled electrical heating and cooling in a number of areas, and this is supported by reference to the ECG 19 data, which indicates that the consumption profile most closely matches that of a typical air conditioned office. For Building C, it is gas use which appears excessive (19% above the HEFCE average), indicating that underperformance is related to heating system efficiency, excessive ventilation, or excessive fabric heat loss. This is particularly surprising because, as described in Chapter 3, Building C will have been built to significantly higher thermal efficiency standards than many of the existing buildings represented by the HEFCE dataset.

Total energy use in Building B is by contrast around 17% below the HEFCE average. In terms of the ECG 19 benchmarks the energy mix for this mixed mode building might be expected to be somewhere between that for a naturally ventilated office and that for an air conditioned building. On this basis the performance could be considered to equate to something between a “typical” and “good” standard.

In terms of carbon emissions Buildings A and D exceed the HEFCE average by 55% and 24% respectively. Despite having relatively modest energy use Building B performs poorly in carbon terms, due to its reliance on grid electricity for heating. Conversely, as a result of its low electricity use, Building C is just below the HEFCE average for carbon emissions. As well as carbon emissions based upon metered energy consumption, Figure 4.2.9 also shows the carbon emissions predicted by the EPC’s for regulated energy use. In all cases these indicate a design expectation for a standard exceeding that of a “good” naturally ventilated office, however the same standard is by no means reflected in terms of metered overall emissions. This is significant as it indicates clearly that the design controls relating to regulated energy enforced by Building Regulations, and which are also a key metric in BREEAM, are not effectively pinning back overall emissions in these buildings.

4.3.3 The application and impact of particular BREEAM Energy criteria

Based upon the analysis presented in Chapter 3, the themes associated with the criteria within the Energy section of BREEAM are as follows:

- Energy efficiency of building services
- CO_2 emissions (regulated energy)
- Monitoring of energy use
- Renewable energy
- Energy efficiency of building fabric
- Energy efficiency of domestic appliances
- Energy efficiency of IT equipment

Reference to the BREEAM standards reveals that credits within the Energy section are relatively heavily weighted, making up 19% of the available rating under BREEAM 2008. BREEAM 2006 features a combined Energy and Transport, of which Energy related credits represent 14% of the total rating. Reference to the BREEAM reports however indicates that scoring for the case study buildings was relatively low (figure 4.3.10), being in all cases below the 55% average standard required to achieve a “Very Good” certificate (Table 4.3.8).

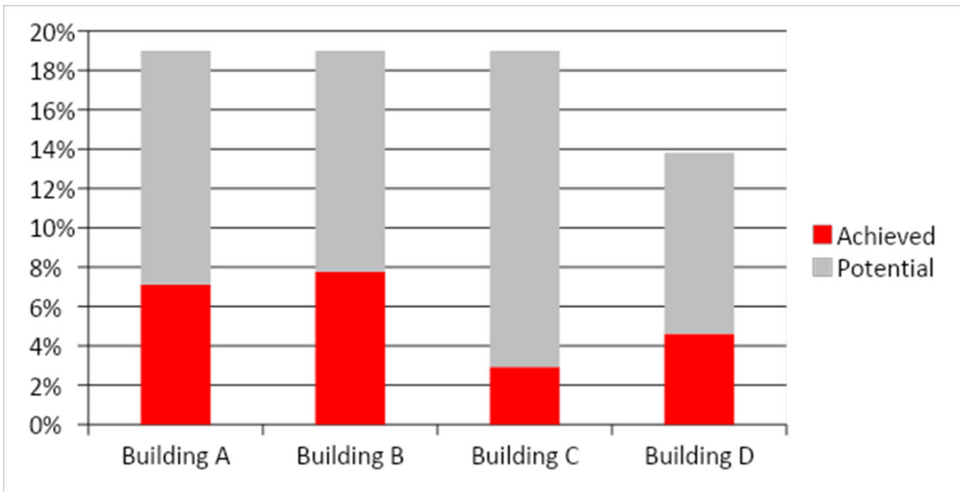

Figure 4.3.9 – BREEAM Energy credits achieved as a proportion of the total available

Table 4.3.8 – Summary of Energy category scoring for case study buildings

	Building			
	A	B	C	D
Number of Energy issues assessed	7	5	9	4
Energy credits available	24	22	26	21
Energy credits achieved	9	9	4	7
Proportion of Energy credits achieved	38%	41%	15%	33%

As summarised in Table 4.3.9, a total of 20 different Energy issues were identified, however many were deemed “not applicable” to some or all of the case study buildings. This was either because they are not assessed for the particular building type in general, or because the buildings do not contain particular features (for example a swimming pool). In all, the case study buildings achieved credits across a total of 5 issues, addressing the following themes:

- Energy efficiency of building services
- CO_2 emissions (regulated energy)
- Monitoring of energy use
- Renewable energy
- Energy efficiency of building fabric

Through analysis of the available collected data, both the manner in which each of these issues were applied, and the likely performance effect for the case study buildings is described below.

Table 4.3.9 - Detailed scoring for all buildings, by issue (energy section)

Issue		Score			
Reference	Title	Building A	Building B	Building C	Building D
Ene 01 (E1)	Reduction of CO_2 emissions	5	6	2	4
Ene 02 (E2)	Sub metering of substantial energy uses	1	1	1	1
Ene 03 (E3)	Sub metering of high energy load and tenancy areas	0	NA	0	1
Ene 04 (E4)	External lighting	1	1	1	1
Ene 05 (P11)	Low or zero carbon technologies	0	0	0	NA
Ene 06	Building fabric performance and avoidance of air infiltration	NA	NA	0	NA
Ene 07	Cold storage	NA	NA	NA	NA
Ene 08	Lifts	2	1	0	NA
Ene 09	Escalators and travelling walkways	NA	NA	NAS	NA
Ene 10	Free cooling	NAS	NAS	0	NA
Ene 11	Energy efficient fume cupboards	NAS	NAS	NA	NA
Ene 12	Swimming pool ventilation and heat loss	NA	NA	NA	NA
Ene 13	Labelled lighting controls	NAS	NAS	NAS	NA
Ene 14	BMS	NA	NA	NAS	NA
Ene 15	Provision of energy efficient equipment	0	NA	NAS	NA
Ene 16	CHP community energy	NAS	NAS	NAS	NA
Ene 17	Residential areas: Energy consumption	NA	NA	NAS	NA
Ene 18	Drying space	NAS	NAS	NAS	NA
Ene 19	Energy efficient laboratories	NAS	NAS	NA	NA
Ene 20	Energy efficient IT systems	NAS	NAS	0	NA
NA = Not assessed for this particular building NAS = Not assessed under the scheme used for this building					
Additional issues listed in manuals but not assessed for any case study buildings: HW12-13/HW18-27/Hea 14-15					

Ene 1 (E1) - Reduction of CO_2 Emissions

> Issue aim: "To recognise and encourage buildings that are designed to minimise the CO_2 emissions associated with their operational energy consumption (BREEAM, 2008)".

Up to 15 credits are available for demonstrating reductions in modelled CO_2, relative to the minimum standards of Building Regulations. This issue makes use of the CO_2 emissions modelling required to satisfy Building Regulations, and "piggybacks" on it by making direct use of the output generated, as a differentiator. As such, the credits reward a wide range of possible design interventions relating to reducing the energy consumption of building services, using low carbon energy sources for building services, on-site generation of electricity, and/or improving the thermal performance and airtightness of the building fabric. No specific guidance is provided as to how improvements should be achieved, and success is therefore dependent upon the application of pre-existing expertise within the project team. The modelling upon which the issue is based excludes unregulated energy use, and the issue therefore only partially addresses the stated aim of minimising CO_2 emissions associated with operational energy consumption.

The case study buildings achieved varying amounts of credits for this issue, as follows:

- Building A – 5 credits
- Building B – 6 credits
- Building C – 2 credits
- Building D – 4 credits

A review of the BREEAM reports suggests that credits have been awarded based upon appropriate modelling output. For buildings A and B as-built calculations have been used, whilst for Buildings C and D assessment is based upon design stage output. For Building A the assessor additionally reports carrying out a visual inspection as follows.

> "During the site visit, the fundamental design principles that the building was based on were checked to confirm that they had been installed (e.g.

ventilation strategy, heating systems and low energy lighting). It was visually confirmed that these have been installed in accordance with the original design drawings and specification. A representative of the main contractor confirmed that there were no significant design changes and that technical criteria applicable to the credit award have been fulfilled".

Full post occupation verification of the modelling input was not feasible, both because the calculations were not made available, and because the study was not configured to assess the required parameters i.e. u-values, airtightness, ventilation heat loss, and the size and energy efficiency of heating, hot water, ventilation, energy generation and cooling plant. As discussed in section 4.1.4, it was however possible to identify a number of significant general inconsistencies between the building services strategies described in the BREEAM reports, and those in operation in the case study buildings:

1. Building A is designed to for a mixed mode ventilation strategy, however the majority of the building appears to be fully mechanically vented in practice (notices having been posted throughout the building asking occupants not to open windows).
2. Building B is described in the BREEAM report as being naturally vented, however mechanical ventilation has been installed to the majority of the ground floor area.
3. Building B is provided with windcatchers to the 1st floor, however the building manager was unaware of their presence
4. Building C is described in the BREEAM report as naturally vented, however mechanical ventilation has been installed in the majority of rooms.

As the case study buildings have all achieved credits under this issue, it should be expected that their CO_2 emissions resulting from regulated energy will be lower than those of a similar property designed to the minimum standard stipulated by Building Regulations Part L 2006. The precise expected performance improvement is not possible to calculate without access to the modelling data, as the minimum standard varies according to assumptions made relating to the split between heating and hot water, and lighting loads. For reference however, a building achieving 6 credits under this issue (an asset rating of 40) would be expected to produce approximately 25% less CO_2 annually from regulated energy use, than the same building achieving 2 credits (an asset rating of 53).

Ene 2 (E2) - Sub-metering of substantial energy uses

> Issue aim: “To recognise and encourage the installation of energy sub-metering that facilitates the monitoring of in use energy consumption”.

One credit is available where accessible, labelled sub-meters are installed for the following:

- Space Heating
- Domestic Hot Water
- Humidification
- Cooling
- Fans (major)
- Lighting
- Small Power
- Other major energy-consuming items where appropriate

All four case study buildings have systems which require sub-metering under this issue. This credit is mandatory for certification at “Very Good” standard. All buildings attempted and achieved the credit.

- Building A – 1 credit
- Building B – 1 credit
- Building C – 1 credit
- Building D – 1 credit

Review of the BREEAM reports reveals that credits have generally been awarded based upon design drawings and specification clauses, supplemented in some cases by statements of compliance from main contractors. In Building A, compliance was additionally verified by inspection of the distribution board, combined with as-installed drawings provided by the installer.

As previously noted, it was not possible to obtain any electrical sub-metering data for the case study buildings. The facilities management team for Buildings A and D confirmed that whilst sub-metering had been specified for both buildings, it was in every case either faulty, or had not been properly commissioned i.e. was not visible on the BMS. For Building B the hospital facilities management team were unaware of the presence of sub-meters, again indicating that meters were either missing or defective, or had not been linked to the BMS. For Building C the facilities management team were similarly unaware of the presence of sub-meters, and obtain their energy use data via manual reads from the fiscal meter.

The aim of the credit is that monitoring of in-use energy consumption is facilitated. It can also reasonably be inferred that such monitoring might be used to control and possibly reduce electricity use, as part of an ongoing management strategy. In the case study buildings however, no monitoring appears to have taken place, and no related improvement should therefore be expected.

Ene 3 (E3) - Sub-metering of High Energy Load and Tenancy Areas (Sub-metering of areas/tenancy)

> Issue aim: “To recognise and encourage the installation of energy sub-metering that facilitates the monitoring of in use energy consumption by tenant or end user”.

One credit is available where accessible, labelled sub-meters are installed for differently tenanted areas, or for different function areas or departments within the building. Relevant function areas include:

- Computer suites
- Lecture halls
- Conference rooms
- Laboratories

All four case study buildings have function areas which require sub-metering under this issue. The credit was achieved for Building D, but not for Buildings A and C. The issue was not assessed for Building B (no reason was provided for this in the BREEAM report).

- Building A – 0 credit
- Building B – Not assessed
- Building C – 0 credit
- Building D – 1 credit

Review of the BREEAM report for Building D reveals that the credit was awarded on the basis of a letter from the designer, and a schematic design drawing. However, as previously noted, it was not possible to obtain any electrical sub-metering data for this building. The facilities management team for Building D confirmed that whilst sub-metering had been specified for the building, it was in every case either faulty, or had not been properly commissioned i.e. was not visible on the BMS.

The aim of the credit is that monitoring of in-use energy consumption is facilitated. It can also reasonably be inferred that such monitoring might be used to control and possibly reduce electricity use, as part of an ongoing management strategy. In the case study buildings however, no monitoring appears to have taken place, and no related improvement should therefore be expected.

Ene 4 (E4) - External lighting

> Issue aim: "To recognise and encourage the specification of energy-efficient light fittings for external areas of the development".

One credit is available where external lighting meets minimum standards of luminous efficacy, and is prevented from operating in the daytime by a photocell and/or time switch control. Buildings A, B and D have a small amount of building mounted external lighting. Building C includes a large car park is included within the assessment area, which has a substantial amount of bollard and column lighting.

All buildings achieved the credit.

- Building A – 1 credit
- Building B – 1 credit
- Building C – 1 credit
- Building D – 1 credit

Review of BREEAM reports reveals that the credit was generally awarded based upon a combination of design specification (for the controls) and written assurances from designers and/or main contractors (for the efficacy). For Building A, this was supplemented by a site inspection by the assessor, who was able to verify the fitting type, and the presence of a photocell.

It was not possible to verify the precise efficacy of installed light fittings or the presence of effective controls, using the research methods applied. There was however no evidence of conspicuously high energy feature or floodlighting in use on any building; neither were any external lights observed to be on during the daytime. Due to the absence of working sub-meters within the buildings it was not possible to isolate the energy use for external lighting.

The aim of the credit is to specify energy efficient light fittings for external areas. It does not however seek to limit the quantity of external lighting, which was very large for Building C and very small for the remaining case study buildings. Neither does the stipulation of “energy efficient” lighting arguably represent a change from standard practice, with compliant fluorescent and sodium vapour lamps being routinely used for external utility lighting. It is therefore expected that adherence to the criteria would result a large reduction in overall electricity only in comparison to buildings which make significant use of feature lighting, or those for which lighting is used during the daytime.

Ene 08 - Lifts

Issue aim: “To recognise and encourage the specification of energy-efficient transportation systems” (BRREAM, 2008)

One credit is available where a “transport demand analysis” is conducted to optimise the number and size of lifts provided, and that at least two lift strategies are considered and the most energy efficient specified. A second credit is available where the three most beneficial of the following energy saving features are incorporated into the chosen lift system:

a. The lifts operate in a stand-by mode during off-peak and idle periods. For example the power side of the lift controller and other auxiliary equipment such as lift car lighting and ventilation fan switch off when the lift is not in motion.
b. Where lift motors use a drive controller capable of variable-speed, variable-voltage, variable-frequency control of the drive motor.
c. The lift has a regenerative unit so that energy generated by the lift (due to running up empty and down full) is returned back to the grid or used elsewhere on site.
d. The lift car uses energy-efficient lighting and display lighting (>60 Lumens/watt or fittings that consume less than 5W e.g. LEDS).

All buildings have at least one lift installed. Two credits were achieved for Building A, one for Building B and none for Building C. The credit was not assessed for Building D.

- Building A – 2 credits
- Building B – 1 credit
- Building C – 0 credit
- Building D – Not assessed

Review of BREEAM reports indicates that the credits for Building A were awarded based upon a transport demand analysis and design provided by the lift manufacturer. The installation was also visually inspected by the BREEAM assessor. Information provided in relation to the second credit confirms that this lift contains:

- Stand-by mode during off-peak and idle periods.
- Drive controller capable of variable-speed, variable-voltage, and variable-frequency control of the drive motor.
- Energy-efficient lighting and display lighting (<50l/watt)

For Building B compliance appears to be based upon an informal assessment by the services engineer, which concludes that due to the small building size the lift is sized to meet disabled access requirements in lieu of demand. The installed lift is deemed to be "the most energy efficient available" but no evidence is referenced which substantiates this. For Building C manufacturer's information has been provided to justify the lift specification on energy efficiency grounds, however the credit is withheld as no demand analysis has been carried out.

It appears that the energy efficiency of the lifts has been considered in Buildings A, B and C, although the demand analysis does not appear to be particularly robust (being either generated by the lift supplier, or based upon a qualitative judgement by the design team). Due to a lack of functioning sub-metering it is not possible to make any meaningful assessment of their energy performance in use.

Selecting the most energy efficient of two unspecified lift strategies does not appear to be a robust method of reducing in-use energy consumption, given that the parties defining the options and making the selection have a direct commercial link to the project. The incorporation of particular energy saving features as required to achieve the second credit may however be expected to reduce energy consumption to some degree. A small reduction in unregulated energy use may therefore be expected to be observed for Building A, although neither the predicted energy consumption nor the magnitude of the expected savings are stated in the BREEAM report.

4.3.4 Summary

No overall aim is stated for the BREEAM Energy section, however examination of the criteria suggests that the intention is to differentiate certified buildings on the basis of their energy demand, and the resulting CO_2 emissions. The building energy monitoring suggests however that no clear positive differentiation is evident for the case study buildings, for either parameter. Despite being designed to exceed current building control energy standards, only one of the four building displayed a (modest) reduction in energy use by floor area, compared to the existing stock of education buildings. Similarly only one building (not the same one) displays lower CO_2 emissions than the HEFCE average.

4.4 - Water

4.4.1 Introduction

As described in detail in Chapter 3, the water consumption of the case study buildings was quantified using meter readings. The impact of BREEAM on that performance was then explored through close examination of the BREEAM reports, combined with design review, a walk through survey, building manager interviews and facilities manager interviews.

4.4.2 Water consumption in case study buildings

Measured water consumption data

As discussed in Chapter 3, monthly water consumption data was provided by the facilities management teams for Buildings B and C, in the form of manual monthly meter reads. No data was available for Buildings A and D, and in both cases the facilities management team confirmed that the meters for the buildings had been faulty since installation. The water supply for all buildings is understood to be exclusively mains fed and no water sub-metering has been installed in any building. The monthly consumption data supplied for Buildings B and C is represented in Figures 4.4.1 and 4.4.2. Data bars coloured blue represent the same 12 month period used for the electricity consumption monitoring, with additional data shown in grey. As for energy consumption, data is presented relative to building floor area.

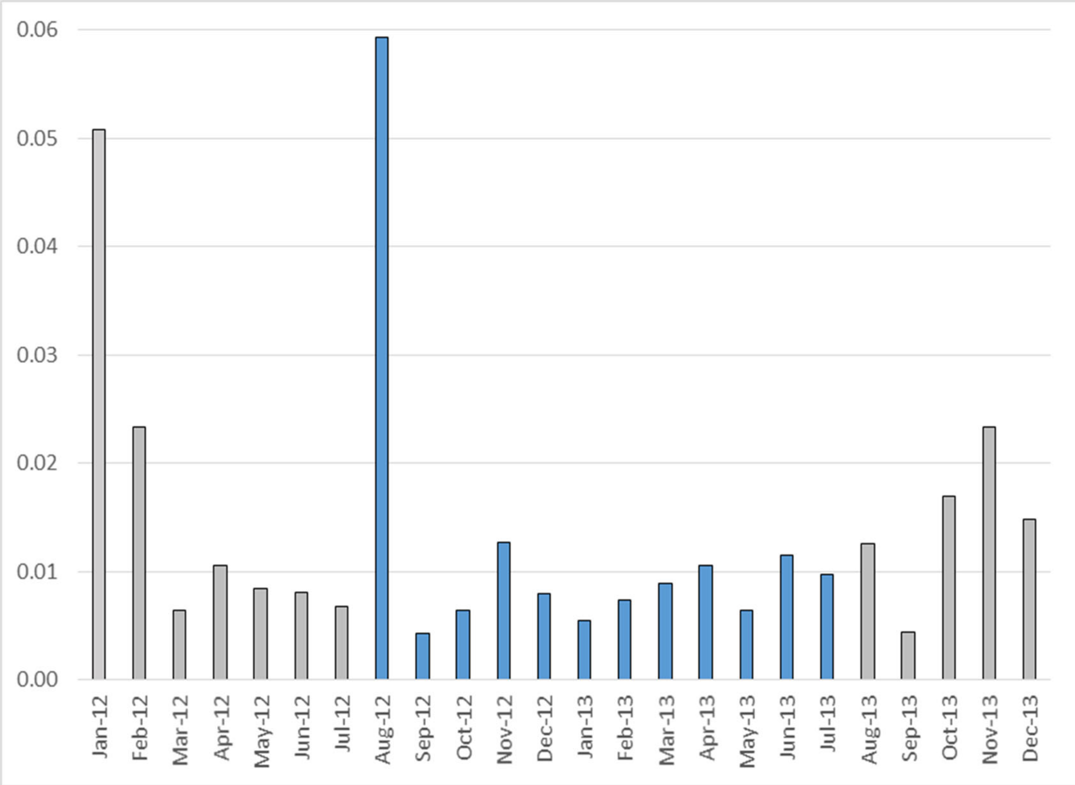

Figure 4.4.1 – Metered water consumption for Building B

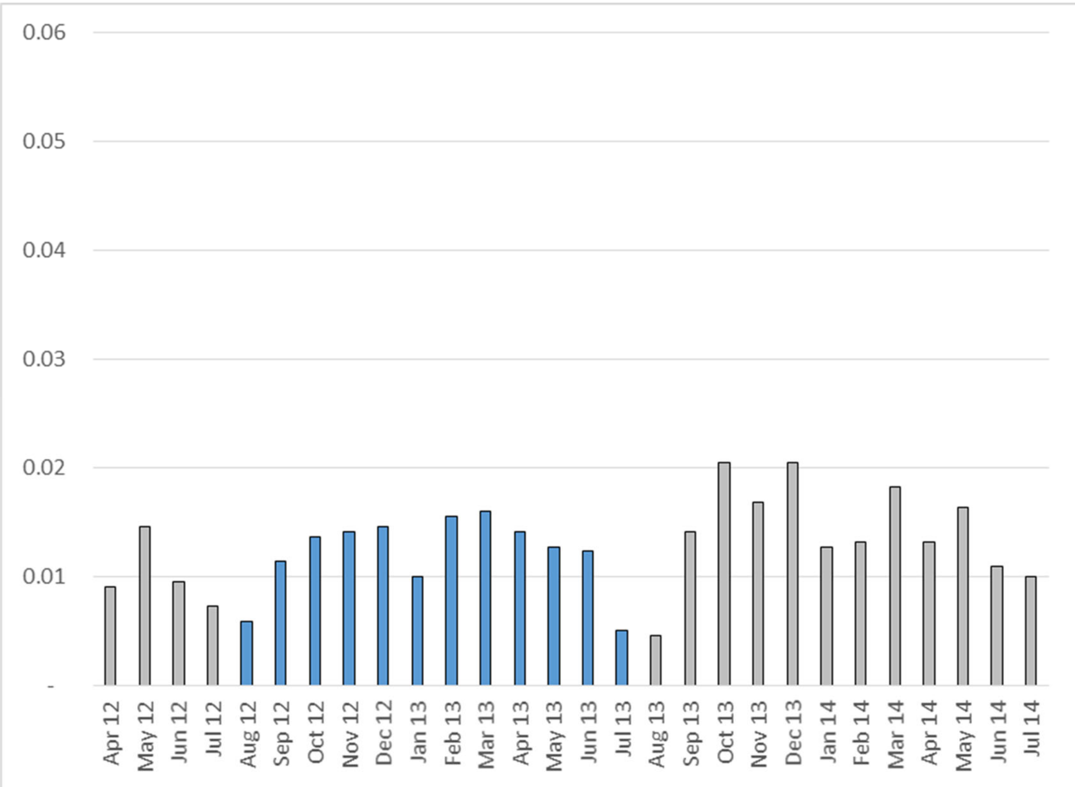

Figure 4.4.2 – Metered water consumption for Building C

Building B has a rather variable consumption rate, which may in part be expected given that it hosts training events and is therefore intermittently used by relatively large quantities of people. The first very large spike in consumption in January 2012 might also reasonably be discounted, as this was the first meter reading taken and would therefore likely have included previous use within the construction period. A second spike in August 2012 is however apparent, where water use in the month equated to more than 7 times the mean for the monitoring period. The building manager was unable to offer any operational explanation for this irregularity and were similarly unaware of any repairs having been carried out to faulty equipment in that period. Other possible explanations might include faulty metering or recording of consumption, an intermittent equipment fault, or other usage of which the building manager was not made aware. By contrast, Building C displays a far more consistent pattern, with consumption dropping during summer and Christmas holiday periods when students would not have been present in the building, but remaining relatively constant at other times.

Performance of buildings against benchmarks

The observed annual water use for Buildings B and C has been compared with various benchmarks as summarised in Figure 4.4.3. The benchmarks obtained relate in all cases to existing building stock, rather than newly constructed buildings, and may therefore fail to fully represent latest sanitary ware specifications. Notwithstanding this, the consumption data for both Buildings B and C compare very favourably with both the Watermark and CIRIA benchmarks. They also compare favourably to current average reported water use for HEFC Universities, including average figures for their own institution.

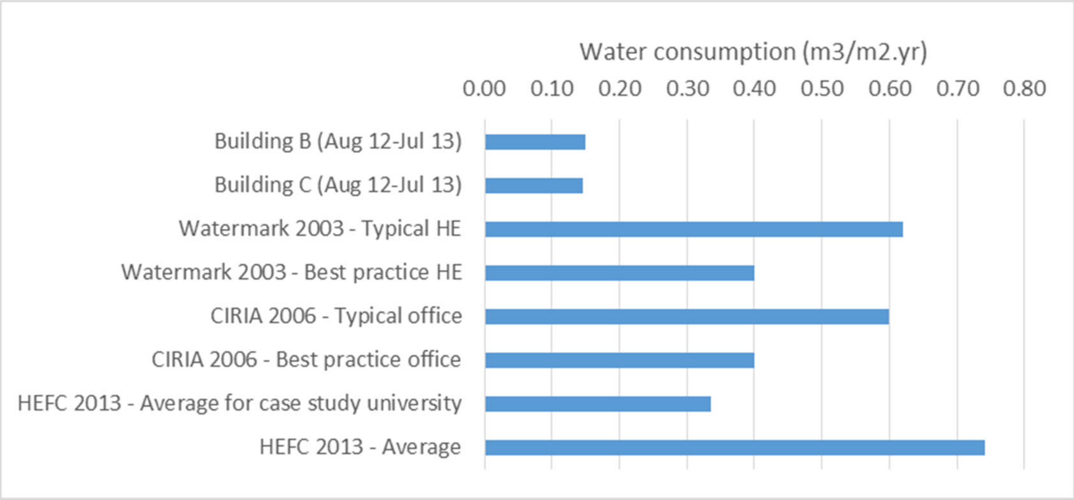

Figure 4.4.3 – Annual water consumption for Buildings B and C relative to benchmark data

4.4.3 Implementation and impact of particular BREEAM Water criteria

Based upon the analysis presented in Chapter 3, the themes associated with the criteria within the Water section of BREEAM are as follows:

- Water efficiency in-use
- Monitoring of water use
- Water leak detection/mitigation
- Water re-use
- Water for irrigation
- Water for vehicle cleaning

Reference to the BREEAM standards reveals that credits within the Water section are relatively lightly weighted, making up 7.5% of the available rating under BREEAM 2008, and just 5% for BREEAM 2006. Reference to the BREEAM reports indicates that scoring for the case study buildings was variable (Figure 4.4.4), being in some cases well below, and in other cases well above the 55% average standard required to achieve a "Very Good" certificate (Table 4.4.1).

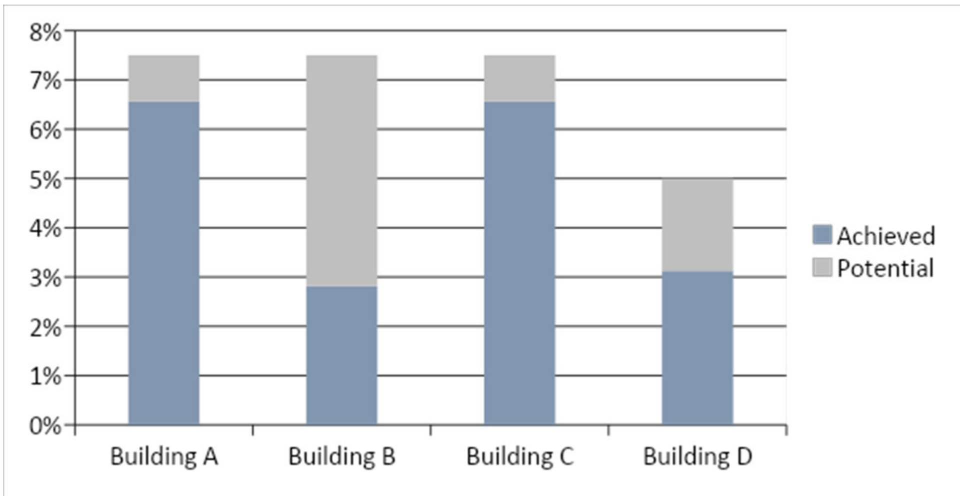

Figure 4.4.4 – BREEAM Water credits as a proportion of the total available

Table 4.4.1 – Summary of Water category scoring for case study buildings

	Building			
	A	B	C	D
Number of Water issues assessed	6	6	6	6
Water credits available	8	8	8	8
Water credits achieved	7	3	7	5
Proportion of Water credits achieved	88%	38%	88%	63%

As summarised in Table 4.4.2, a total of 7 different Water issues were identified, although one related to vehicle wash facilities, which were not present in any of the case study buildings. In all, the case study buildings achieved credits across a total of 5 issues, addressing the following themes:

- Water efficiency in-use
- Monitoring of water use
- Water leak detection/mitigation
- Water for irrigation

Through analysis of the available collected data, both the manner in which each of these issues were applied, and the likely performance effect for the case study buildings is described below.

Table 4.4.2 - Detailed scoring for all buildings, by issue (water section)

Issue		Score			
Reference	Title	Building A	Building B	Building C	Building D
Wat 01 (W1)	Water consumption	2	1	3	2
Wat 02 (W2)	Water meter	1	1	1	1
Wat 03 (W3)	Major leak detection	1	0	1	0
Wat 04 (W4)	Sanitary supply cut off	1	0	1	1
Wat 05 (W5)	Water recycling	0	0	0	0
Wat 06 (W6)	Water irrigation systems	1	1	1	1
Wat 07	Vehicle wash	NA	NA	NAS	NA
NA = Not assessed for this particular building NAS = Not assessed under the scheme used for this building					

Wat 1 (W1) – Water consumption

> Issue aim: "To minimise the consumption of potable water in sanitary applications by encouraging the use of low water use fittings" (BRE, 2008).

For BREEAM 2008, two credits are available in relation to WC flush volumes. Where the "effective flush volume" is 4.5l or less a single credit is scored. Where the "effective flush volume" is 3l or less, or where a WC having an "effective flush volume" of 4.5l or less is fitted with a "delayed action inlet valve", a second credit is awarded. "Effective flush volume" for dual flush WC's is based upon a ratio of full flush to reduced flush of 1:3, giving a standard 6/4l dual flush toilet an "effective flush volume" of 4.5l. A "delayed action inlet valve" is one which prevents the cistern re-filling until it has completely emptied. A third credit is available where the BREEAM "Water Calculation Tool" is used to calculate the water saving generated by using the following, with the two most effective being employed throughout the building:

- Taps having a 6l/min maximum flow rate and being either spray, push, lever, or electronically controlled.
- Showers having a maximum flow rate of 9l/min
- Urinals that are waterless, ultra low flush, or which are fitted with presence detection
- Baths of 100l capacity with taps which stop automatically when the bath is full

Three credits are also available for BREEAM 2006, calculated based upon similar use of reduced water sanitaryware.

1 credit is a mandatory minimum requirement for a "very good" rating. The case study buildings achieved varying amounts of credits for this issue, as shown in Table 4.4.3. A review of the BREEAM reports reveals that credits have been awarded based upon a combination of design specification clauses and manufacturers information. For Building A, the assessor has additionally visited the building and checked the installed products. For Building B the PCR is based upon photographs and purchase orders provided by the main contractor. By means of the walk through survey it was possible to verify that the provision matched the specification in general terms, although no measurement of specific flush volumes or flow rates was carried out.

Table 4.4.3 – Summary of credit scoring for BREEAM issue Wat 1

	Credit 1	Credit 2	Credit 3	Total credits achieved
Building A	4l flush WC's	Not achieved	Waterless urinals Low flow taps with proximity sensors	2
Building B	3/6l dual flush WC's	Not achieved	Not achieved	1
Building C	2/4l dual flush WC's		Low flow taps and urinals fitted with proximity sensors	3
Building D	Electronic sensor taps and waterless urinals	Not achieved	Not achieved	1

A relatively robust level of evidence has been provided in relation to the credits achieved, and the presence of many of the specified features were additionally confirmed by the researcher. The credits achieved in the buildings might therefore be expected to result in a reduction in water use in sanitary applications. In these buildings, that might be expected to form a significant proportion of total water use, although other potential uses do exist, particularly the laboratories in Buildings A and B, and the commercial kitchen in Building D.

Wat 2 (W2) – Water meter

> Issue aim: "To ensure water consumption can be monitored and managed and therefore encourage reductions in water consumption" (BRE, 2008).

1 credit is available where a pulsed output water meter is provided on the incoming water supply to the building. Additional meters are required for swimming pools or plumbed-in laboratory process.

All case study buildings achieved the credit, as follows:

Building A – 1 credit

Building B – 1 credit

Building C – 1 credit

Building D – 1 credit

Review of the BREEAM reports reveals that the credit has in all cases been awarded, based upon the presence of a pulsed water meter on design drawings and/or in specification clauses. For Building A, as-installed drawings were additionally provided by the contractor, whilst for Building B installation was confirmed in a letter from the main contractor. As previously discussed, it was not possible to obtain water consumption data for all case study buildings. The facilities management team for Buildings A and D confirmed that whilst metering had been specified for both buildings, it was in both cases either faulty, or had not been properly commissioned i.e. was not visible on the BMS. For Buildings B and C meter readings provided by the facilities management teams were based on manual reads of the utility company meter. In neither building were the facilities management team aware of the presence of a pulsed output water meter, again indicating that meters were either missing or defective, or had not been linked to the BMS.

Given that the building facilities management teams were in all cases unable to access pulsed metering data, no effect should be expected in connection with the credits achieved under this issue.

Wat 3 (W3) – Major leak detection

> Issue aim: “To reduce the impact of major water leaks that may otherwise go undetected” (BRE, 2008).

One credit is available where a leak detection system with an audible alarm is installed along the incoming water supply, between the building and the site boundary.

The case study buildings achieved credits under this issue as follows:

Building A – 1 credit

Building B – 0 credits

Building C – 1 credit

Building D – 0 credits

Review of BREEAM reports reveals that credits have been awarded based upon drawings, specification clauses, and statements of intent from installers. For Building A, the contractor provided a copy of their BMS operations manual confirming the inclusion of leak detection. As previously discussed, however, the water meter for Buildings A has been dysfunctional since installation. As the leak detection system described is reliant on pulsed output from this meter, that the criteria does not therefore appear to have been properly applied. The proposed system for Building C is similarly reliant on a pulsed output from meters. The facilities management team were unable to access meter reads for this building via the BMS, and were additionally unaware of the existence of leak detection facility.

Information provided by the facilities management teams for Buildings A and C suggest that no major leak detection is in operation for these buildings. No effect should therefore be expected in connection with the credits achieved under this issue.

Wat 4 (W4) – Sanitary supply cut off

> Issue aim: “To reduce the risk of minor leaks in toilet facilities” (BRE, 2008).

One credit is available where presence detection is installed which shuts off the water supply to toilet areas, when they are unoccupied.

The case study buildings achieved credits under this issue as follows:

Building A – 1 credit

Building B – 0 credits

Building C – 1 credit

Building D – 1 credit

Review of the BREEAM reports reveals that credits have been awarded based upon drawings, specification clauses, and statements of intent from designers. For Building A, as-installed drawings were additionally provided by the contractor. The researcher noted the presence of detectors in WC areas but was unable to positively confirm whether they were in operation.

Shutting off the water supply to toilet areas in periods of non-occupation might be expected to reduce the impact of any leaks that did occur (although not the risk of them occurring, as is suggested by the issue aim). A reduction in annual water consumption might therefore be expected in connection with the credits achieved.

Wat 6 (W6) – Water irrigation systems

> Issue aim: “To reduce the consumption of potable water for ornamental planting and landscape irrigation” (BRE, 2008).

One credit is available where either a zoned drip feed irrigation system with rainstat is installed, or where plants are watered using reclaimed water, or where planting does not require an automatic irrigation system.

All of the case study buildings achieved this credit:

Building A – 1 credit

Building B – 1 credit

Building C – 1 credit

Building D – 1 credit

Review of the BREEAM reports reveals that credits for the buildings were awarded based upon statements from designers relating to the proposed irrigation strategy. For Building A, the designers state that landscaping is to be watered by the university gardeners, using bowsers filled from a central rainwater collection system. For Buildings B and D no irrigation was deemed to be required, and for Building C the planting was expected to be watered “by precipitation or manual watering”. The researcher did not observe automatic irrigation systems in use on any buildings.

No automatic watering systems were specified or installed in the case study buildings. A reduction in water consumption might therefore be expected in comparison to buildings with planting areas which do make use of automatic watering systems.

4.4.4 Summary

No overall aim is stated for the BREEAM Water section, however examination of the criteria suggests that the intention is to differentiate certified buildings on the basis of their demand for potable water. Water consumption data was unavailable for two of the four case study buildings, due to the absence of functioning metering on Buildings A and D. Results for Buildings B and C reveal however excellent performance, exceeding all benchmarks and in each case demonstrating consumption by floor area of just 20% of the HEFCE average.

4.5 – Internal Environmental Quality

4.5.1 Introduction

A building occupant survey (BUS) was used to measure the perceived internal environmental quality of the case study buildings, and its effect on the health and wellbeing of building occupants. This data was further supported by a walk through survey, design review, and interviews with facilities management staff and building managers, all as described in detail in Chapter 3. The results are presented below, alongside the survey benchmarks. The likely impact of BREEAM on the observed performance is then explored through close examination of the BREEAM reports for the buildings.

4.5.2 Internal environmental quality in case study buildings

Heating, ventilation and cooling

Survey results relating to thermal conditions (Tables 4.5.1 - 4.5.6) are split into summer and winter. Only Building C exceeds the BUS benchmark mean for overall comfort in both summer and winter. For Building B, winter thermal comfort is coded “red”, meaning that the building mean is statistically significantly below both the scale midpoint and benchmark mean. Closer examination of the results reveals that this mean is much reduced by a score of 2 awarded by the building manager, who also reported in interview that the building heating had failed totally during the first winter of operation, before the remaining respondents were present. This result therefore appears to indicate a specific commissioning problem, rather than an ongoing issue. Meanwhile, Buildings A is coded “red” for summer comfort, with the table indicating a broad distribution of responses. Further analysis indicates that the mean score for the 7 occupants based in the main communal 1st floor research office is just 2.28, whereas the average rating for the remaining areas is 6. In this case a perceived problem therefore exists with summer overheating within a particular room (which has large areas of south east facing) and does not appear to occur in other occupied areas. Building D is also flagged “red” in summer for thermal comfort, despite more than a third of respondents rating the temperature at the scale midpoint i.e. neither too hot or too cold. As for

Building A the range of responses is wide, but in this case, separate analysis by room does not reveal any stark variations. Comments made by occupants suggest however that overheating is a problem for those seated next to windows, particularly in the main office area, which features large expanses of west facing glazing. In terms of control over heating and cooling Buildings A and B, which feature localised control over heating/cooling plant, are rated amber, meaning that their mean falls below the scale midpoint, but exceeds the BUS benchmark. Buildings C and D, which do not feature any localised temperature controls, are flagged as “red”, meaning they fall significantly short of the BUS benchmark.

Table 4.5.1 – Response to question “How would you describe typical working conditions in your normal work area in WINTER – Temperature in winter?”

TEMPERATURE IN WINTER									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Uncomfortable						Comfortable		
	1	2	3	4	5	6	7		
A	1	0	3	0	2	4	2	4.83	67
B	0	1	0	2	1	0	0	3.75	32
C	0	3	2	2	2	7	6	5.33	87
D	2	1	5	6	8	8	3	4.7	64
Benchmark	-	-	-	-	-	-	-	4.32	-

Table 4.5.2 – Response to question “How would you describe typical working conditions in your normal work area in SUMMER – Temperature in summer?”

TEMPERATURE IN SUMMER									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Uncomfortable						Comfortable		
	1	2	3	4	5	6	7		
A	2	2	3	2	0	2	2	3.76	41
B	0	1	0	1	1	1	0	4.24	72
C	0	2	4	3	4	6	1	4.95	86
D	2	4	7	7	3	3	1	3.44	29
Benchmark	-	-	-	-	-	-	-	4	-

Table 4.5.3 – Response to question “How would you describe typical working conditions in your normal work area in WINTER – Temperature in winter?”

TEMPERATURE IN WINTER									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Too Hot						Too Cold		
	1	2	3	4	5	6	7		
A	0	0	1	4	1	1	3	5.1	91
B	0	0	0	2	1	0	1	5	88
C	0	4	3	10	2	1	1	3.66	7
D	1	2	2	15	6	4	2	4.46	46
Benchmark	-	-	-	-	-	-	-	4.5	-

Table 4.5.4 – Response to question “How would you describe typical working conditions in your normal work area in SUMMER – Temperature in summer?”

TEMPERATURE IN SUMMER									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Too Hot						Too Cold		
	1	2	3	4	5	6	7		
A	3	3	2	3	2	0	0	2.84	22
B	0	1	0	3	0	0	0	3.5	69
C	1	0	6	8	2	1	0	3.88	82
D	4	5	6	10	1	2	0	2.73	21
Benchmark	-	-	-	-	-	-	-	3.26	-

Table 4.5.5 – Response to question “How much control do you personally have over the following aspects of your working environment – Heating?”

CONTROL OVER HEATING									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	No Control						Full Control		
	1	2	3	4	5	6	7		
A	6	2	2	1	1	2	0	2.64	71
B	1	0	1	0	1	1	0	3.75	96
C	19	1	0	3	0	0	1	1.69	32
D	21	6	3	2	1	0	0	1.7	32
Benchmark	-	-	-	-	-	-	-	2.24	-

Table 4.5.6 – Response to question "How much control do you personally have over the following aspects of your working environment – Cooling?"

CONTROL OVER COOLING									
Building	Number of Responses by Rating							Total Number of Responses	Mean Rating for Building
	No Control						Full Control		
	1	2	3	4	5	6	7		
A	6	2	2	2	1	1	0	2.5	59
B	1	0	1	0	2	0	0	3.5	92
C	18	1	1	3	0	0	1	1.78	22
D	16	6	5	3	3	0	0	2.19	41
Benchmark	-	-	-	-	-	-	-	2.42	-

Survey results relating to ventilation (Tables 4.5.7 - 4.5.11) are also split into summer and winter conditions. Buildings A and B met or exceeded the benchmark expectation for freshness of air, although particular occupants rated Building A as being stuffy in winter. Further analysis again reveals a split between occupants of the main research office in Building A (mean = 5.71) and those in other areas (mean = 3). Buildings C and D perform less well and are flagged "red" for ventilation, being considered particularly stuffy in winter and summer respectively. When considered in relation to the ventilation strategies employed, predominantly mechanically ventilated Building A performs well whilst predominantly naturally ventilated Building D performs poorly. The results for the mixed mode Buildings B and C are however variable. In terms of control, the mixed mode buildings performed best, presumably due to the presence of opening windows in these buildings. Meanwhile, Buildings A and D are flagged "red", despite being provided with local control of their mechanical vent (Building A) and vent louvres (Building D), indicating that occupants may be more comfortable operating opening windows than operating mechanical controls.

Table 4.5.7 – Response to question "How would you describe typical working conditions in your normal work area in WINTER – Air in winter?"

AIR IN WINTER									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Fresh						Stuffy		
	1	2	3	4	5	6	7		
A	1	3	2	4	0	2	0	3.41	6
B	2	2	0	0	0	0	0	1.5	1
C	0	1	2	7	5	3	2	4.72	71
D	1	2	3	15	9	2	0	3.87	26
Benchmark	-	-	-	-	-	-	-	4.24	-

Table 4.5.8 – Response to question "How would you describe typical working conditions in your normal work area in SUMMER – Air in summer?"

AIR IN SUMMER									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Fresh						Stuffy		
	1	2	3	4	5	6	7		
A	1	1	0	6	0	3	2	4.53	61
B	1	2	0	0	1	0	0	2.5	1
C	2	0	3	5	3	4	0	4	26
D	1	2	2	6	7	7	3	4.8	71
Benchmark	-	-	-	-	-	-	-	4.48	-

Table 4.5.9 – Response to question "How would you describe typical working conditions in your normal work area in WINTER – Air in winter?"

AIR IN WINTER – Odourless/Smelly									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Odourless						Smelly		
	1	2	3	4	5	6	7		
A	4	2	1	3	2	0	0	2.81	22
B	3	1	0	0	0	0	0	1.25	1
C	2	3	4	9	2	1	0	3.45	57
D	9	5	2	13	3	1	0	2.9	26
Benchmark	-	-	-	-	-	-	-	3.34	-

Table 4.5.10 – Response to question "How would you describe typical working conditions in your normal work area in SUMMER – Air in summer?"

AIR IN SUMMER – Odourless/Smelly									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Odourless						Smelly		
	1	2	3	4	5	6	7		
A	4	1	2	5	0	0	0	2.66	7
B	2	1	0	1	0	0	0	2	1
C	5	1	5	4	2	1	0	3	22
D	8	2	3	8	5	2	0	3.23	43
Benchmark	-	-	-	-	-	-	-	3.5	-

Table 4.5.11 – Response to question "How much control do you personally have over the following aspects of your working environment – Ventilation?"

CONTROL OVER VENTILATION									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	No Control						Full Control		
	1	2	3	4	5	6	7		
A	6	2	3	1	1	1	0	2.42	32
B	1	0	0	0	1	0	1	4.33	88
C	7	1	2	7	2	2	3	3.43	74
D	15	5	8	1	1	2	0	2.3	29
Benchmark	-	-	-	-	-	-	-	2.89	-

Lighting

Table 4.5.12 indicates that occupants consider Buildings B and D to have close to ideal levels of natural light. For Building C, occupants would prefer more natural light, although the building still exceeds the BUS benchmark. Building A is flagged "red" however and it is clear that although half of respondents report that lighting levels are ideal, most of the remainder consider that there is too much natural light. No split is evident in terms of rooms within the building, suggesting that other factors such as location within a room or personal preference may be generating this variation. In terms of glare from the sun (Table 4.5.13) Buildings A-C meet or exceed the BUS benchmark. Building D is flagged "red" indicating that the mean exceeds both the BUS benchmark and the scale midpoint. Further examination of the data reveals a broad distribution of responses suggesting that, as discussed in relation to thermal comfort, satisfaction of respondents may be linked to the position of their desks within the large highly glazed open plan office in which the majority are based.

Table 4.5.14 summarises the views of the building occupants on the level of artificial light at their workstations. The study benchmark indicates that artificial lighting may be too bright in buildings generally, and this was the case in Building C, which also significantly exceeds the BUS benchmark in terms of glare from artificial lights (Table 4.5.15). Building A, conversely, is flagged "red" for having insufficient light overall. One respondent in this building commented that lighting is "uneven throughout the office", which is also reflected the range of responses from this room.

In terms of control over lighting Buildings B and C are provided with manual light switching and in both cases comfortably exceed benchmark expectations (Table 4.5.16).

Building A meanwhile makes use of presence detection to control lighting in office areas and is flagged "red" with a mean score significantly below benchmark (this mean reduces further to 2.0 for the main research office taken in isolation). Building D makes use of a mixture of manual light switching in smaller rooms and presence detection in large offices and lecture theatres. Building D meets the benchmark performance for the building overall, however the mean for the main open plan office taken in isolation is 2.65, which is significantly below the benchmark expectation.

Table 4.5.12 – Response to question "How would you describe the quality of the lighting in your normal work area – Natural light?"

NATURAL LIGHT – Too Little / Too Much									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Too Little						Too Much		
	1	2	3	4	5	6	7		
A	0	0	1	7	1	4	1	4.78	99
B	0	0	0	3	0	0	0	4	63
C	1	1	6	11	2	0	2	3.86	52
D	3	4	2	19	3	2	0	4.06	66
Benchmark	-	-	-	-	-	-	-	3.77	-

Table 4.5.13 – Response to question "How would you describe the quality of the lighting in your normal work area – Glare from sun and sky?"

GLARE FROM SUN AND SKY – None / Too Much									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	None						Too Much		
	1	2	3	4	5	6	7		
A	3	3	1	2	2	2	1	3.57	46
B	1	0	0	0	2	0	0	3.66	48
C	4	3	2	9	3	1	1	3.45	41
D	4	6	0	12	6	5	0	4.16	72
Benchmark	-	-	-	-	-	-	-	3.69	-

Table 4.5.14 – Response to question "How would you describe the quality of the lighting in your normal work area – Artificial light?"

ARTIFICIAL LIGHT – Too Little / Too Much									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Too Little						Too Much		
	1	2	3	4	5	6	7		
A	0	2	1	10	1	0	0	3.71	4
B	0	0	0	3	0	0	0	4	15
C	0	0	0	12	7	1	3	4.77	89
D	0	2	1	21	4	4	1	4.03	16
Benchmark	-	-	-	-	-	-	-	4.33	-

Table 4.5.15 – Response to question "How would you describe the quality of the lighting in your normal work area – Glare from lights?"

GLARE FROM LIGHTS – None / Too Much									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	None						Too Much		
	1	2	3	4	5	6	7		
A	3	4	0	7	0	0	0	2.78	7
B	1	0	0	2	0	0	0	3	12
C	4	1	0	12	4	0	2	3.9	79
D	5	3	1	14	4	4	1	3.63	59
Benchmark	-	-	-	-	-	-	-	3.5	-

Table 4.5.16 - Response to question "How much control do you have over the following aspects of your working environment – Lighting"

CONTROL OVER LIGHTING									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	No Control						Full Control		
	1	2	3	4	5	6	7		
A	7	1	0	3	1	2	0	2.71	37
B	0	1	0	1	1	0	1	4.5	84
C	7	0	1	7	4	1	4	3.69	56
D	14	3	4	7	0	2	3	2.93	41
Benchmark	-	-	-	-	-	-	-	3.24	-

Table 4.5.17 shows that occupants of Buildings A, C and D experience too much noise from colleagues. This problem is particularly acute in Buildings A and D, where the majority of respondents are based in large open plan offices. Noise from other people is also considered excessive in Buildings A, B and D (Table 4.5.18). For Building B comments indicate that this is a direct result of the building arrangement which has the office area open to the main ground floor breakout space.

Table 4.5.17 – Response to question "How would you describe noise in your normal work area – Noise from colleagues?"

NOISE FROM COLLEAGUES – Too Little / Too Much									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Too Little						Too Much		
	1	2	3	4	5	6	7		
A	1	0	0	5	2	4	2	4.92	97
B	0	0	0	4	0	0	0	4	25
C	0	3	1	11	4	2	2	4.4	64
D	0	1	3	12	10	4	3	4.74	96
Benchmark	-	-	-	-	-	-	-	4.24	-

Table 4.5.18 – Response to question "How would you describe noise in your normal work area – Noise from other people?"

NOISE FROM OTHER PEOPLE – Too Little / Too Much									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Too Little						Too Much		
	1	2	3	4	5	6	7		
A	0	0	1	6	2	3	1	4.76	81
B	0	0	0	2	1	0	1	5	92
C	0	2	2	12	4	2	1	4.22	34
D	0	1	2	11	10	6	2	4.74	96
Benchmark	-	-	-	-	-	-	-	4.41	

Table 4.5.19 indicates that despite particular problems noted above, the occupants of Buildings A, B and C rate the overall comfort of their building environments highly, with Building B being in the 97th percentile of the BUS dataset. Building D meanwhile is rated above the scale midpoint but fails to significantly exceed the benchmark mean.

In terms of perceived health (Table 4.5.20) all buildings significantly exceed the benchmark expectations, with Buildings A and B performing particularly well. Meanwhile, occupants feel that Buildings B and C increase their productivity whilst Buildings A and D decrease it. Building C is the best performing in this respect, whilst Building D is flagged "red", being significantly below both the scale midpoint and the BUS benchmark mean.

Table 4.5.19 – Response to question "All things considered, how do you rate the overall comfort of the building environment?"

OVERALL COMFORT – Unsatisfactory / Satisfactory									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Unsatisfactory						Satisfactory		
	1	2	3	4	5	6	7		
A	0	0	1	2	5	4	2	5.28	67
B	0	0	0	0	0	3	1	6.25	97
C	0	0	0	3	5	11	5	5.82	89
D	0	1	5	5	14	6	2	4.83	54
Benchmark	-	-	-	-	-	-	-	4.79	-

Table 4.5.20 – Response to question "Do you feel less or more healthy when you are in the building?"

HEALTH (Perceived) – Less Healthy / More Healthy									
Building	Number of Responses by Rating							Mean Rating for Building	Study Mean Percentile
	Less Healthy						More Healthy		
	1	2	3	4	5	6	7		
A	0	0	0	9	2	2	1	4.64	92
B	0	0	0	2	1	1	0	4.75	94
C	0	2	2	16	1	1	1	4.09	69
D	4	2	5	15	1	5	1	4.03	64
Benchmark	-	-	-	-	-	-	-	3.74	-

Table 4.5.21 – Response to question “Please estimate how you think your productivity at work is decreased or increased by the environmental conditions in the building?”

PRODUCTIVITY – Decreased / Increased											
Building	Number of Responses by Rating									Mean Rating for Building	Study Mean Percentile
	Less Healthy								More Healthy		
	-40%	-30%	-20%	-10%	0	10%	20%	30%	40%		
A	0	2	2	1	3	1	4	0	0	-1.53	41
B	0	0	0	0	2	2	0	0	0	5	73
C	0	1	0	2	9	3	5	3	0	7.27	81
D	1	1	4	9	6	2	4	0	1	-5.17	21
Benchmark	-	-	-	-	-	-	-	-	-	0.56	-

Summary of case study building performance – Internal environment

As previously noted, although the areas of Building A occupied by survey responders are designed for a mixed mode ventilation strategy, it appears that they are operated as fully mechanically vented. The ventilation also provides heating and cooling, the former being supplemented by radiators in some areas. The building is reported to have good air quality, however the main office is highly glazed and is uncomfortably hot in summer. Control over temperature is poor in absolute terms, but exceeds the benchmark expectation. Many occupants consider that the building has too much natural light, however this does not appear to result in excessive glare, indicating that the blinds are effective. Conversely the survey suggests strongly that too little artificial lighting has been provided in the building, and that too little control is provided over it. Occupants rate the building as being satisfactory overall in terms of noise, however there does appear to be a particular problem with noise from colleagues and other people. This is supported by a number of comments received, particularly in relation to noise from telephone calls in the main open plan office area. Overall, the building performs well in relation to benchmark means, and is considered healthy and comfortable. This does not appear to translate into a positive effect in terms of perceived productivity however, and there are some particular environmental problems in the building, notably that of summer overheating and noise from colleagues and other people.

Building B was designed to be predominantly naturally vented, however the completed building includes mechanical ventilation to the ground floor, where a mixed mode ventilation strategy appears to be in operation, combined with electric underfloor heating. Occupants consider the air quality to be excellent all year round, and thermal comfort levels in summer exceed benchmark expectations. In winter the building is considered uncomfortably cold however, and the building manager reports that serious problems were experienced with the underfloor heating system in the first two winters. Following a series of interventions this does now however appear to be functioning correctly, and terms of personal control over heating and cooling the building scores well against the benchmark. The building reportedly performs well with respect to the amounts of both natural and artificial light, and provides relatively good control over the latter. There is a particular problem in relation to “noise from others”, which is likely to result from the main office being open plan with the conference breakout area. Overall however, occupants are highly satisfied in relation to acoustics. Of the case study buildings, this one is most highly rated in terms of overall comfort and health, and also significantly exceeds the benchmark mean for perceived effect on productivity.

Building C was initially conceived as a naturally ventilated building, however mechanical ventilation has been added to many offices and classrooms during the design process. Air quality in summer is reportedly good, however the building is considered uncomfortably hot, stuffy and smelly in winter. Personal control of heating and cooling is very limited, with more than 70% of respondents selecting the lowest possible rating in each case. Discussions with occupants suggest that temperature control dials provided in rooms are entirely ineffective, and that the only means of changing the temperature in the building is by telephoning the facilities manager. Natural light levels appear to be satisfactory, however the levels of artificial lighting are considered too high, which also translates to problems with glare. Acoustically the building exceeds benchmark expectations in general, although occupants consider that there is too much noise from colleagues, with some commenting particularly that it is sometimes difficult to concentrate in the larger offices. The building performs best out of the case study buildings in terms of perceived effect on productivity, and also exceeds the benchmark mean for health and overall comfort. The internal environment appears to be generally good, aside from the particular issue relating to poor air quality and overheating in winter.

Aside from the lecture theatres, Building D is entirely naturally vented, with ventilation being provided by automatically controlled low level louvres, rather than opening windows. Heating is provided by automatically controlled radiators and trench heating, whilst cooling Building D is by means of chilled beams. Air quality is good in winter, although some occupants complained of draughts from the low level ventilators. The main office areas are highly glazed and in summer the temperature is reported to be uncomfortably hot and variable. Control over both heating and cooling falls below benchmark expectations. Whilst the artificial lighting is considered good, occupants report the amount of natural to be excessive, with glare from the sun a problem. The building fails to meet the benchmark mean in terms of noise, with noise from colleagues and other people an issue. Noise from outside is also a problem for this building, with a number of comments being received relating to break in noise from the external courtyard and from the adjacent school. Building D was rated the lowest of the four in terms of overall comfort, health and effect on productivity, and falls significantly below benchmark expectations for the latter. Artificial lighting levels are considered ideal, but in other areas the internal environment is considered relatively poor; summer overheating, glare, noise and cold draughts in winter being particular areas of dissatisfaction.

Comparison of case study building performance – Internal environment

Table 4.5.22 ranks the performance of the buildings relative to each other and to the benchmark mean, for the various aspects of internal environment that were considered. Performance can be seen to be rather variable, with no building exceeding benchmark expectation in all categories. Building B performs well, being the best performing building in 7 out of 10 categories, and exceeding the benchmark mean in 9 out of 10. For other buildings performance is more variable, with Building D for example exceeding the benchmark mean in only 6 out of 10 categories.

Table 4.5.22 – Performance ranking of buildings for particular survey parameters

Rank	Thermal – Summer	Thermal – Winter	Air – Summer (Fresh)	Air – Winter (Fresh)	Natural Light	Artificial Light	Acoustics (Noise Overall)	Comfort	Health	Productivity
1	C	C	B	B	B	B	B	B	B	C
2	B	A	C	A	D	D	C	C	A	B
3	Benchmark	D	Benchmark	D	C	A	A	A	C	Benchmark
4	A	Bench	A	Benchmark	Benchmark	Benchmark	Benchmark	D	D	A
5	D	B	D	C	A	C	D	Benchmark	Benchmark	D

Correlation analysis of BUS survey data

Correlation analysis of the BUS survey data was carried out by measuring Pearson's correlation coefficient as described in Chapter 3. Individual correlations are discussed below, however it is also relevant to consider which variables correlate with the overall areas of comfort, productivity and health. Figure 4.5.1 shows the statistically significant correlations observed between overall comfort and other variables. In this case general design factors show a large correlation, with perceptions of image and personal safety also being significant. Of the environmental factors measured by the survey it is notable that whilst overall measures of air quality, temperature, noise and lighting show a statistically significant correlation with comfort, the majority of the more particular environmental measures do not. For example, no statistically significant relationship was observed relating to the level of control over services, daylighting levels or glare control.

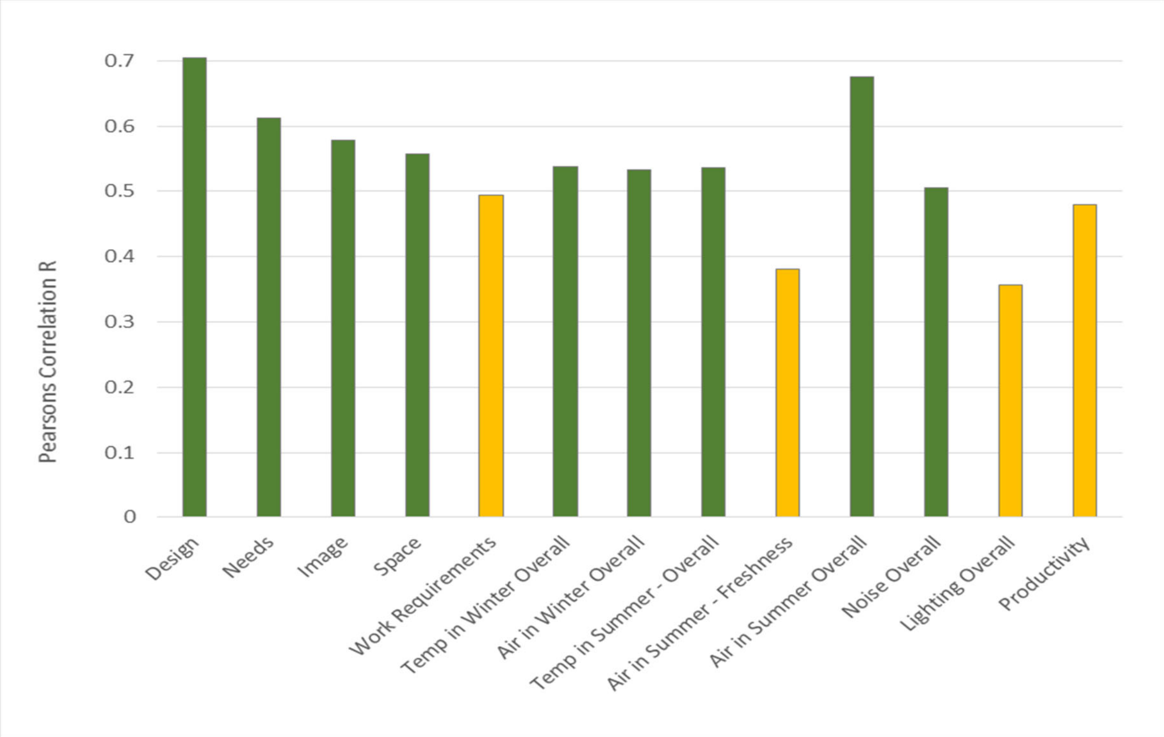

Figure 4.5.1 – Statistically significant Pearson's correlation values between Comfort and other variables ($p<0.05$)

Figure 4.5.2 relates productivity to other variables. Interestingly, productivity appears to be far less closely associated with general design factors than comfort. Unlike comfort, productivity does however correlate significantly with the effectiveness of facility management response to problems. In terms of environmental factors temperature and noise are significant as is air quality, particularly in the summer. Additionally, although the quality of lighting overall shows no significant relationship with productivity, ease of control of lighting does show a small correlation. Productivity can be seen to show only a medium correlation with comfort, and appears to be much less dependent upon the building environment overall.

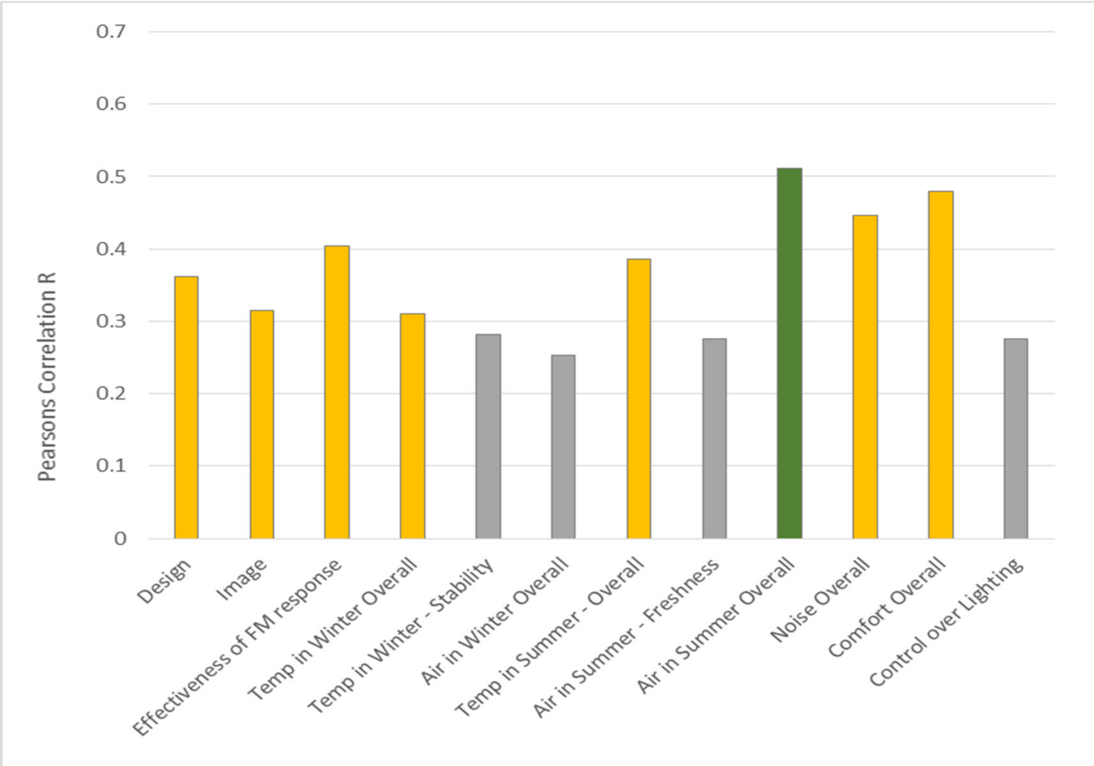

Figure 4.5.2 – Statistically significant Pearson's correlation values between Productivity and other variables ($p<0.05$)

Figure 4.5.3 indicates that feelings of health while in a building are related to how highly individuals rate the building in terms of general design, including effective use of space and how well facilities meet their needs. In terms of environmental factors, freshness of air in winter and overall satisfaction with lighting show a medium correlation, whilst satisfaction with summer temperatures shows a small correlation. If it is supposed that health is a dependant variable in this instance, it can be concluded that environmental factors as a whole therefore actually have a surprisingly limited impact on perceptions of health.

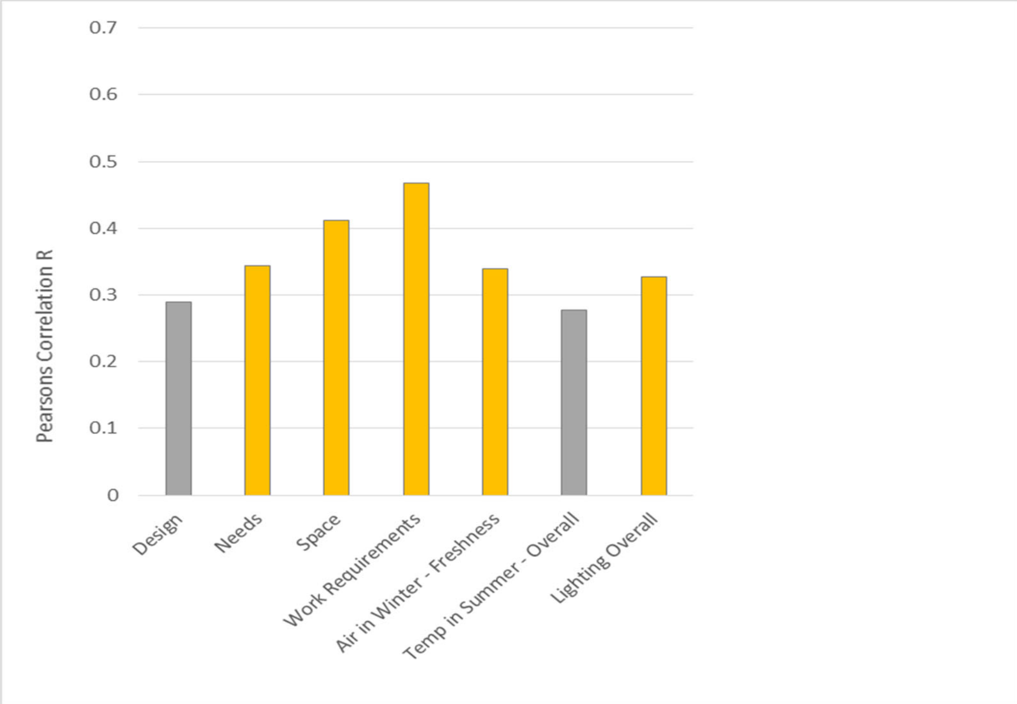

Figure 4.5.3 – Statistically significant Pearson's correlation values between Health and other variables ($p<0.05$)

Overall, and as might be expected, there are some significant correlations between key environmental quality variables, and comfort. It should be noted however that many particular environmental factors do not appear to be linked to comfort at all. Productivity shows correlations with many of these same key environmental variables, and with comfort itself. No such clear relationship is however evident between health and the general quality of internal environment, although certain particular aspects do correlate to some extent. Of all of the variables only "temperature in summer overall" displays a statistically significant effect on comfort, productivity and health, suggesting that avoiding summer overheating is likely to be a key factor is achieving occupant satisfaction. Perhaps most interestingly, in terms of the assumptions embedded in many BSAS, no significant relationship is revealed between health and comfort, or health and productivity.

4.5.3 Application and impact of particular BREEAM Health and Wellbeing criteria

Based upon the analysis presented in Chapter 3, the themes associated with the criteria within the Health and Wellbeing section of BREEAM are as follows:

- Daylighting
- View out
- Artificial lighting
- Natural ventilation
- External pollutants
- CO2 levels
- Mechanical ventilation and cooling
- Volatile organic compounds
- Thermal comfort
- Legionella
- Acoustics
- External amenity space
- Chilled drinking water
- Safe and effective fume cupboards

Reference to the BREEAM standards reveals that credits within the Health and Wellbeing section are second only to the Energy section in terms of weighting, contributing 15% of the total under both BREEAM 2006 and 2008. Reference to the BREEAM reports indicates that scoring for the case study buildings was variable (Figure 4.3.4), ranging from 50-83% (compared to an overall average of 55% required to achieve a “Very Good” certificate (Table 4.5.25).

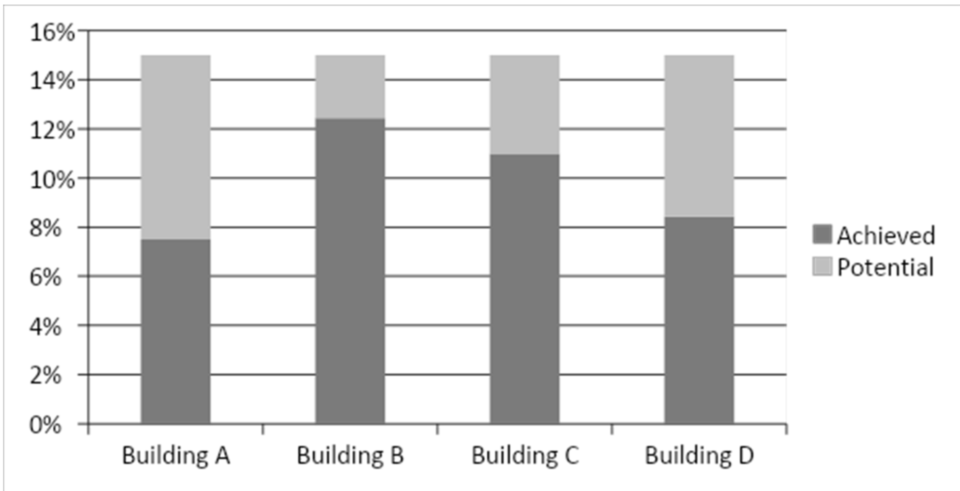

Figure 4.5.4 – BREEAM Health and Wellbeing credits as a proportion of the total available

Table 4.5.22 – Summary of Health and Wellbeing category scoring for case study buildings

	Building			
	A	B	C	D
Number of Health and Wellbeing issues assessed	15	14	14	15
Health and Wellbeing credits available	18	15	15	16
Health and Wellbeing credits achieved	9	12	11	9
Proportion of Health and Wellbeing credits achieved	50%	83%	73%	56%

As summarised in Table 4.5.23, a total of 18 different Health and Wellbeing issues were identified, however many were deemed "not applicable" to some or all of the case study buildings. This was either because they are not assessed for the particular building type in general, or because the buildings do not contain particular features (for example laboratory fume cupboards). In all, the case study buildings achieved credits across a total of 13 issues, addressing the following themes:

- Daylighting
- View out
- Artificial lighting
- Natural ventilation
- Volatile organic compounds
- Thermal comfort
- Legionella
- Acoustics

Through analysis of the available collected data, both the manner in which each of these issues were applied, and the likely performance effect for the case study buildings, is described below.

Table 4.5.23 - Detailed scoring for all buildings, by issue (health and wellbeing section)

Issue		Score			
Reference	Title	Building A	Building B	Building C	Building D
Hea 01 (HW1)	Daylighting	0	1	0	0
Hea 02 (HW2)	View out	1	1	1	1
Hea 03 (HW5)	Glare control	1	1	1	1
Hea 04 (HW4)	High frequency lighting	1	1	1	1
Hea 05 (HW5)	Internal and external lighting levels	1	1	1	1
Hea 06 (HW6/7)	Lighting zones and controls	1	1	1	2
Hea 07 (HW8)	Potential for natural ventilation	0	1	0	0
Hea 08 (HW9/10/11)	Indoor air quality	0	0	0	1
Hea 09	Volatile organic compounds	0	1	1	NA
Hea 10 (HW14)	Thermal comfort	0	1	1	1
Hea 11 (HW15)	Thermal zoning	1	1	1	0
Hea 12 (HW16)	Microbial contamination	1	1	1	1
Hea 13 (HW17/M24)	Acoustic performance	2	2	2	0
Hea 14	Office space	NAS	NAS	NAS	NAS
Hea 15	Outdoor space	NA	NAS	NA	NAS
Hea 16	Drinking water	NA	NA	NAS	NAS
Hea 17	Specification of laboratory fume cupboard	0	NA	NA	NA
Hea 18	Containment level 2 and 3 laboratories	0	NA	NAS	NA
NA = Not assessed for this particular building NAS = Not assessed under the scheme used for this building					
Additional issues listed in manuals but not assessed for any case study buildings: HW12-13, 18-27					

Hea 01 (HW1) - Daylighting

Issue aim: “To give building users sufficient access to daylight” (BRE, 2008)

A credit is available where the building is designed to meet prescribed standards of daylighting. The standard is based upon achieving an average daylight factor of at least 2%, with additional requirements also applied relating to uniformity of lighting and provision of a view of the sky. The standard applies to “occupied areas” generally, with more stringent requirements for areas where desk based activities are expected. Under the BREEAM 2006 Bespoke scheme, 100% of this area must comply. For BREEAM 2008 Bespoke the figure is 80%, whilst for higher education buildings assessed under the Education 2008 scheme the value is 60%. For the latter, a second credit is available where the standard is met for 80% of occupied areas. Under the 2008 Bespoke scheme, the provision of daylight must additionally be designed in accordance with a number of particular technical documents.

The case study buildings achieved credits under this issue as follows:

Building A – 0 credit

Building B – 1 credit

Building C – 0 credit

Building D – 0 credit

A review of the BREEAM report shows that the credit was awarded for Building B based upon compliance in more than 80% of occupied areas (the main reception/breakout area was deemed non-compliant as it did not meet room depth criteria). The credit is evidenced based upon correspondence and daylighting calculations produced by the services engineer, along with relevant design drawings. The post construction validation consists of an email from the main contractor stating that the building has been constructed in accordance with these drawings.

A comprehensive audit trail therefore appears to exist in relation to the credit for Building B. Potential weaknesses exist in this audit trail however; for example the calculations do not appear to have been verified by the BREEAM assessor. Additionally, using the main contractor to verify whether the building has been constructed in accordance with these calculations lacks robustness, given that if any design changes did occur after the calculations were carried out they would incur direct costs for re-calculation, as well as risking non-compliance.

The issue is configured to deliver minimum levels of daylighting to all, or most, of those areas within the building where occupants spend significant amounts of time. As discussed above, the results of the building occupant survey indicate that occupants consider levels of natural light to be close to ideal in Buildings B and D, slightly too low in Building C, and too high in Building A. Levels of daylighting exceed the survey benchmark levels in all cases. The aim of the issue therefore appears to have been substantially met in all buildings, although only Building B has achieved a credit. Review of the BREEAM reports indicates that for Buildings A, C and D the credit was not attempted (no daylighting calculations were produced). One possible reason for this is that these buildings all contain large lecture theatres, which have little or no glazing and are therefore unlikely to have complied.

Hea 02 (HW2) - View Out

> Issue aim: "To allow occupants to refocus their eyes from close work and enjoy an external view, thus reducing the risk of eyestrain and breaking the monotony of the indoor environment" (BRE, 2008)

One credit is available where the configuration of the building allows an "adequate view out" from all "relevant building areas". Relevant building areas are defined as those which will contain workstations, benches or desks. Note that, unlike issue Hea 1, lecture theatres appear to be excluded from the assessment. For the Bespoke 2006 scheme an "adequate view out" is defined as a view from desk height, of a window within 7m providing an external view of something at least 10 metres beyond it. For the 2008 versions, the view must instead be of a wall within 7m, having at least 20% window openings.

The case study buildings achieved credits under this issue as follows:

Building A – 1 credit

Building B – 1 credit (offices and skills laboratory only)

Building C – 1 credit

Building D – 1 credit (small computer suites only)

The case study buildings are relatively highly glazed and the majority of areas provided with desks have generous allocation of windows. Building B and D were awarded an area weighted credit for complying in certain areas only, as indicated. A review of the BREEAM reports indicates that the issue has been assessed directly by the BREEAM assessor, based upon design drawings. For Building A, spot checks were additionally carried out on site by the BREEAM assessor, as part of the post construction review. For Building B the main contractor provided an email to confirm that the building had been constructed in accordance with the drawings submitted. In this case the credit requirements are very straightforward and appear to have been correctly applied. It is notable that the requirement has been considerably reduced between BREEAM 2006 and BREEAM 2008, the latter requiring only that desks are within 7m of a wall with a minimum of 20% glazed area.

The aim of the issue is clearly explained within the BREEAM guidance, being to reduce eyestrain and visual monotony for those working at a desk. The requirement itself does not appear particularly robust however, particularly for the BREEAM 2008 scheme, where the criteria do not call for line of sight to a window, or for there to be anything visible through the windows on which eyes could be re-focused. No justification is provided for the limit of 7m. The aim suggests that the "view" provided might be expected to produce beneficial effects in terms of the health and comfort of occupants. In Buildings A, B and C survey respondents are all based in compliant areas, whereas for Building D the opposite is true. For the case study buildings this is broadly consistent with the results of the Building User Survey, for which Building D is the most poorly rated in terms of health and comfort.

Hea 03 (HW3) - Glare control

> Issue aim: "To reduce problems associated with glare in occupied areas through the provision of adequate controls" (BRE, 2008)

One credit is available where an "occupant-controlled shading system" is provided on all windows, glazed doors and rooflights in "relevant" building areas. For the BREEAM Bespoke 2008 assessment there is a further requirement that in all other "occupied areas" the potential for "disabling glare" must be designed out by means of brise-soleil, low eaves, or bioclimatic design that provides shading from high level summer and low level winter sun. As previously noted, "relevant areas" are those containing desks, benches or workstations (excluding lecture theatres); "occupied areas" are those likely to occupied by periods of 30 minutes or more. No definition is provided for "disabling glare".

The case study buildings achieved credits under this issue as follows:

Building A – 1 credit

Building B – 1 credit

Building C – 1 credit

Building D – 1 credit

A review of the BREEAM reports indicates that only the first part of the credit has been applied for the bespoke assessments. All buildings are therefore expected to have occupant controlled shading to "relevant areas", however the additional requirement for control of "disabling glare" in other areas has not been deemed applicable to these buildings. No explanation was given for this.

The evidence submitted consists of design drawings, specifications and schedules, along with various emails from consultants and main contractors confirming particular points of detail. For Building A, it was noted that the blinds were not installed at the time of the post construction site visit, with the credit instead being awarded based upon subsequent assurances provided by the project architect. For Building B, post construction validation was provided in the form of an email from the main contractor. Observations of the case study buildings confirmed that roller blinds were installed to all “occupied areas” within the case study buildings. These were manually operated in most instances, and where motorised blinds were provided they were locally controlled. Manual vertical strip blinds were observed in the laboratories in Building B only. The university facilities management team confirmed that they rate both the importance and effectiveness of glare control highly, saying “We have put effort into finding a blind that suits our needs. We have nominated contractors and a strong specification”.

The aim of the issue is to reduce problems associated with glare. These problems are not defined, but might reasonably be expected to include difficulty in using computer screens, and general visual discomfort. A high level of satisfaction in relation to glare might therefore be expected, contributing in turn to a general improvement in health, comfort and productivity. The aim of the issue appears to have been partially achieved for the case study buildings. Blinds are in place, however the survey results do not suggest that the case study buildings are performing significantly better than other buildings, with Building D performing significantly worse. This may not be surprising given that blinds can only block glare, and do not deal with its source. Additionally the survey does not demonstrate any strong correlation between glare and either health, comfort or productivity. This indicates that whilst occupants consider that glare is present, it does not appear to be impacting on them in any significant way. Lowering blinds may blinds may therefore be successful in counteracting the effects of glare in the buildings, but without influencing the amount and orientation of glazing, it is not clear that the criteria dictate anything over and above the minimum practical provision required for any office area.

Hea 04 (HW4) - High Frequency Lighting

> Issue aim: “To reduce the risk of health problems related to the flicker of fluorescent lighting” (BRE, 2008)

One credit is available where all fluorescent and compact fluorescent lamps are fitted with high frequency ballasts. The reasons given for this are that lights fitted with these do not produce visible flicker or audible buzzing, and may improve energy efficiency by up to 10%.

The issue represents a “minimum standard” for a “very good” rating and is therefore compulsory. All case study buildings achieved the credit.

Building A – 1 credit

Building B – 1 credit

Building C – 1 credit

Building D – 1 credit

Review of the BREEAM reports indicates that the credit has been awarded based on specification clauses. For Building A, spot checks were also carried out on site by the BREEAM assessor as part of the post construction review, whilst for Building B post construction validation was provided in the form of an email from the main contractor.

Analysis of the BREEAM criteria suggest that the specific aim of the credit is to eliminate flicker and buzz from fluorescent lighting, leading to an improvement in health for occupants. Whilst the building user survey results do not assess light flicker or buzz directly, the case study buildings do in all cases exceed the survey benchmark in terms of the perceived effect the building on occupant health. It is also suggested that a reduction in electricity consumption should be expected, although this appears to be tangential to the issue aim. As previously discussed, the overall energy performance of the buildings is unexceptional, whilst the data collected is not sufficient to identify a marginal reduction in lighting energy use.

Hea 05 (HW5) - Internal and external lighting levels

> Issue aim: “To ensure lighting has been designed in line with best practice for visual performance and comfort” (BRE, 2008)

One credit is available where the internal artificial lighting for the building is designed to meet the minimum illuminance levels specified in the CIBSE Code for Lighting 2006 (CIBSE, 2006) (CIBSE Code for Lighting 2002 (CIBSE, 2002) in the case of the Bespoke 2006 scheme). For areas where computer screens are regularly used, the internal lighting design must also comply with particular parts of CIBSE Lighting Guide 7 (CIBSE, 2007), relating to avoidance of glare from artificial lighting. For external areas, artificial lighting must meet the illuminance values specified in CIBSE Lighting Guide 6.

The case study buildings achieved credits under this issue as follows:

Building A – 1 credit

Building B – 1 credit

Building C – 1 credit

Building D – 1 credit

Review of the BREEAM reports reveals that compliance for Buildings A, B and D is based upon direct replication of the BREEAM requirement in a specification clause and/or a letter or email from a project team member confirming that the design and installation is compliant. Only for Building C were the specific lux values required in each area included in the specification and marked on the layout drawings. For Building A, spot checks by the BREEAM assessor, and an email from the electrical contractor confirm that the installation was installed in accordance with the design. The above appears to represent a very weak level of evidence, as it relies almost exclusively on general assurances from the construction team. Only for Building C were some of the specific requirements of the issue (i.e. the internal illuminance levels) included in the design information provided as evidence.

The stated aim of the issue is to provide “best practice” “visual performance and comfort”, through adherence to CIBSE standards relating to light levels and prevention of glare. It is therefore expected that building occupants will express satisfaction in relation to the artificial lighting provision. This appears to be the case in Buildings B and D, for which occupants report close to ideal levels of lighting at their work station, and below benchmark incidence of glare. In Building A however, occupants report that there is too little artificial light, whilst in Building C there is far too much. Glare from artificial lighting is also reported to be a problem in Building C. The survey does not provide data in relation to the external artificial lighting provision.

Hea 06 (HW6 / HW7) - Lighting zones and controls

> Issue aim: "To ensure occupants have easy and accessible control over lighting within each relevant building area" (BRE, 2008)

One credit is available where internal artificial lighting is zoned to allow "separate occupant control" within rooms, to suit varying occupancy. In particular it is required that office areas are split into lighting zones covering no more than four workstations, and that workstations next to windows are separately zoned. In "seminar and lecture rooms", presentation and audience areas must be separately zoned. Specific additional requirements are listed for lecture theatres. "Separate occupant control" is defined as "Light switches/controls for a particular area/zone of the building that can be accessed and operated by the individual(s) occupying that area/zone. Such controls will be located within, or within the vicinity of, the zone/area they control."

The case study buildings achieved credits under this issue as follows:

Building A – 1 credit

Building B – 1 credit

Building C – 1 credit

Building D – 1 credit

Evidence presented for the Buildings is predominantly in the form of design drawings, supplemented by various letters and emails to clarify particular points. Additional validation is provided for Building A in the form of spot checks on site by the BREEAM assessor at post construction review, along with an email from the electrical contractor. For Building B post construction validation is provided by an email from the main contractor. Reference to the notes for Buildings A-C makes it clear that the BREEAM assessors consider presence detection and/or daylight sensors to be a form of occupant control, although this is not explicit in the BREEAM scheme requirements. The correspondence required to clarify the design information in each case suggests that the design information submitted did not provide the level of detail required to confirm the switching arrangements in the buildings. This in turn suggests a rather weak level of verification, based upon general assurances from the construction team, rather than specific design solutions. It also suggests that installers may not have been provided with sufficient information to achieve a compliant installation. Observations by the researcher on site revealed a rather confusing picture in terms of light switching. In Buildings A, B and C single unlabelled rocker switches were provided to smaller rooms, which allowed the user to cycle through various modes. These modes did not however always result in a different pattern of lighting, suggesting either that the modes were disabled, or possibly that they related to changing the lighting automation settings. Larger lecture theatres typically had multiple unmarked switches of the same type. In Building D small panels are typically provided with five numbered buttons and additional buttons marked with up and down arrows. Of these, three buttons had a visible effect on the room lighting, achieving all on, all off and part on. The remaining buttons had no observable effect. In the larger office areas in Buildings A and D no light switches were evident to the researcher and the building managers were additionally unable to advise the location of these.

The aim of the credit is clear in providing easy control of lighting within office and teaching spaces, although the intended "health and wellbeing" effect is not made explicit. Good control over artificial lighting might be expected, however the categorisation of presence detection and/or daylight sensors as occupant control is considered likely to reduce the impression of control significantly. This is particularly the case in the large office areas in which many survey respondents were based in Buildings A and D, and in which no switching was evident. These expectations are consistent with the survey results, which indicate that levels of control were significantly below benchmark levels in Buildings A and D. Control was above benchmark levels in Buildings B and C, although only in Building B did results exceed the scale midpoint.

Hea 07 (HW8) - Potential for natural ventilation

> Issue aim: "To recognise and encourage adequate cross flow of air in naturally ventilated buildings and flexibility in air-conditioned / mechanically ventilated buildings for future conversion to a natural ventilation strategy" (BRE, 2008)

One credit is available where “occupied areas” of the building are provided with an adequate source of natural ventilation. This may be achieved by providing a specified ratio of opening windows/internal floor area, or by using an approved design tool. For the 2008 scheme versions there must additionally be at least two levels of ventilation, controllable by building users. Under the Education scheme, ventilation must also meet the requirements of Building Bulletin 101 (BB101) (Education Funding Agency, 2014), with any mechanical actuators also being fully modulating and silent in operation.

The case study buildings achieved credits under this issue as follows:

Building A – 0 credit

Building B – 1 credit

Building C – 0 credit

Building D – 0 credit

Evidence presented for the Building B is in the form of design drawings and windows schedules. Post construction validation is provided by an email from the main contractor, attaching as-built drawings and window schedules. The researcher observed however that the only natural ventilation to the technician’s room adjacent to the main lecture theatre is an external door. This appears to have been considered satisfactory by the assessor, but would seem to be inadequate in practice. The researcher additionally noted that opening windows in the main upstairs laboratory were substantially blocked by equipment trolleys and shelving. The building manager was furthermore unaware of the presence of windcatchers provided in both this laboratory and upstairs meeting room (the controls for which appeared in any case to be ineffective).

For Building A the BREEAM report states that the credit was not sought because “certain rooms within the building would not have sufficient window opening areas to achieve the credit and therefore mechanical ventilation is being provided (e.g. lecture theatres).” For Building C the assessor notes that although opening windows are provided, “comfort cooling is supplied to the majority of areas to comply with BB101.” For Building D the report notes that “Due to the deep plan of the building the appropriate window areas requirement will not be achievable.” The comment in relation to Building C appears nonsensical, as the presence of comfort cooling does not prevent the credit being achieved. The comment in relation to Building D is also surprising, given that the majority of the building is designed to be naturally ventilated.

The provision of adequate natural ventilation facility might expected to contribute to good air quality in Building B. Conversely, failure to achieve the same in Building D (which is a substantially naturally ventilated building) might be expected to result in poor air quality. Air quality in Buildings A and C are unlikely to be affected, as opening windows are supplemented by mechanical ventilation in occupied areas. These predictions align generally with the survey results, which indicate good year round air quality in Building B and “stuffy” summer conditions in Building D. The poor air quality in the laboratory in Building B is not represented in the survey results, as no respondents have their work stations located in that room. The problems in this room do not in any case suggest inadequate design, but rather a lack of appreciation of the ventilation strategy by the building manager.

Hea 08 (HW9/10/11) - Indoor air quality

> Issue aim: “To reduce the risk to health associated with poor indoor air quality / To ensure adequate indoor air quality” (BRE, 2008)

One credit is available under all schemes where, for naturally ventilated buildings, ventilation openings are required to be at least 10m from “sources of external pollution”. For buildings incorporating mechanical ventilation, inlets and exhausts must be at least 10m apart, and additionally at least 20m from “sources of external pollution”. “Sources of external pollution” are defined as including roads, car parks and building services outlets. For the 2008 Education scheme buildings are additionally required to comply with the criteria contained within Building Bulletin 101. For the 2008 scheme there is also a requirement to provide a minimum 12l/s/p of fresh air to office areas, and to install CO_2 monitoring to areas such as auditoria. For the Bespoke 2006 scheme two separate credits are available. The first under issue HW10 requires the provision of CO_2 monitoring to areas including auditoria. The second under issue HW11 requires provision of a minimum 12l/s/p fresh air to offices, compliance with CIBSE Guide B2 (CIBSE 2016), and limiting room depths in naturally ventilated areas.

The case study buildings achieved credits under this issue as follows:

Building A – 0 credit

Building B – 0 credit

Building C – 0 credit

Building D – 1 credit (HW10)

For Building A the BREEAM assessors report notes that the credit cannot be achieved due to the proximity of the nearby car park. For Buildings B and D the report notes that the required separation between inlets and outlet will not be achieved." For Building C the report states simply that the credit has not been targeted. For the CO_2 related credit in Building D, design stage compliance is based upon a clause from the mechanical services specification which calls for CO_2 monitoring to be installed in return air ductwork. The specification is extremely general however and makes no reference to which locations this is to be applied to.

The aim of the credit is to improve internal air quality by reducing recirculation of building air, reducing intake of vehicle fumes into the building and avoiding excessive build-up of CO_2. Where achieved, this might be expected to improve air quality in the building, providing increased levels of health, comfort and productivity. The credit achieved for Building D relates particularly to CO_2 levels in auditoria, and some improvement in productivity in particular might therefore be expected in these areas. Failure to specify the scope of the CO_2 monitoring in the design throws significant doubt, however, on where and whether it has in fact been installed. Verification of this facility would require a detailed technical investigation beyond the scope of this study. The Building User Survey results show that Building D is rated the most poorly out of the case study buildings, in terms of health comfort and productivity. The survey does however relate primarily to building occupant desk spaces, and does not ask particularly about conditions in lecture theatres.

Hea 09 - Volatile organic compounds

> Issue aim: "To recognise and encourage a healthy internal environment through the specification of internal finishes and fittings with low emissions of volatile organic compounds (VOC's)" (BRE, 2008)

One credit is available where prescribed standards are met for a number of common building products relating to their potential for emission of VOC's, and toxic substances more generally. These include manufactured timber products such as plywood and MDF, floor coverings such as vinyl and carpet, ceiling tiles, wall coverings, adhesives, paints and varnishes.

The case study buildings achieved credits under this issue as follows:

Building A – 0 credit

Building B – 1 credit

Building C – 1 credit

Building D – N/A

For Building A the design stage credit was awarded based upon the issue requirements being incorporated into the Architect's specification. At post construction review the main contractor has provided product data sheets to demonstrate compliance for some of the materials used, however these did not cover all relevant materials and so the credit has been withheld. For Building B the credit has been awarded based upon a letter from the project architect stating that the requirement will be communicated to "tenderers". The post construction validation consists of an email from the main contractor stating that they have complied with the requirement, along with inclusion of manufacturer's information for two particular products. For Building C, manufacturer's literature has been provided for a number of particular products, along with a general assurance from the main contractor that the standards will be complied with. The issue was not assessed for Building D. The level of evidence presented for both Buildings B and C appears to be extremely weak. The specific requirements in relation to the credit do not appear to have been incorporated into the design information, and no independent checks appear to have been carried out in relation to the products actually used. There is additionally no straightforward means of checking the providence of products such as paint and plywood once they have been installed, and therefore little prospect of detection should products not meet the requirements.

The aim of the credit relates explicitly to providing a healthy internal environment. However, the combination of highly specific credit requirements and a very weak level of design information and verification places doubt on the correct execution of the requirements. Testing for VOC's within the buildings is possible, but beyond the resources of this study. Post construction verification of the products used in the building is also problematic. All case study buildings exceed the survey benchmark in relation to perceptions of health, however the study does not provide adequate data with which to examine any possible link with volatile organic compounds.

Hea 10 (HW14) - Thermal comfort

> Issue aim: "To ensure, with the use of design tools, that appropriate thermal comfort levels are achieved" (BRE, 2008)

One credit is available where thermal modelling demonstrates that the building can deliver thermal comfort in occupied spaces to meet the criteria set out in CIBSE Guide A (CIBSE, 2015a). The modelling must be selected and used in accordance with CIBSE AM11 (CIBSE 2015b). CIBSE Guide A prescribes temperature ranges applicable to areas including lecture theatres, seminar rooms, teaching spaces and offices.

The case study buildings achieved credits under this issue as follows:

Building A – 0 credit

Building B – 1 credit

Building C – 1 credit

Building D – 1 credit

For Building A, the BREEAM report confirms that compliant thermal modelling was carried out, but that the building did not comply in certain limited areas of the second floor. Curiously the report goes on to state "This is due to the reliance on natural ventilation and the lightweight structure.", although as previously described the majority of the building is mechanically ventilated and cooled. For Building B the credit has been awarded based upon modelling results produced by the services engineer. Post construction validation is provided in the form of an email from the contractor confirming that the building has been constructed in accordance with the drawings. For Building C, the services engineer's specification states that thermal modelling has been carried out in accordance with the requirements. The report notes that as a result of this analysis, comfort cooling was added to the majority of rooms. For Building D the credit is awarded based upon a letter from the services engineer, and a summary of the modelling. An audit trail has therefore been provided in each case. There does not however appear to be any independent scrutiny of either the choice of modelling tool, or the calculations themselves; factors which may significantly affect the results (Bordass *et al*., 2001; Menezes, 2012).

The aim of the credit is to achieve "appropriate" thermal comfort. Above benchmark satisfaction relating to thermal comfort might therefore be expected in Buildings B, C and D. Failure to examine the input parameters as part of the assessment might however be expected to reduce the effectiveness of the criteria in practice, particularly as it is clear that fundamentally erroneous information has been used for Building A. The BUS measured thermal comfort of occupants directly and suggests that whilst generally satisfactory, there are particular areas of concern. Building C is considered too hot in winter, with analysis suggesting that inadequate control of temperature was provided for the building. Meanwhile, Building D suffers from overheating in summer, suggesting that the modelling conducted did not accurately reflect either the design or operation of that building, in use.

Hea 11 (HW15) - Thermal zoning

> Issue aim: "To recognise and encourage the provision of user controls which allow independent adjustment of heating/cooling systems within the building" (BRE, 2008)

One credit is available where the heating and cooling systems are designed to allow occupant control of zoned areas within “occupied spaces”. The zoning must allow for “separate control of each perimeter area (i.e. within 7m of each external wall) and the central zone (i.e. over 7m from the external walls)”. The controls must be located in or close to the space they relate to.

The case study buildings achieved credits under this issue as follows:

Building A – 1 credit

Building B – 1 credit

Building C – 1 credit

Building D – 0 credit

Review of the BREEAM report for Building A reveals that design stage compliance was based on proximity to individual heating/cooling sources, and notes that “Most occupied spaces have been designed to operate as a single temperature zone. In the smaller rooms there are no areas over 7m from the radiators or VRF units”. This statement would however translate to a maximum 14m x14m zone, and does not clearly demonstrate compliance. For the large lecture theatres the report notes that “temperature sensors have been located throughout the space linked to the heat emitters to control the temperature so it is even for the whole space”; again it is unclear that this demonstrates compliance, as no separate occupant control is suggested. At post construction stage the assessor visited the site but it appears that the installation was incomplete. Compliance was ultimately based upon as-built drawings provided by the services sub-contractor. These reportedly indicated TRV’s to all radiators, occupant controls for VRF units, and occupant controls for the lecture theatres, although no evidence of the latter was found during the researcher’s visit. For Building B, compliance is based upon heating layouts indicating thermostats in each room, along with a photo of an installed thermostat. No mention is made of the cooling, although controls were observed for these during the researcher’s visit. For Building C the assessors report begins by stating that “the assessor is permitted to make a reasonable judgement regarding the requirement to separately zone parts of rooms over 7m from the external wall. We judge that in an 8m deep room a single heating zone is sufficient”. The report goes on to describe the proposed heating and cooling system based upon the mechanical engineers specification and radiator schedules, and “notes” and drawings received by email from the services engineer. This describes a system with TRV's to radiators, room thermostats for trench heating and room thermostats for chilled beams and the design stage credit is awarded on this basis. In the operational building however the researcher observed that the TRV's in the classrooms appeared to be centrally controlled, and that no thermostats appear to have been installed for the trench heating. Additionally the chilled beams have been replaced by mechanical ventilation which, although provided with temperature control dials, was widely believed by occupants to be fully centrally controlled. Overall, the evidence provided for compliance appears rather weak. The design stage assessment for Buildings A and C is vague and includes some significant interpretation of the requirements. The post construction stage verification is also weak, relying on contractors as-built drawings in the case of Building A and a single photo in the case of Building B.

The aim of the credit is clearly to achieve a greater level of control over temperature for building users. The potential benefits of this are not stated, however it appears reasonable to expect that this is intended to improve thermal comfort, and therefore general comfort, health and productivity. The criteria do not appear to have been implemented in Building C, and no effect is therefore anticipated in that building. Buildings A and B do appear to be at least partly compliant, and some positive effect may therefore be expected. Control over heating and cooling is directly assessed by the building user survey. In this respect Building C performs very poorly in terms of control, with over 70% of occupants indicated that they had "no control" over heating and cooling. Buildings A and B fared better and significantly exceed the benchmark mean in respect to control of heating and cooling. The absolute level of control is still relatively low however, with neither exceeding the scale midpoint, and with over 40% of respondents in Building A awarding the minimum possible rating. As detailed in section 4.1, the provision for control in Building C appears to have been largely removed through the design and build process. In Building A controls have remained although the cooling provision appears to be at least partly controlled by facilities management. In Building B only one occupant experiences significant problems with control, perhaps indicating a specific rather than a general problem.

Hea 12 (HW16) - Microbial contamination

> Issue aim: "To ensure the building services are designed to reduce the risk of legionellosis in operation" (BRE, 2008)

One credit is available where all water systems in the building comply with Health and Safety Executive's "Legionnaires' disease - The control of legionella bacteria in water systems. Approved code of practice and guidance 2000" (HSE, 2010). Additionally, where humidification units are specified they must be of the steam humidification type. The approved code of practice includes general provisions in relation to the design of both domestic hot and cold water systems, and to evaporative cooling units, both of which are present in all four case study buildings

The issue represents a minimum standard for a "very good" rating and is therefore compulsory. All case study buildings achieved this credit.

Building A – 1 credit

Building B – 1 credit

Building C – 1 credit

Building D – 1 credit

Review of the BREEAM reports shows that compliance is in all cases evidenced in the form of a general specification clause and/or a letter of confirmation from the designer and/or installer to the effect that the design complies with the approved code of practice. Similarly the designers have in each case confirmed that no humidification plant has been specified. This level of evidence appears very weak, as it does not include details of the specific provisions made, or include any third party scrutiny of designs or installations.

The aim of the credit is to reduce the risk of the bacteria legionellosis occurring in the building water systems. However, as the code of practice represents a legal minimum standard, and as the evidence provided to support this compliance is limited to general assurances from the designers and/or installers, there does not appear to be any reason to suppose that this issue has delivered any additional benefit or certainty in terms of prevention of legionellosis for the case study buildings. Building managers reported zero occurrence of legionellosis related illness across the four buildings which, whilst positive, is not unexpected, as the incidence of legionnaires disease is not widespread; Naik *et al*.

(2012) report 235 case of legionnaires disease in England and Wales in 2011, of which around 50% were believed to have resulted from foreign travel.

Hea 13 (HW17/M24) - Acoustic performance

> Issue aim: “To ensure the acoustic performance of the building meets the appropriate standards for its purpose” (BRE, 2008)

One credit is available where specified indoor ambient noise levels are achieved for a range of room types. These standards must be verified by means of post completion testing carried out by a qualified acoustician. A second credit is available where specified reverberation times are achieved for areas “used for speech”, with this performance again to be verified post completion. The requirements relate to a range of rooms in the case study buildings, including offices, meeting rooms, teaching rooms, lecture theatres and laboratories.

The case study buildings achieved credits under this issue as follows:

Building A – 2 credits

Building B – 2 credit (area weighted)

Building C – 2 credit

Building D – 0 credit

Review of BREEAM reports reveals that design compliance for Building A is evidenced by means of a report produced by an acoustician, coupled with a report produced by the Architect confirming that the design is in accordance with the acoustician’s recommendations. Post completion testing results indicated a failure in two particular instances relating to duct noise. The credit was however awarded, based upon a commitment received from the contractor to rectify and re-test these areas. For Building B compliance is evidenced by means of an acoustician’s report and post completion testing. For the first credit the lecture theatre and technicians room did not comply, whilst for the second credit only the lecture theatre and seminar rooms were assessed.

Partial weighted credits were therefore awarded for each. For Building C design stage compliance was evidenced by means of a Stage D acousticians report providing general suggestions in connection with compliance with Building Bulletin 93 (BB93) (EFA, 2003) supplemented by an email from the same acoustician stating that particular parts of the requirements had been satisfied. The evidence provided for Building B appears relatively robust, as it includes advice and testing carried out by a third party professional. The evidence for Building A is similarly robust, with the exception that the credit was awarded despite some test failures. The evidence for Building C is much weaker, as it relies on general assurances and includes no post completion testing results.

The aim of the credit is to achieve "appropriate acoustic performance". Reference to the criteria reveals that the specific intention is to achieve particular standards in relation to break-in noise and speech legibility. In terms of break-in noise in office areas there is evidence to suggest that this issue may have had a positive effect, with the buildings achieving the credit all exceeding benchmark expectations in terms of noise overall. Additionally no comments were received in relation to break in noise for these buildings, whereas five were received for the building which did not achieve it (Building D). It is notable however that the issue does not attempt to address noise generated within the rooms themselves. This was a significant issue across the case study buildings and may be an area in which the issue could be further improved.

4.5.4 Summary

No overall aim is stated for the BREEAM Health and Wellbeing section, however examination of the criteria suggests that the intention is to differentiate certified buildings on the basis of good internal environmental quality, supplemented by some particular additional issues relating to provision of chilled drinking water, external amenity space, and safety of fume cupboards. The study data indicates that three of the four buildings significantly exceeded benchmark expectations for comfort, but that only two exceed benchmark expectations in relation to the perceived effect of the building on occupant health.

CHAPTER 5 - DISCUSSION

This section begins with a summary of the knowledge gap and research aim, followed by detailed exploration of the case study findings. The contribution to knowledge is then articulated. Following this, the implications for criteria configuration are discussed and recommendations are then put forward for their improvement.

5.1 Knowledge gap and research aim

Despite representing the pre-eminent model for measuring the sustainability of new and refurbished buildings and by association, the setting of minimum standards and subsequent market transformation, BSAS have been widely criticised in academic literature from both a theoretical and empirical standpoint (Cole, 2005). The design and construction stage interventions promoted by BSAS do not appear to be a reliable means of improving overall building performance (Scofield, 2009; Monfared and Sharples, 2011) and whilst a number of general theoretical weaknesses have been identified within these methodologies, the particular factors limiting their effectiveness are currently poorly understood. This knowledge gap has been addressed through close examination of the content, application and impacts of a particular BSAS when applied to four case study buildings. The links between content, methodology and results have been examined in relation to energy use, water use and internal environmental quality, with a view to identifying failures within the assessment process; in particular challenging the assumptions that design change is accurately manifested within completed buildings and that physical changes reliably translate to improved sustainability in use. Greater understanding of these potential failure modes provides a platform for generating recommendations for increasing the effectiveness of BSAS.

5.2 Case study findings

Addressing research objectives 1, 2 and 3 has generated a body of data which describes the particular BSAS design criteria applied to each case study building, the physical manifestation of those design criteria and the in-use performance of the building. For each criterion, this data has been analysed with a view to testing whether the design intervention has been correctly implemented and if so, whether it has produced its intended effect. This analysis was attempted for criteria ranging across 23 different BREEAM "issues" relating to energy use, water use and internal environmental quality. As discussed in detail in Chapter 3 this analysis represents just a portion of the 104 issues assessed under BREEAM 2008. With the scope of the analysis being primarily limited by the availability of research resource. The analysis has additionally been applied to just 4 buildings, all located in the same country and with a broadly similar use profile. Notwithstanding these limitations, robust conclusions have been possible in relation to the application of particular criteria to particular buildings. In certain cases it has also been possible to comment upon the likely impact of these interventions on overall building performance.

By establishing the presence of a feature or equipment within a building it has often been possible to determine the physical manifestation of a design intervention with a high degree of certainty. This has typically been achieved by cross referencing the compliance evidence presented in the BREEAM assessment reports with walk through surveys and discussion with building mangers and facilities management teams. In other cases, for example, where the feature or equipment is hidden from view, it has instead been necessary to infer its existence through examination of building performance metrics. In still other instances, even where features or equipment are visibly installed, it has been necessary to look to building performance data to demonstrate that they are producing their intended effect. Examining the link between physical manifestation and performance effect has proven more challenging than establishing physical manifestation alone. A particular limitation in this regard was the lack of functioning energy and water sub-meters within the buildings. This omission is itself relevant to the study as it indicates a failure to correctly implement BREEAM criteria, which in the case of basic electricity sub-metering, are compulsory for BREEAM rated buildings. It has limited the scope to analyse the efficiency of particular aspects of a building, which would have supported further analysis in respect of certain criteria. Analysis in relation to water use was limited further still, with just two of the four case study buildings having functioning whole building metering. Finally, although a range of benchmark data sets are available for both energy and water use as discussed in Chapter 3, their respective quality, contemporariness and applicability to the case study building types are highly variable.

When considering performance in terms of internal environmental quality the data collected was far more granular, with BUS survey respondents being asked to comment specifically on a range of performance metrics. The main limitation of this data was that it relied on human perception to generate information for quantitative analysis. Thus although data was collected in a highly structured manner and benchmarked against a robust dataset, personal preference will inevitably have influenced results. This limitation was of particular significance for the smaller buildings and especially for Building B, which has just four permanent staff. Overall, conclusions in relation to how criteria have manifested themselves in the buildings are generally more certain than those relating to the resulting effect on performance. This has created important potential for bias in the results. It has been far easier in practice to demonstrate that a criteria has had no effect on building performance (typically because the relevant feature or equipment has not been installed) than to prove that it has had an effect. This is reflected in the findings, which relate largely to observed failures. With only limited references made to building upon observed successes.

Energy

Analysis of the BREEAM criteria reveals that differentiation in relation to Energy was attempted through assessment of regulated energy use, augmented by particular additional elements that are principally concerned with fixed services. Through sub-metering, there was also an aspiration for improved facility to monitor energy use. Of the 20 Energy issues, just five were attempted across all case study buildings. The aims of these particular issues relate to reducing regulated energy use, provision of energy sub-metering, the use of energy efficient fittings and controls for external lighting, and the energy efficient design of lifts. The criteria making up these issues rely on a range of strategies for their application, which the investigation suggests have various strengths and weaknesses.

The use of statutory modelling to reduce regulated energy use (Ene 1) is an example of a BREEAM requirement that is both complex and applied at a whole building level. It piggybacks upon established external regulation. In this case resulting in a “performance specification” which rewards results, regardless of method. This approach has the advantage that a minimal administrative burden is applied, as the modelling activity is already required to achieve Building Regulations compliance. Using this method, design teams also have scope to introduce substantial design improvements and the flexibility to choose those that are most practical and cost effective. On the other hand, the accuracy with which design stage energy modelling predicts performance in use, is known to be poor (Menezes *et al*., 2012), henceforth it is uncertain to what extent the particular chosen improvements will be effective. The awarding of credits in relation to this issue also lacks transparency, as the parameters upon which the modelling is based are not communicated within the BREEAM reports. Furthermore, it is technically difficult to verify many of the parameters and assumptions embedded in these credits at completion stage and the suggestion that for Building A the issue was effectively validated using a "post completion" visual inspection, carried out by the BREEAM inspector, is considered to be fanciful. Such validation would, in reality, require a line-by-line check of the modelling calculations, followed by robust construction stage monitoring and/or post completion testing. Finally, the use of statutory modelling promotes reductions in carbon emissions resulting from regulated energy use, whilst failing to address unregulated consumption.

Conversely, the requirement that lift numbers, size and type are based upon energy efficiency (Ene 8) is an example of a BREEAM requirement that rewards method, regardless of result. This approach is also complex but is focussed on a particular building element i.e. the lifts. It has the advantage of being non-prescriptive, and therefore gives designers maximum flexibility to align enhancements with the wider needs of the project. Calling upon designers to consider and justify their lift design in terms of energy would appear to represent good practice. Encouraging the choice of lift strategy purely on the basis of energy efficiency seems however to be a flawed approach and ignores the commercial and operational factors which are also likely to be important to project teams. In practice, with no clear framework being provided by BREEAM for the assessment, the issue appears to be open to commercial manipulation. In particular, asking consultants to generate two options and then choosing the one with the lowest projected energy use does not seem a robust means of prioritising energy efficiency over other considerations. The value of this process was further undermined for the case study buildings by its implementation, which in two buildings was based on an "informal assessment" by the services engineers. In no case was the decision process communicated within the BREEAM report, making verification of its effect impossible.

Finally, a number of criteria were simple and focussed, being applied in the form of relatively straightforward specification enhancements. Particular features were specified, that is; electric sub-meters (Ene 2 and 3), high efficacy external light fittings, photocell controls (Ene 4) and various energy saving design features for lifts (Ene 8). These requirements have the advantage of being "bolt on" requirements which designers are able to add without significant impact on the wider design. The expected improvements may also be clearer and more readily verified, when compared to credits that relate to modelling or other complex design processes. The lack of inherent consideration of the specific buildings when awarding these credits can however limit their impact. For example three of the case study buildings were awarded credits for using energy efficient bulbs on a very small number of external light fittings. Verification may additionally be hampered by technical complexity, for example it was not possible for the researcher to check whether the stated energy saving features had indeed been embedded in the lift machinery. Similarly, whilst a number of electric sub-meters do appear to have been fitted in the case study buildings, failure to properly commission them has subsequently rendered them useless.

In summary, therefore, BREEAM "Very Good" certification does not appear to be a robust differentiator in terms of Energy use or CO_2 emissions, for the case study buildings. A number of specific potential reasons for this have been identified, which might be summarised as follows:

- The criteria are not applicable, for example none of the buildings contained a swimming pool.
- The criteria are not always attempted. Overall uptake of credits from the section was variable, ranging from 15-41%. Non-of the buildings attempted the credit relating to Low or zero carbon technologies, despite all of them making use of them.
- The criteria are not robustly configured, for example the use of design stage modelling of regulated energy use is known to be a poor predictor of actual energy use.
- The criteria are limited in scope, in that the criteria are focussed primarily on fixed building services (for which energy efficiency is already a regulatory consideration), whilst largely ignoring issues such as portable equipment and occupancy patterns.
- The criteria are weakly defined, for example the requirement to define two options for lifts and select the most energy efficient is not a robust means of ensuring low energy use.
- The criteria does not address significant aspects of energy consumption for the particular building, for example the use of high efficacy external lighting produces little or no benefit where the lighting is limited in scope.

- The criteria are difficult for the BREEAM assessor to verify, for example the presence of energy control features in lifts
- The criteria assume subsequent effective commissioning, for example the linking of electrical sub-meters to the BMS.
- The criteria are not configured to directly reduce energy consumption. For example, installing electrical sub-meters will not necessarily result in a reduction in use.

Water

Analysis of the BREEAM criteria reveals that differentiation in relation to Water use is based upon control of consumption for sanitary conveniences, irrigation and vehicle washing. This is supported by particular requirements relating to water metering, water re-use and leak detection and minimisation. Of the seven Water issues, five were applied to the case study buildings. The aims of these particular issues related to provision of low water use sanitary ware fittings, provision of a BMS compatible water meter, leak detection on incoming services, leak control in toilet areas, and the specification of landscaped areas not requiring automatic watering systems.

The criteria used in the Water section are universally simple in technical terms. Reduction in day-to-day water use for sanitary conveniences is the only whole-building issue within the category, for which improvement is sought through specification of a comprehensive range of sanitary ware, based upon manufacturers data (Wat 1). This approach is considered to be robust in terms of its likely effectiveness, is simple to enact using existing specification documents and is open to verification both during and after construction. The remaining criteria are of the “bolt on” type. These can be defined as technically simple, independent of other design considerations and focussed on particular building elements. Restrictions on the provision of automatic watering systems (Wat 6) are straightforward to specify and verify, although their effectiveness as a benchmarking measure is contingent on an assumption that the use of non-conforming irrigation systems is common. The remaining measures relate to the provision of a pulsed water meter (Wat 2), leak detection on incoming water supplies (Wat 3) and automatic shut off valves for supplies to sanitary areas (Wat 4). These are also straightforward to specify, but being located largely in service spaces are more difficult to verify. The effectiveness of these credits is also less certain because of the assumptions embedded within them. Wat 2 is reliant upon a link between water metering and consumption. Similarly Wat 3 and Wat 4 will only be effective if and when a leak occurs. These criteria are also sensitive to commissioning failure. This is evidenced by the fact that none of the case study buildings scoring credits in relation to pulsed water meters or major leak detection were found to have operational systems in practice.

The water use by floor area measured for Buildings B and C was substantially below all of the benchmarks considered, including the average for other buildings operated by the same university. As such BREEAM “very good” certification appears to demonstrate robust differentiation for these buildings in terms of Water use. It is notable however that Buildings B and C consume very similar amounts of water by floor area, despite them scoring quite different numbers of credits (Building C scored 7 credits in the section, whilst Building B scored 3). Additionally, two of the nine available credits have demonstrated to be entirely ineffective across all four buildings. A number of specific potential reasons for this variation in performance have been identified, which might be summarised as follows:

- The criteria are not applicable, for example, none of the case study buildings had a vehicle washing facility.
- The criteria are not always attempted. Overall uptake of credits from the section was variable, ranging from 38-88%. None of the buildings attempted the credit related to Water recycling.
- The criteria do not address significant aspects of water consumption for the particular building. For example, restriction on the design of automatic watering systems for buildings, for which low maintenance landscaping was perhaps always intended.
- The criteria relate to mitigation of risk rather than impacting on routine performance. For example, the “major leak detection” system specified would reduce water consumption only in the event that a leak occurred in the underground pipework between the building and its nominal site boundary.
- The criteria assume subsequent effective commissioning, for example, the linking of pulsed water meters and leak detection systems to the BMS.
- The criteria are not configured to directly reduce water consumption. For example, making a water meter capable of being linked to a BMS system will not necessarily result in a reduction in water use.

Internal Environmental Quality

Analysis of the BREEAM criteria reveals that differentiation in relation to Health and Wellbeing was attempted through assessment of a broad suite of environmental metrics. Of the 18 Health and Wellbeing issues, 12 were applied to some or all of the case study buildings. The aims of these particular issues relate to: providing high levels of day lighting whilst minimising glare, providing views out of the building for desk based staff, providing adequate and controllable artificial lighting, providing potential for natural ventilation, minimising internal and external air pollution, providing good thermal comfort, preventing legionellosis and controlling break-in noise and reverberation. The strategies used where applied to the whole building, but the criteria are polarised between highly simplistic and highly technically complexity. The investigation suggests that each of these approaches has a number of strengths and weaknesses, as follows.

The criteria applied to the case study buildings for the Health and Wellbeing section were universally applied at a whole building level. Many are awarded based upon relatively technically complex criteria and typically rely on pre-existing third party best practice guidance and/or certification. These criteria include calculation of building wide day lighting factors (Hea1), designing artificial lighting to achieve particular illuminance values (Hea 5), application of dynamic thermal modelling (Hea 10), application of standards relating to legionellosis (Hea 12), and design for and testing of acoustic performance factors (Hea 13). These credits constitute a performance specification, and by making use of third party guidelines they are able to mobilise respected good practice standards. However, they do fully rely upon correct understanding and application of best practice by the design team. The BREEAM standards do not prescribe how the standards are to be achieved and the design solutions do not appear to have been scrutinised in detail by the BREEAM assessors. For the case study buildings this is reflected in a generally weak level of verification. Across these technically complex issues, credits were often awarded based upon direct reproduction of the BREEAM clause in the design specification, in many cases even this was not carried out. Instead, the credit was awarded based upon a side letter or email from the design consultant responsible. Only for the acoustic performance was any verification testing carried out, and even in this case a failed test was considered adequate, based upon an assurance from the contractor that the problem would be rectified.

By contrast, other criteria are relatively simple from a technical point of view. For example, particular criteria relating to adequacy of the view out (Hea 2), zoning for lighting (Hea 6), potential for natural ventilation (Hea 7), indoor air quality (Hea 8) and thermal zoning controls (Hea 11) are based on very simple and rigid dimensional requirements. A view out is, for example, determined to be adequate where desks are within 7m of a wall with at least 20% of glazed area. Meanwhile, glare prevention is achieved through a straightforward provision of window blinds (Hea 3) and avoidance of light flicker and buzz is achieved through use of high frequency ballasts (Hea 4). These criteria are clearly configured primarily for simplicity of application and do not require or accommodate a high level of judgement by the design team. Some such as the provision of blinds are "bolt-on" requirements needing only an additional specification clause to incorporate, along with the necessary budget. Others such as requirements for natural ventilation include fundamental requirements in terms of building configuration. The simplicity of the requirements provides the BREEAM assessor with more scope to assess the evidence provided, although in reality this was still found to be extremely weak in some cases. For example it was necessary for the designer of Building D to write to the BREEAM assessor to assure them that appropriate zoned light switching would be installed, as this was not apparent from either the specification or drawings. Simplicity of requirement also led in some cases to credits perhaps being unreasonably withheld. For example, the credits for having a "view out" were withheld for large areas of Building D purely because rooms were 7.5m wide instead of 7m, despite the universal provision of highly glazed elevations providing expansive views over the university campus.

Overall, the issue criteria for the Health and Wellbeing section can be characterised as a mixture of highly technical performance specification based on established third party guidance and/or calculations, and very simple requirements based on either building geometry, or provision of simple equipment. The aims of the individual issues are generally clear, however they also relate largely to subjective environmental metrics. It was possible to measure some relevant aspects of the internal building environment directly using the building user survey, and in many cases the case study buildings performed well. However, results were usually inconsistent across buildings, providing limited evidence to suggest that achievement of credits is a guarantee of above-average performance. Overall, performance of the case study buildings was also mixed, with only three buildings exceeding benchmark expectations for comfort and only two exceeding benchmark expectation for perceived effect on occupant health. A number of specific potential reasons for this mixed performance have been identified, which might be summarised as follows:

- The criteria are not applicable, for example only one of the buildings contained fume cupboards.
- The criteria are not always attempted. Overall uptake of credits from the section was variable, ranging from 50-83%. None of the buildings attempted the credit relating to indoor air quality.
- The criteria are not configured to directly improve health and wellbeing. For example, the study indicates only a weak or moderate correlation with health for just three particular aspects of internal environment, and no correlation at all with comfort overall.
- The criteria are not robustly configured. For example the geometric requirements relating to a "view out" do not guarantee a view out if they are conformed to, nor necessarily preclude one if they are not.
- Assurances of compliance by designers, or general specification clauses, have been widely accepted as evidence, in lieu of appropriate design information. For example in respect to intended light switching arrangements.
- The criteria are poorly configured, for example acoustic criteria are focussed on preventing noise travelling between rooms, whereas building occupants in the case study buildings complained primarily about noise from colleagues located within the same workspace.
- The criteria may be difficult for the BREEAM assessor to verify, for example the level of volatile organic compounds present in building materials.
- The criteria were not supported by subsequent effective commissioning, for example the presence of inoperable heating controls in Building C.
- The criteria are not coordinated, for example the use of blinds to control glare is not consistent either with providing adequate day lighting, or providing a view out.
- The criteria may describe common, rather than best, practice. For example, the provision of blinds on office windows.

5.3 Contribution to Knowledge

The study has provided empirical evidence to support and substantially expand understanding of a number of important proposed theoretical weaknesses of BSAS. These are summarised in Figure 5.3.1 and discussed in detail below.

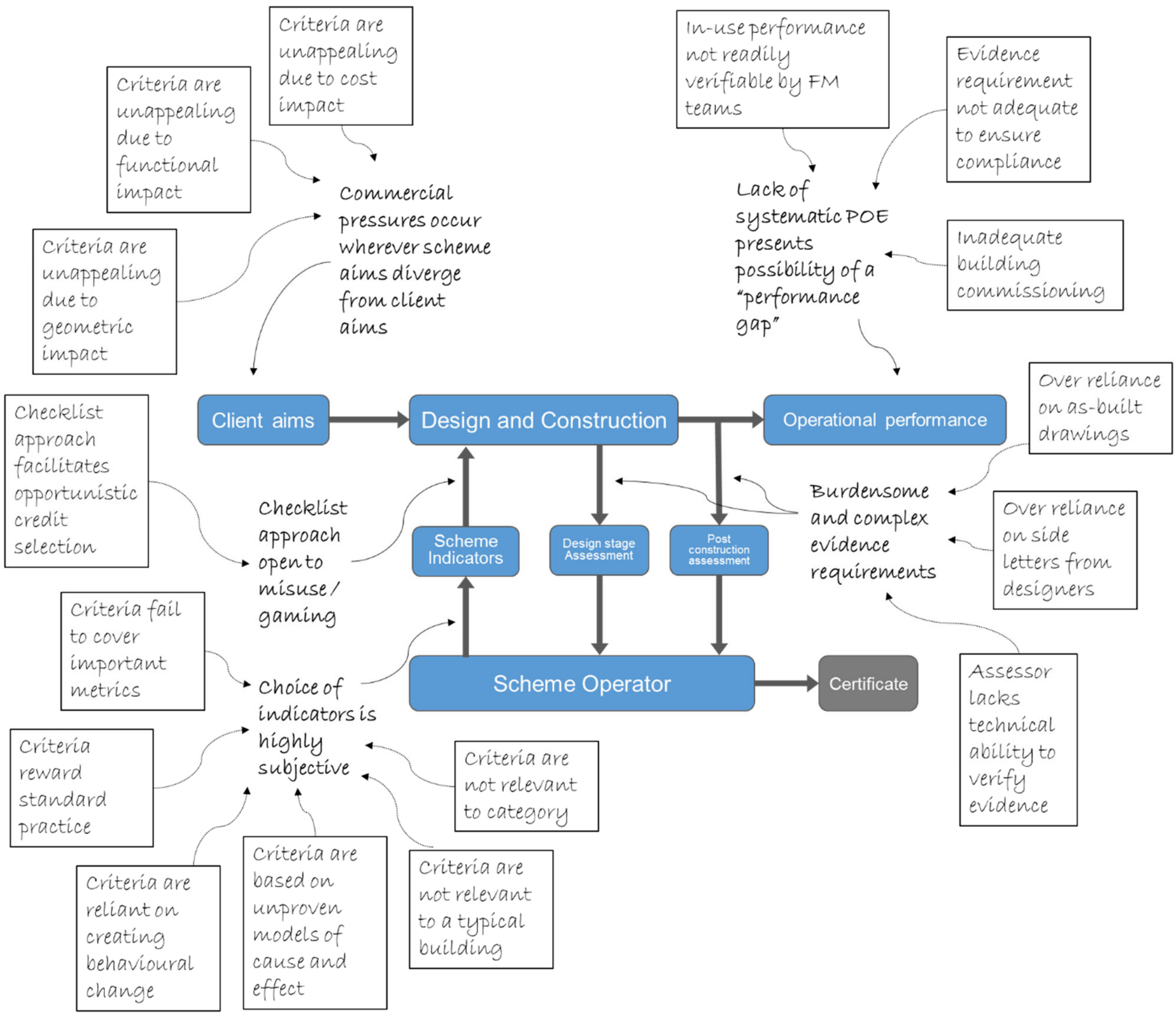

Figure 5.3.1 – Theoretical and observed limitations of building sustainability assessment scheme content and process

Choice of indicators is highly subjective

Literature review suggests that indicators are an imperfect means of assessment, being both incomplete by definition and subjectively selected (Brandon and Lombardi, 2011). These weaknesses of content were illustrated clearly in elements of the BREEAM scheme analysed in relation to the case study buildings. There were, for example, important metrics which the scheme completely failed to address; most notably perhaps through energy credits being awarded almost entirely in relation to regulated use, with unregulated use being largely discounted. In other instances, scheme criteria lacked impact because they rewarded standard construction practice, such as installing blinds on office windows; in others they failed to generate improvement because they related to unusual features, such as car washing facilities, which were not present in the case study buildings. More subtly, the effectiveness of many criteria was reliant upon unproven models of cause and effect. For example, the BUS survey data for the case study buildings fails to establish a correlation between perceptions of internal environmental quality and perceived health. If, as suggested by this data, improvements to IEQ do not significantly improve health, then the configuration of the majority of the BREEAM Health and Wellbeing section cannot produce its intended effect. Similarly, a large portion of BREEAM Energy section credits are based on the EPC rating of the building which has been proven by multiple research projects to be an unreliable predictor of energy use. A further important specific example of reliance on weak causal links is evident in criteria relying upon creating behavioural change to achieve an effect. An example from the study criteria is that of rewarding installation of energy and water sub-metering, as a means of reducing consumption, without stipulating any form of ongoing framework for their application.

Commercial pressures occur wherever scheme aims diverge from client aims / Checklist approach is open to misuse/gaming

The potential for construction project teams to manipulate the checklist approach by selecting BSAS criteria on the basis of expediency is widely purported in the literature (Cole, 2005). Potential clearly exists for project teams to target the criteria which most appeals to them, whether because they are the cheapest to implement or because they have the least impact on function. As the research methodology did not provide direct access to the design process, the results of this behaviour were not directly observed. These pressures were however indirectly evident in the study, most notably where criteria were not met despite being apparently closely aligned with the building design. For example, the credit for providing a view out was not achieved in Building D purely due to a small number of rooms being 7.5m wide, rather than 7m maximum stipulated by the criteria. Although the majority of the building provides excellent views out, and despite the fact that this credit could have been achieved by changing the shape of these rooms, it was not pursued. The credit relating to potential for natural ventilation was also not achieved for this building, also due to the building being considered by BREEAM to be too deep in plan and despite it having been designed to operate as such. Similarly, day lighting credits were not achieved for Buildings A and D, purely because large windows were not provided in lecture theatres. These examples highlight the impact of wider client concerns such as functionality, site geometry and town planning consents in driving credit selection. As distinct from other criteria which failed to produce an effect, in the examples cited above, the aims of the BREEAM criteria were apparently achieved without meeting the criteria; a case of assessment underestimating building performance.

Burdensome and complex evidence requirements / Lack of systematic post occupancy evaluation presents the possibility of a "performance gap"

Failure to incorporate POE into BSAS is considered a fundamental theoretical weakness of the approach; without this feedback any opportunity for objective assessment and improvement is lost (Alwaer and Kirk, 2012). Schemes instead rely on submission of "evidence" to prove that criteria have been correctly implemented and it is additionally proposed by some commentators that this may produce an unreasonable burden on a project. Analysis of the case study buildings supports this proposition indirectly, in two ways. Firstly, the stated evidence requirements of BREEAM were, in many instances clearly inadequate to robustly demonstrate compliance. Certain credits, such as those relating to the efficiency of installed lifts had no post-construction evidence requirement at all and were entirely based upon a design stage statement of intent. In other cases the evidence requirement, whilst substantial, was simply inadequate to demonstrate compliance; for example, credits relating to limiting VOC levels were awarded based on submission of a suite of manufacturer's data sheets for a wide range of materials, but lacked any mechanism for testing whether these were in fact the actual materials installed. Secondly, even where evidence requirements were theoretically robust, assessors appear to have been able to award credits based on a lesser standard. At design stage this was evident in the routine use of side letters from project team members confirming that certain features had been incorporated in the design. This approach suggests strongly that these features were not clear in the design documentation itself, and as an example in the case of light switching, observed to be poorly implemented. At post-construction stage confirmation of adoption of criteria were similarly routinely provided by side letters from contractors, confirming that particular design criteria had been complied with. For Building B in particular, the BREEAM assessor does not appear to have visited the building at all.

5.4 Criteria Configuration

Scheme criteria represent a critical link in the BSAS process and examination of their implementation has revealed that their effectiveness may be significantly frustrated by their configuration. Following analysis of the study data in the context of the theoretical failing identified in the literature, content, appeal and evidence emerge as key efficacy-determining characteristics. Furthermore, a high degree of interdependency is noted, with criteria content being seen to determine the assessment methodology used and vice versa. These aspects of criteria are considered in further detail below.

Content

In order to differentiate buildings on grounds of sustainability, the substantive content of criteria must be selected to produce or recognise a particular effect in a completed building. Each issue within the BREEAM scheme has a stated aim. Therefore it is reasonable to expect that this would be fulfilled by the criteria contained within it. It is also reasonable to expect that the result will align with the wider aim implied by the category name. Surprisingly, examination of the criteria for the case study buildings suggests that neither alignment of the criteria with the specific aims, nor their implied wider sustainability impact can be taken for granted. On a very basic level it is noted that many issue aims were not achieved because the criteria related to features that were not present in the case study buildings; for example 8 out of 20 issues within the Energy section were not applicable to any of the case study buildings. In other cases, criteria failed to meet their stated aim by rewarding standard design approaches. For example, case study buildings were awarded credits based upon the *absence* of arguably unusual features, such as automatic irrigation systems (Wat 06 – Water irrigation systems), or the *inclusion* of commonplace features, such as office blinds (Hea 3 – Glare control). Similarly, credit was also awarded for features regardless of their extent, for example, the use of low energy external light fittings, which numbered just two on Building A. Scope was also impacted in some cases by a lack of appropriate criteria, for example, criteria within the Energy category of BREEAM almost entirely fail to address unregulated energy loads. The impact of some individual criteria were additionally negated through failure to establish a benchmark against which the associated stated aim might be measured; for example, issue "Ene 8 – Lifts" calls for consultants to model two design options for lifts and select the one with the lowest energy consumption without requiring these options to be related in any way to baseline practice. Other issues have stated aims that have rather uncertain, indirect, links to wider sustainability impacts. For example, the awarding of credits relating to the installation of electric and water sub-metering (Ene 2 – sub-metering of substantial energy uses / Wat 2 – Water meter), the effects of which are predicated upon building users subsequently employing monitoring as an aid to reducing consumption. Similarly, two of the five issues attempted within the Water section relate to mitigation of the effect of leaks (Wat 3 – Major leak detection / Wat 4 – Sanitary supply shut off), without also assessing whether such leaks might be expected to occur in a particular building. More fundamentally, the Health and Wellbeing section of BREEAM appears to be substantially founded upon an assumption that occupant health can be improved by increasing comfort, although analysis for the case study buildings shows that there was no observable correlation between these two metrics. In line with this finding, a clear majority of the internal environmental factors addressed by issues examined within the Health and Wellbeing category failed to produce any perceivable effect on occupant health.

Appeal

Few of the examined credits within BREEAM have mandatory threshold levels. There is therefore considerable scope for project teams to choose which criteria they wish to adopt. This is arguably a fundamental handicap in ensuring overall effect, as poor performance in relation to credits that are not attempted may reduce or completely offset good performance in those areas for which credits are awarded. In this context, the "appeal" of criteria has the potential to significantly impact both the scope and the degree of effect. The consequences of such flexibility are empirically apparent in the assessments for the case study buildings; for example, the average uptake of credits for the case study building in the Health and Wellbeing section (66% (range 50-83%)) was more than double that in the Energy section (32% (range 15-38%)). The effect of "appeal" on the uptake of particular credits was also evident within categories; for example all four buildings scored the credit relating to “Wat 6 - Water irrigation systems”, which was achieved in all cases by omission; meanwhile none attempted the credit for “Wat 5 - Water recycling systems”, which requires a substantive provision, and comes with cost and space requirements attached to it. Explicit evidence of the relationship between appeal and design constraints was also encountered in assessment reports. For example, the credit relating to issue “Hea 07 - Potential for natural ventilation” was not attempted for Building D due to many of the rooms being “too deep in plan”, despite this having been designed (and operated) as an entirely naturally ventilated building. In this case changing the configuration of the rooms was rejected because it conflicted with the broader project aims. In other cases credits were not attempted because they failed to align with the operational design intent. For example, three case study buildings failed to achieve a credit for issue “Hea 1 – Daylighting”, purely through a failure to provide glazing within large lecture theatres. In all cases the provision of additional windows in these areas was feasible, but was inconsistent with the intended functional use of the space. Conversely, some credits appear to have been appealing despite having no apparent alignment with operational design intent. For example, all buildings achieved credits in relation to provision of electrical sub-metering (Ene 2 – Sub-metering of substantial energy uses), although none of these were ultimately found to be in operational use. Whilst not explicitly stated within the assessment reports, such criteria, which call for small, inexpensive, “bolt on” items may perhaps therefore be more appealing than those requiring the wider design layout or function of the building to be altered.

Evidence

The use of BSAS as performance standards, particularly in connection with statutory approvals, necessitates the use of a robust certification process. The BREEAM scheme calls for project teams to submit extensive and specific “evidence” in support of their application. This is reviewed by a licensed BREEAM assessor. There are separate requirements depending upon whether it is “design” or “post construction” stage certification that is being sought. Examination of the evidence submitted for the case study buildings suggests however that the nature of these evidence requirements represents a third critical factor in determining the potential effectiveness of criteria. An observed weakness in many cases was that full and effective validation of design stage evidence required considerable technical knowledge and/or a detailed understanding of the project. For example, issue “Hea 10 - Thermal comfort“ requires that buildings achieve modelled thermal performance complying with CIBSE Guide A, using a modelling methodology selected and used in accordance with CIBSE AM11. Rigorous independent verification of the results of such modelling would require that the BREEAM assessor have a working knowledge of the standards and chosen modelling technique and be able to interrogate the results with reference to the building design parameters. In practice, this credit was awarded based upon receipt of either a copy of the modelling results (Buildings B and D), or a specification clause stating that such modelling has been carried out (Building C). This appears less than satisfactory and it is noted that occupants reported significant levels of discomfort in terms of thermal conditions in all three of these buildings. In other cases, the scope of the specified evidence was itself insufficient, particularly in relation to enhancements to building services equipment. Evidence for these items generally related to demonstrating *inclusion* of the equipment, either in the design, or as a physical manifestation. This often proved inadequate to ensure that the equipment was operational in practice. For example, heating controls were provided in rooms throughout Building C in order to comply with criteria contained in issue “Hea 11 - Thermal Zoning”, however these were discovered to have been bypassed in operation, with temperature instead being controlled centrally by the facilities manager. More generally, and despite the existence of a compulsory BREEAM credit “Man 1 – Commissioning” achieved by all buildings, poor commissioning of services appears to have been responsible for failure of various items of equipment in use. Examples of this included inoperable windcatchers in Building B (Hea 07 - Potential for natural ventilation), electrical sub-meters which could not be read by the BMS in Buildings A and D (Ene 2 - Sub-metering of substantial energy uses), and non-functioning water leak detection systems in Buildings A and C (Wat 3 – Major leak detection). It was apparent that ensuring correct realisation of the design intent was also hampered in some cases by physical access limitations. This is directly acknowledged in the BREEAM standards in some cases, which either do not list any post construction evidence requirements (Ene 8 – Lifts), or rely on very weak evidence such as as-built drawings (Wat 4 – Sanitary supply shut off). In other cases evidence requirements were substantial, but still failed to provide effective verification. For example, to achieve a post construction stage credit for “Hea 9 – Volatile organic compounds” it was necessary to submit a manufacturer’s confirmation of VOC content for a wide range of selected materials, based on specific testing regimes. There was no requirement to demonstrate that these were the actual materials used in the building. Finally, it is apparent from reviewing the assessment reports that considerable variation exists in relation to interpretation of evidence requirements. There were many examples of design stage evidence being provided in the form of side letters or emails from consultants. For example light switching arrangements required in relation to “Hea 6 - Lighting zones and controls” required additional clarification in the form of letters or emails from consultants for all four buildings. Such clarifications suggest that the design information is inadequate to convey the intended requirements and therefore unlikely to achieve the desired result. This was also realised in practice, it being noted that the light switching arrangements in all buildings consistently failed to meet the criteria in an intuitive manner and in many cases failed to meet it at all. At post construction stage there was also considerable reliance on assurances from contractors. For Building A the BREEAM assessor carried out a walk through inspection of the building, but in numerous instances relied on subsequent written confirmation that unsatisfactory items had been completed or altered. For Building B the assessor does not appear to have visited the site at all, with all evidence being provided in the form of letters or emails from contractors, or from the construction stage drawings.

Content, appeal and evidence requirements were therefore observed to be significant factors in determining the effectiveness of scheme criteria. The examined criteria included widespread and sometimes significant shortfalls in relation to these three factors, which have in many cases demonstrably reduced or negated their particular operational effect in the case study buildings. They have additionally been shown to be highly interdependent as indicated in Figure 5.3.1.

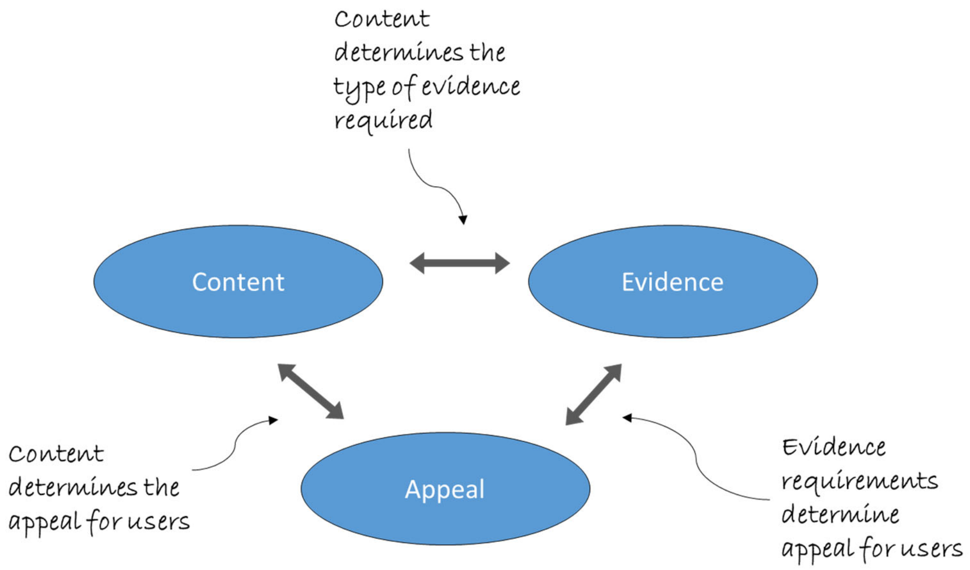

Figure 5.4.1 – Factors determining the effectiveness of credit criteria

Based upon the above analysis, effective BSAS criteria should therefore be configured to produce a substantial, certain and comprehensive effect, closely aligned with the explicit and implicit aims of the issue and category. They should ideally be cost effective and demonstrate minimal, or at least proportionate, impact on the wider spatial and functional design of the building. Finally, they should be readily verifiable by the

BREEAM assessor, and recognisable to building managers and occupants once the building is in use. In particular, the best criteria would be those that avoid or minimise the following shortcomings:

Content

- Not (collectively) comprehensive for a category
- Not aligned with the category
- Not applicable in a typical building
- Rewards standard practice
- Relies on an indirect effect (eg behavioural requirement)
- Relies on unproven/disproven pathway (unreliable)

Appeal

- Unappealing due to disproportionate functional impact
- Unappealing due to disproportionate geometrical impact
- Unappealing due to disproportionate cost impact

Evidence

- Evidence requirement is not comprehensive and/or relevant
- Assessor lacks technical knowledge to verify design stage evidence
- Failure to incorporate relevant evidence into design information
- Post construction evidence relies on as-built drawings or assurances from installers (hidden or undistinguishable features)
- Effect relies on subsequent commissioning
- Not readily verifiable by facilities managers or users in an operational building

5.5 Criteria complexity and scope

In addition to content, evidence and appeal, analysis of the study results also indicates substantial variation in both the complexity and scope of criteria. Criteria were observed to vary from simple to complex, and were applied in a manner varying from the highly focussed “bolt on“ requirements, to whole-building assessment. Complex criteria were observed to rely on detailed technical assessment and they often “piggy-back” upon existing third party assessment methods or guidance. Simple criteria may be configured as requirements to install (or avoid installing) particular equipment. Others relate to simple building geometry. Meanwhile, focussed criteria included requirements to improve a particular building feature, whereas whole-building criteria sought to produce a more general performance effect. It should be noted that different criteria types were often included within a particular BREEAM issue. For example, one credit is achieved under issue Hea 8 (indoor air quality) for a simple requirement to locate mechanical ventilation intakes and exhausts a set distance apart, whilst compliance with the second credit requires adherence to a more complex and detailed third party best practice guidance.

Complexity and scope have the clear potential to both influence, and be influenced by, criteria content, evidence and appeal. As indicated in Figure 5.5.1, evidence requirements have been observed to increase with both complexity and scope. Even relatively simple analysis such as daylight calculations become burdensome when applied across many rooms, whilst robustly evidencing complex whole building energy assessments such as those required for Ene 1 are clearly beyond the scope of the existing BREEAM assessment regime. When considered in relation to content, increased scope evidently increases comprehensiveness of assessment and may also be achieved independently of complexity. Applied appropriately, simple measures such as improving light switching arrangements have no less potential to produce performance benefits than the application of complex calculation standards relating to, for example, lighting levels. The appeal of criteria may also be impacted by complexity, however in this case the overall effects appear less clear. Credits relating to very simple criteria such as room sizes were not attempted in the case study buildings, even where these clearly aligned with the wider design aims of the building; meanwhile very complex criteria such as the calculation of lighting levels and whole building energy use were completed across multiple buildings. Similarly, some highly focused credits such as those relating to water recycling were not attempted whilst many whole building criteria were achieved. Thus whilst complexity may increase the evidence requirements it does not necessarily reduce the overall appeal of criteria, possibly influenced by a wide range of other factors. In the case of water recycling, for example, the capital cost of installation may make a simple criterion unattractive, whilst even complex criteria such as those relating to lighting levels, may be low cost where the requirements are already substantially included in the base design. Added to this, the knowledge that evidence requirements will not necessarily be robustly applied may limit their actual effect on appeal.

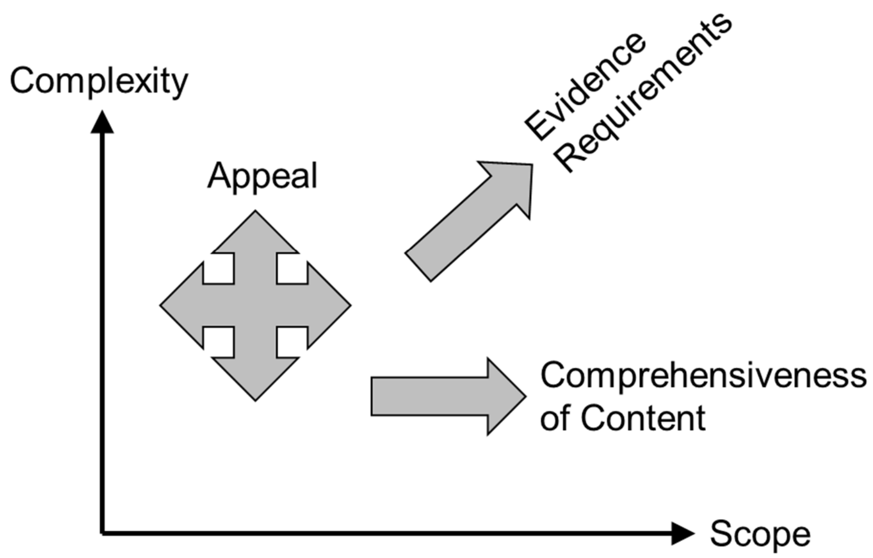

Figure 5.5.1 – Influence of criteria complexity and scope on content, evidence and appeal

5.6 Recommendations for improved efficacy

The findings suggest that the studied BSAS includes a number of inherent weaknesses relating to the criteria against which credits are awarded. To produce their intended effect, BSAS criteria must firstly be both relevant and comprehensive in terms of their content. This is no easy task in practice, given the range of building types and configurations that must be covered; notwithstanding this, the efficacy of the assessment applied to the case study buildings was limited by some significant omissions and unsubstantiated assumptions. A lack of criteria that directly addresses substantive metrics such as unregulated energy use, provides ample potential explanation for the apparent failure of BSAS to reliably differentiate buildings in broader terms. Similarly, awarding credits based on assumptions such as building internal environmental quality, being a determining factor for health and wellbeing may result in schemes significantly over-promising on their effects. The findings further confirm that even where criteria are well selected and configured, the scheme content will not produce its intended effect unless it is both targeted by project teams, and effectively evidenced by assessors. In practice this too was observed to be rather uncertain. Appeal in particular was seen to be highly dependent upon the alignment of criteria with the wider design aims and functional requirements, such as the building geometry. Meanwhile, evidencing was seen to be simple for some criteria and highly challenging for others. In practice, many examples of poor evidencing were noted, either because the requirements were not robust, or because they were not rigorously applied. Appeal and evidence were further noted to be influenced by the scope and complexity of the criteria applied. Many criteria were applied at the whole building level, however in other cases, multiple highly focussed credits were instead used to replace or augment the whole building assessment. This approach was evidently undermined by the high degree of flexibility provided in choosing credits, resulting in less appealing sections losing their overall impact. In terms of complexity, "piggy-backing" on complex third party standards created criteria that was theoretically comprehensive, but which in practice acted as a "black box", with no practical means provided for assessors to evidence them.

The occurrence and avoidance of these observed limitations may be illustrated clearly through examination of two particular key BREEAM criteria. Based on the findings set out above, Wat 1 and Ene 1 are examples of issues that respectively typify highly effective and highly problematic criteria. Comparison of these two issues, as applied to the case study buildings, clearly shows how the detailed make-up of criteria can fundamentally determine their overall impact. The criteria that constitute issue Wat 1 (Water consumption) align closely with the properties identified as being desirable across the study results, being comprehensive, simple and readily evidenced. As described in detail in Chapter 4, up to three credits are available under this issue. These are awarded based upon criteria calling for the installation of various items of water efficient sanitary ware i.e. WC's, basin taps, urinals, showers and baths. Whilst exclusions apply for taps provided for certain specialist applications, the base load water consumption of a building relating to its sanitary operations is comprehensively covered. The equipment specified clearly exceeds standard practice and acts directly to reduce water use, without relying on tangential impacts such as behavioural change. Certainty of effect is provided through direct reference to manufacturer's specification documents, and as the criteria relates only to substitution of one fitting for another, the wider design impact is minimal. The evidence requirements are also straightforward; these being a copy of relevant design information at design stage and visual inspection or copies of purchase orders at post construction stage. Furthermore, the fact that the equipment in question remains substantially visible in the completed building and is used by occupants on a daily basis providing excellent ongoing opportunity for ensuring their correct and continued operation. On this basis, and notwithstanding the apparent shortcomings of many of the remaining issues in the water section, it is perhaps unsurprising that the two cases study buildings for which data was available substantially exceeded relevant benchmarks in relation to water consumption.

The strengths of the Wat 1 criteria described above contrast starkly with the equivalent issue within the Energy section i.e. Ene 1 (reduction of CO_2 emissions). The criteria for this issue lack comprehensiveness, are complex and do not contain effective evidence requirements. Credits are awarded based upon the CO_2 index taken from the building's EPC certificate, derived in turn from the SAP calculation. In this case, the effect relates only to the parameters considered by SAP, relating primarily to building services and fabric, thereby failing to achieve a comprehensive scope including unregulated energy use or occupancy levels or patterns. Even within this much-reduced scope, the effect is considered uncertain as SBEM is designed as a compliance rather than a modelling tool and is known to be a poor predictor of actual performance. Opportunities for improving the CO_2 index exist across a swathe of design factors ranging from equipment to building layout, so the wider design impact associated with scoring these credits may be considered proportionate. The evidence requirement is also notionally straightforward as it "piggy-backs" upon the existing Building Control regime. Research suggests however that adequate interrogation does not always occur within this existing system and no framework is provided to assist BREEAM assessors with further effective validation of the calculations. Finally, reliance on such a range of factors, many of which are not readily visible in the completed building, is likely to make monitoring by building managers highly challenging, and intuitive monitoring by occupants largely impossible.

Energy use within a university building is more complex and arguably far more difficult to predict and control than water use. Nevertheless, based on the comparison presented above and the wider findings of this study, it is possible to suggest some improvements to the criteria for issue Ene 1. Firstly the lack of comprehensiveness of the content could be addressed simply by renaming the "Energy" section of BREEAM to make it clear that it only assesses energy relating to building services. Omitting unregulated energy from the assessment removes a major component of the inaccuracy associated with using SAP as a predictor of overall energy use. From a logical point of view, omitting unregulated energy use from the assessment is readily justifiable, as it is the sustainability of the building that is being assessed, rather than the behaviour of its occupants. Variation in regulated energy use resulting from occupancy patterns could similarly be justifiably disregarded for the same reason. Within this reduced scope, the major residual factor driving inaccuracy in energy modelling is a failure to construct and commission buildings in accordance with their design. Addressing this known problem would arguably produce a far more robust sustainability benefit than the existing strategy of awarding criteria based on modelling output alone. Therefore. criteria might instead be configured to ensure that key elements of the modelling input, such as building geometry and heating unit efficiencies were identified and verified by the assessor. As has been noted for issue Wat 1, physical observation of installed equipment can be a robust means of evidencing correct implementation of design. Such evidence has the further crucial benefit of being easily verified post-occupancy by the building or facilities managers.

The Health and Wellbeing section of BREEAM has no equivalent wide ranging, whole building assessment issue to compare with Wat 1 and Ene 1; issues instead deal individually with the different elements of internal environmental quality. Nevertheless, these issues collectively share similar failings to those noted in relation to Ene 1. Comprehensiveness of effect is most notably lacking, there being no evidence that the criteria combined to produce any improvement in health and wellbeing in the study building occupants. As for Ene 1, this shortfall could perhaps most simply be improved by renaming the section to align it with the criteria, which relate more accurately to internal environmental quality than health and wellbeing. Similar problems were also observed in relation to reliance on complex third party guidance and modelling to produce effects, for example as required for issue Hea 10 (Thermal comfort). As for the energy modelling used for Ene 1, the Hea 10 criteria dictate the application of the method and award credits according to the result, without providing a framework to assist the assessor in verifying the process. Where reliance on modelling is unavoidable, a framework could introduced similar to that proposed for Ene 1. This would allow the critical assumptions embedded in the calculations to be identified and checked as physical entities. Not only would this provide a means for assessors to effectively evidence the criteria, it would also generate a set of defined building parameters which could be usefully passed on to facilities managers.

The criteria used for issue Wat 1 demonstrates that BSAS criteria can be configured with the appropriate content that does not disproportionately impact building function. Such criteria are not only straightforward to evidence, but can also be identified and monitored by facilities management teams. Meanwhile, criteria such as those used for Ene 1 align poorly with both the aims of the BSAS and the wider aims of building designers. Such criteria may additionally be difficult to evidence and offer no assistance in terms of ongoing monitoring by those managing the building in occupation. It is acknowledged that the disparate measurement metrics assessed by BSAS will require a range of approaches. It appears however that significant compromises have been made in terms of robustness in the studied scheme, in order to cover pertinent areas of sustainability. Avoiding the range of specific pitfalls for criteria identified in section 5.4 therefore represents only one component of the recommendations that emerge from this study. Further to the need for improved criteria through which to assess and improve buildings, there is perhaps an equally pressing need to balance the scope of assessment schemes with their efficacy. A scheme may therefore need to be configured to assess “energy used for building services” and “internal environmental quality”, rather than “energy” and “health and wellbeing”. Aspects of building sustainability that are problematic to measure may have to be excluded, or different approaches developed. Alternatively, the resources devoted to assessing and evidencing schemes may have to be increased, potentially incorporating post occupancy evaluation, where more straightforward means do not exist.

CHAPTER 6 – CONCLUSION

This chapter begins with a brief introduction summarising the research context. This is followed by a summary of the research objectives and corresponding findings. Recommendations are suggested for improving the configuration of BSAS criteria. The limitations of the study and recommendations for further research are also discussed. Finally, the contribution to knowledge is summarised.

6.1 Knowledge gap and research findings

BSAS have achieved significant and increasing uptake, since their inception 20 years ago. Early schemes have been updated and adapted to suit changing expectations and new technologies. Schemes have also proliferated internationally, both through the start-up of new national schemes and adaptation of leading schemes such as BREEAM and LEED to different regions. As a result, around 65 BSAS are now in operation globally. However, this widespread general acceptance of BSAS has occurred against a background of considerable academic criticism and fundamental theoretical limitations have been identified relating to the general approach employed. The use of indicators as a basis for assessment introduces considerable subjectivity into scheme content, whilst the paucity of minimum requirements provides excessive freedom for designers to target certain areas of performance over others. Reliance on design standards to generate a rating is considered to be unreliable in general and can additionally create an excessive administrative burden for project teams. Overarching these concerns is the commercial context, which may motivate project teams to select credits for reasons of design or production expediency, rather than because they will provide the most benefit in the completed building. In empirical terms, such limited research as has been carried out so far has failed to demonstrate that BSAS reliably produces measurable improvement in operational buildings. Further work in this field is hampered by a number of factors. Schemes do not generally incorporate a post occupancy evaluation and quantitative measurement of their impacts is restricted by a requirement for wide-ranging, often commercially sensitive, performance data. Furthermore, benchmarking is complicated by the fact that ratings are typically both highly specific to the particular building type and awarded independently of key operational factors such as opening hours and intensity of use. For these reasons, a lack of knowledge exists in relation to the effect that specifying a BSAS rating for a building has on its sustainability in use.

Furthermore, not only is it unclear to what extent sustainability is increased in certificated buildings, but the success of otherwise of the critical mechanisms employed pursuant to this aim have also remained largely unexamined. This study has addressed this knowledge gap using robust empirical data, gathered using a case study approach.

The study findings confirm that subjective selection of indicators can result in less than comprehensive criteria for the section within which they are grouped. For example, the energy section of BREEAM substantially fails to address unregulated energy use. Certain indicators were also observed to rely on unsubstantiated models of cause and effect. For example, it is assumed that improving particular elements of internal environmental quality will increase occupant “health and wellbeing”. Others relied on uncertain impacts relating to behavioural change. For example, the reduction of water use through the provision of sub-metering. Still further indicators contained criteria that were satisfied by inclusion of standard building features, such as blinds on office windows. Conversely, others were achieved through non-inclusion of relatively unusual features such as automatic irrigation systems. The gaming of the checklist approach was also evident in the case studies, with selection of credits by project teams observed to be highly skewed. One building, for example, achieved just 15% of available credit within the Energy section and 88% in relation to Water. In some instances criteria were additionally clearly avoided, despite being closely aligned with the building design. This occurred particularly where they were dependent upon rigid geometrical requirements. For example, one case study building failed to target credits relating to “potential for natural ventilation” or “view out”, despite having been designed as a substantially naturally ventilated building, with excellent views out. Conversely, the criteria which reward the addition of small scale, inexpensive, “bolt-on” items of equipment were observed to be incorporated regardless of need. For example, credits were achieved in all buildings for incorporating zoned light switching, despite this requirement being absent from design documentation in every case.

Further difficulties were observed in relation to effective evidencing of criteria requirements. The role of the assessor in verification was, in practice, seen to be rather limited. At the design stage, criteria were routinely evidenced through side letters sent from designers to assessor, confirming that particular required features had or would be included. This indicates either assessor’s lacked the technical knowledge to interpret relevant design information, or that requirements had not in fact been included in the original design documentation. A similar situation also appeared to exist at construction stage. Of the two buildings achieving “post-construction” certification, one received a single visit from the assessor, whilst the other was not inspected at all. "Post construction" evidence was largely affected through the use of "as-built" drawings, or side letters received from contractors. Where inspection did take place, identified shortfalls such as failed acoustic tests were similarly closed out following assurances from the project team that items would be rectified. It was further noted that in some cases important criteria such as energy modelling metrics were not, in any case, realistically verifiable in the completed building. For certain criteria, post-construction evidence requirements were entirely absent, for example, in relation to the energy efficient design of lifts. In addition to the potential impact on verification, this inclusion of criteria with no realistic post-construction verification can also be seen to seriously limit the ability of users or facilities management teams to manage the systems following occupation. Elsewhere, even where verification was theoretically straightforward, criteria was often seen to be focussed on the installation of features or equipment, without properly addressing commissioning. For example, although credits were achieved for all four buildings rewarding them for installing a pulsed water meter, only two were found to have working water meters post occupancy, neither of which delivered pulsed outputs. Similarly all case study buildings scored credits for installation of electrical sub-meters, of which none whatsoever were found to be operable in practice.

Three characteristics were therefore identified as being key to determining the success or otherwise of criteria in producing an effect in a complete and occupied building. Firstly, the c*ontent* of criteria is critical, in two respects. At a detailed level, criteria content must align closely with the relevant aspects of sustainability that are purportedly being addressed. Reliance upon unproven or uncertain models of cause and effect, particularly relating to creating behavioural change, are likely to limit impact. Similarly, criteria that reward either standard building practice or the omission of unusual features are unlikely to generate substantial sustainability benefits. In addition, the overall comprehensiveness of content is crucial to generating impact. Excessive freedom to target credits regardless of category produces potential for certain aspects of sustainability to be largely neglected. At the same time, many credits are rendered ineffective because they relate to features that are not present within the building. Thus, although the full range of criteria for a particular BREEAM section may present as relatively comprehensive, this is not necessarily reflected in actual assessments, for which non-applicable and un-attempted credits will necessarily have no impact. Secondly, the *appeal* of credits to project teams can be seen to be fundamentally important, particularly where a high degree of discretion is allowed in criteria selection. Appeal may be particularly reduced where criteria include rigid geometric requirements or adversely impact the functional use of the building. High financial cost associated with adding or upgrading features will also clearly reduce appeal, whilst the opposite is likely to be true of criteria associated with omissions of, or reductions in, facilities. Criteria that is not attempted because they are unappealing will, by definition, have no impact on the completed building. Conversely, criteria that are appealing because they require little or no change to the existing design intent will also fail to produce substantive benefits. Thirdly, the *evidence* requirements of criteria have great potential to support or limit their effect in a completed building. Without evidence requirements that are correctly configured to validate the criteria and fully reflected in design documentation, any resulting impact becomes highly uncertain. Furthermore, effective evidencing is dependent upon the resources and technical capabilities of assessors. Where assessors are reliant upon assurances given in side letters from designers or contractors then it is questionable as to whether the intended results will be achieved. Similarly, unless site visits are carried out by assessors, a potentially valuable aspect of verification is lost. A particular further frustration related to evidencing is that the effects of many criteria are dependent upon good commissioning; thus an item of equipment may be visually installed at the point of certification, but may not be operational. In some cases such commissioning problems may be obvious at handover and be naturally rectified by building users or facilities management teams. In other instances problems will be less easily identified or corrected, which may result in the intended benefits being lost.

Content, appeal and evidence of criteria as discussed above do not exist in isolation. Evidence requirements are dictated by content and may have a substantive effect on the appeal of criteria, as will content itself. Successful configuration of criteria in a checklist-based scheme can therefore be viewed as a balancing act; content must be comprehensive and appropriate but must additionally be appealing to project teams and straightforwardly evidenced by assessors. In attempting this task, two further important characteristics emerged in respect to criteria, those of scope and complexity. A high degree of variation was observed in terms of scope. Many criteria are applied at a whole building level, particularly those relating to internal environmental quality, whilst others relate closely to specific systems or reward the addition of stand-alone “bolt-on” items of equipment. Complexity of criteria was also seen to be highly variable. Where requirements relate to specific items of equipment then criteria may be relatively straightforward. Similarly, very simple geometrical requirements can be used to demonstrate compliance. Conversely, other criteria called for adherence to additional specialist design standards or modelling requirements, which may be both extensive and technical. Broadly speaking, whole-building criteria can be seen to provide a greater contribution to comprehensiveness of content than stand-alone items, but these also tend to increase evidence requirements. Complexity also raises evidence requirements, but without improving content. Meanwhile, appeal was observed to be largely independent of scope and complexity in practice, indicating that these may be subservient to previously identified factors such as cost, building function and geometry. Overall, simple, whole building criteria were observed to have the greatest potential to produce comprehensive, reliably evidenced scheme content.

6.2 Recommendations

The use of BSAS is expanding. Schemes continue to proliferate internationally, whilst established methods such as BREEAM and LEED are increasing their global reach. The format has already demonstrated enduring appeal and BSAS remains the best available means of assessing the overall sustainability of a building. In spite of this, they lack either a robust theoretical basis or an inherent feedback mechanism and the findings of this study indicate that they are therefore fundamentally reliant upon well-designed criteria to translate their aims into effect. A detailed bottom-up examination of three key sections of the BREEAM 2008 scheme has found that the criteria within were highly variable in their configuration, contained various theoretical shortfalls and were, in certain cases, evidently ineffective.

As discussed in detail in Chapter 5, the efficacy of criteria are dependent upon their collective content, their appeal to scheme users and their evidence requirements. Effective criteria must have content that addresses each category in a comprehensive manner, is consistently and closely aligned with the assessment category and is applicable to a typical building. These criteria must either appeal to construction project teams by being aligned with the wider purpose of the building or else the scheme must incorporate mandatory minimum thresholds. They must also rely on evidence that is robust, appropriate, properly incorporated into design information and readily verifiable both by scheme assessors and facilities managers. Conversely, criteria that has content which rewards standard industry practice, or which relies on uncertain, unproven or disproven causal relationships can produce little or no differentiation in terms of sustainability. Those that are unappealing to construction project teams due to disproportionate functional, geometrical or cost impact are similarly rendered ineffective through non-selection. Meanwhile, the effect of criteria relying on evidence that the scheme assessor is not technically qualified to comment upon, or which is otherwise founded on assurances from construction project team members, may be reduced through non-compliance. As previously noted, successful criteria must therefore balance comprehensiveness of content with their appeal to project teams and be readily evidenced. The best criteria will also have broad scope and seek to limit complexity. These requirements have additionally been illustrated through direct comparison of BREEAM issues Wat 1 and Ene 1. The criteria for Wat 1 demonstrates appropriate content, high appeal and robust evidencing in the case study buildings. Meanwhile, the content of Ene 1 was seen to be based upon a limited, poorly performing methodology, had limited appeal and was effectively impossible to robustly evidence. Wat 1 is additionally based on simple evidence requirements, whilst those for Ene 1 are highly complex.

The recommendations for criteria configuration set out above represent a draft framework for examination of BSAS criteria more generally. It is acknowledged that these are based on an examination of the criteria making up just 23 issues within the BREEAM 2006 and 2008 schemes. As such, although the observations made are readily generalizable, it is acknowledged that they have been formulated based upon examination of a single, superseded scheme version. Potential therefore exists to usefully expand these findings through wider examination including other Building Sustainability Assessment Schemes. Such expansion could be readily affected using a range of case studies, ideally across a number of countries. Reflection upon this study suggests however that various refinements to the research approach would be desirable. In terms of the selection of case studies, a high degree of cooperation and openness from building owners, managers and facilities management teams is noted as being highly beneficial. It would therefore be beneficial to agree a level of assistance not only to the building owner, but also to the building manager and facilities manager, prior to the final selection of case studies. This would mitigate the isolated shortfalls in information experienced in this regard, by this study. Similarly, certain high level technical checks should ideally be carried out, to establish how the required data would be collected. Failure, for example, to pre-verify the existence of functioning water meters in the case study buildings resulted in a substantial shortfall in data. A further final and unexpected practical difficulty experienced with this study, was that of obtaining the BREEAM reports. These were not accessible through the BRE and had not been held on file by the building owner. In practice these reports were eventually obtained through individual assessors, which in one case required tracking a person to a new place of work. Without the report, no useful analysis of the building would have been possible. Obtaining these or equivalent documents prior to final case study selection can therefore also be seen to be essential. In terms of methodology, expanding the scope of criteria examined is desirable but can be expected to significantly increase resource demands and introduce requirements for additional research methods. A longitudinal study would also increase resource requirement, but would offer scope to cover a greater range of criteria, perhaps including direct observation of the design and construction process. This approach would also yield results relevant to more recent scheme versions. Finally it is noted that whilst the BUS survey employed to analyse perceptions of internal environmental quality in this study was a useful tool, it is highly targeted towards an office environment. As such, the relatively small number of permanent staff within academic buildings resulted in limited sample sizes in some buildings, and correspondingly limited scope for statistical analysis. Similar studies for other buildings where office staff do not make up the majority would also need to consider this difficulty, and ensure that a suitable alternative method was available.

6.3 Contribution to knowledge

If BSAS are to be effective in their now established role as policy tools then they must produce consistent and appropriate effects, closely aligned with their aims, and reflective of the certification awarded. Such efficacy is currently in doubt and the study findings build upon wide ranging academic commentary outlining the theoretical shortfalls of BSAS. With this study, these proposed limitations have been observed and documented in practice for the first time, both validating and expanding existing understanding. More importantly, examination of contemporaneous validation reports combined with post occupancy evaluation has revealed the hitherto unrecognised importance of criteria in exacerbating or reducing these limitations. The BSAS format has, indeed, been found to be inherently weak as an assessment method, relying as it does on design stage consideration of indicators. It is arguably these very weaknesses that have allowed it to establish itself as the only practical and accepted method of differentiating buildings in terms of sustainability. Indicators allow assessment to be at least nominally comprehensive, whilst the use of design stage assessment allows certification to be awarded at completion of the building contract. Both of these factors are fundamentally necessary for assessment to be attractive as a means of standard setting by policy makers.

The findings of this study provide ample explanation for inconsistent performance suggested by existing empirical studies. Certain observed criteria were poorly contrived in terms of their content and many had clearly not been robustly evidenced. Still more were not attempted because they were inherently unattractive to project teams. In addition to this there were other criteria for which the opposite was true, and for which a clear chain of cause and effect was evident, linking the application of the criteria to material sustainability improvements in the occupied building. The study findings suggest that scheme operators wishing to optimise their performance should review the configuration of their criteria and consider whether the balance between content, appeal and evidence is, in each case, correct. This may require alternative indicators being sought, or even a general downgrading of the range of sustainability aspects covered by assessment. The validation regime for schemes may also require some reconfiguration, to ensure that evidencing is improved. In any case, such a review should be urgently demanded by the policy makers currently reliant on BSAS to drive improvements in building sustainability. Finally more research is undoubtedly required, in order that the initial findings of this study can be examined in context of a range of schemes.

Reference List

Action Energy (2003) *Energy Consumption Guide 19 – Energy Use in Offices*. Available at: www.cibse.org/.../ECG19-Energy-Use-in-Offices-(formerly-ECON19).pdf.aspx (Accessed 9th June 2017).

Ali-Toudert, F. (2008) From green buildings to sustainable urban settlements: a new assessment method, *PLEA 2008 - 25th Conference on Passive and Low energy Architecture.* Dublin, 22nd-24th October. Dublin: PLEA.

Alwaer, H., & Kirk, D. (2012) Building sustainability assessment methods, *Engineering sustainability*, 165(4) pp. 241-253.

Alwaer, H. and Clements-Croome, D. (2010) Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings, *Building and Environment*, 45 (2010), pp.799-807.

Alwaer, H., Sibley, M. and Lewis, J. (2007) Different Stakeholder Perceptions of Sustainability Assessment, *Architectural Science Review*, 51 (1), pp.48-59.

Ammar, M. (2012) Evaluation of the Green Egyptian Pyramid. *Alexandria Engineering Journal,* 51(4), pp.293-304.

Arup (2017) *Building Use Studies Methodology*. Available at: http://www.busmethodology.org/history/ (Accessed 12 May 2017).

Association for the Advancement of Sustainability in Higher Education (AASHE) (2017) *STARS*. Available at: https://stars.aashe.org/ (Accessed 26 May 2017).

Baird, G. (2010). *Sustainable Buildings in Practice What the Users Think.* London: Routledge.

Barlow, S. (2011) *Guide to BREEAM*. London: RIBA.

BizEE (2016) *Degree Days.net - Custom Degree Day Data.* Available at: http://www.degreedays.net/ (Accessed 14 Jan 2017).

Beaufoy, H. (1993) “The Green Office in Britain: A Critical Analysis”, *Journal of Design History*, 6 (3), pp.199-207.

Bell, S. and Morse, S. (2003) *Measuring Sustainability - Learning by Doing.* Toronto: Earthscan.

Becker, J. (2004) "Making sustainable development evaluations work", *Sustainable Development,* 12 (4), pp.200-211.

Beradi, U. (2011) "Sustainability assessment in the construction sector: Rating systems and rated buildings", *Sustainable Development*, 20, pp411-424.

Bitard, P. (2009) *Scope for international cooperation on green building standards.* Available at: http://grips-public.mediactive.fr/knowledge_base/dl/858/orig_doc_file/ (Accessed 9 June 2017).

Birkeland, J. (2008) *Positive Development.* London: Earthscan.

Boonstra, C., & Pettersen, T. (2003) *Tools for environmental assessment of existing buildings*. Available at: www.bvsde.paho.org/bvsaia/fulltext/tools.pdf (Accessed 9 July 2017).

BOMA Canada (2016) *About BOMA Best*. Available at: http://bomacanada.ca/bomabest/aboutbomabest/ (Accessed 26 May 2017).

Bordass, B., Leaman, A., Ruyssevelt, P. (2001a) "Assessing building performance in use 3: energy performance of the Probe buildings.", *Building research and Information*, 29(2), pp 114-128.

Bordass, B., Leaman, A., Ruyssevelt, P. (2001b) "Assessing building performance in use 5: conclusions and implications", *Building research and Information*, 29(2), pp 144-157.

Brandon, P. and Lombardi, P. (2011) *Evaluating Sustainable Development in the Built Environment.* Oxford: Wiley-Blackwell.

British Standards Institute (BSI). (2010). *BS-EN 15643-1:2010 Sustainability of construction works - sustainability assessment of buildings. Part 1: general framework.* London: BSI.

Building Research Establishment (BRE) and Cyril Sweett. (2005) *Putting a price on sustainability.* Watford: Watford : BRE Trust.

Building Research Establishment (BRE) (2006) Bespoke *BREEAM Assessment*. Watford:BRE.

Building Research Establishment (BRE) (2008a) *BREEAM Scheme Document SD 5051 BREEAM Education 2008*. Watford:BRE.

Building Research Establishment (BRE) (2008b) *BREEAM Scheme Document SD 5067 BREEAM Bespoke 2008*. Watford:BRE.

Building Research Establishment (BRE) (2011) *BREEAM New Construction Technical Manual SD 5073*. Watford:BRE.

Building Research Establishment (BRE) (2012) Email to Colin Hobart. 28 March

Building Research Establishment (BRE) (2013) *BREEAM New Construction*. Available at: http://www.breeam.org/ (Accessed 20 May 2017).

Building Research Establishment (BRE) Global. (2016). *BREEAM International New Construction 2016*. Available at: http://www.breeam.com/BREEAMInt2016SchemeDocument/ (Accessed 20 May 2017).

Building Research Establishment (BRE). (2017a). *BREEAM In-use International*. Available at: http://www.breeam.com/in-use (Accessed 20 May 2017).

Building Research Establishment (BRE) (2017b) *Green Book Live*. Available at: http://www.greenbooklive.com/ (Accessed 12 May 2017).

Building Research Establishment (BRE) (2017c). *BREEAM New Construction*. Available at: http://www.breeam.com/new-construction (Accessed 26 May 2017).

Building Research Establishment (BRE) (2017d) *Refurbishment and fit out.* Available at: http://www.breeam.com/uk-refurbishment-and-fit-out-standards (Accessed 26 May 2017).

Canada Green Building Council (2016a) *LEED: The international mark of excellence.* Available at: http://www.cagbc.org/CAGBC/LEED/About_LEED/CAGBC/Programs/LEED/_LEED.aspx?hkey=01b3d086-d0a4-42cf-9e61-7830d801c019 (Accessed 26 May 2017).

Canada Green Building Council (2016b) *LEED Canada for Homes*. Available at: https://www.cagbc.org/@/CAGBC/LEED/GreenHomes/CAGBC/Programs/LEED/GreenHomes/Green_Homes.aspx?hkey=c4fbaa4b-53e3-4694-8c42-67f570f84869 (Accessed 26 May 2017).

Cato, S. (2009). *Green Economics*. London: Earthscan

Chartered Institution of Building Services Engineers (CIBSE) (2002) *CIBSE Code for Lighting 2002*. CIBSE: London

Chartered Institution of Building Services Engineers (CIBSE) (2006). *CIBSE Code for Lighting 2006*. CIBSE: London

Chartered Institution of Building Services Engineers (CIBSE) (2007). *CIBSE Lighting Guide 7*. CIBSE:London

Chartered Institution of Building Services Engineers (CIBSE) (2008). *TM46: Energy Benchmarks*. CIBSE: London

Chartered Institution of Building Services Engineers (CIBSE) (2009). TM48: *Use of Climate Change Data in Building Simulation*. CIBSE: London

Chartered Institution of Building Services Engineers (CIBSE) (2012). *GVF CIBSE Guide F: Energy Efficiency in Buildings*. CIBSE:London

Chartered Institution of Building Services Engineers (CIBSE) (2015a). *GVA/15 CIBSE Guide A: Environmental Design.* CIBSE:London

Chartered Institution of Building Services Engineers (CIBSE) (2015b). *AM11 Building Performance Modelling 2015*. CIBSE:London

Chartered Institution of Building Services Engineers (CIBSE) (2016). *GVB2/16 CIBSE Guide B2: Ventilation and Ductwork 2016.* CIBSE: London

Chartered Institution of Building Services Engineers (CIBSE) (2017b) *Probe – Post occupancy Studies.* Available at: http://www.cibse.org/knowledge/building-services-case-studies/probe-post-occupancy-studies (Accessed 12 May 2017).

City of Melbourne. (2013). *CH2 Facts and Figures*. Available at: http://www.melbourne.vic.gov.au (Accessed 10 May 2015).

Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL) (2017) *CEEQUAL.* Available at: http://www.ceequal.com/ (Accessed 26 May 2017).

Construction Industry Research and Information Association (CIRIA) (2006) *Water key performance indicators and benchmarks for offices and hotels.* Available at: http://www.ciria.org/ProductExcerpts/C657.aspx (Accessed 19 May 2017).

Cole, R. (2005) Building environmental assessment methods: Redefining intentions and roles. *Building Research & Information*, 35(5), 455-467.

Construcción Sostenible BREEAM ES (2017) *BREEAM ES.* Available at: http://www.breeam.es/ (Accessed 26 May 2017)

Crawley, D. and Aho, I. (1999) Building environmental assessment methods: Applications and development trends. *Building Research & Information*, 24(4-5), 300-308.

Creswell, J. (2009) *Research Design – Qualitative, Quantitative and Mixed Method Approaches.* USA: Sage

Department for Communities and Local Government (2008) *The Government's methodology for the production of Operational Ratings, Display Energy Certificates and Advisory Reports*. Available at: https://www.gov.uk/government/publications/government-methodology-for-producting-operational-ratings-display-energy-certificates-and-advisory-reports (Accessed 12 May 2017).

Department for Communities and Local Government (2015). *2010 to 2015 government policy: energy efficiency in buildings.* Available at: https://www.gov.uk/government/publications/2010-to-2015-government-policy-energy-efficiency-in-buildings/2010-to-2015-government-policy-energy-efficiency-in-buildings#appendix-6-energy-performance-of-buildings (Accessed 19 May 2017).

Department for Communities and Local Government (2017) *The Non-Domestic Energy Performance Register*. Available at: https://www.ndepcregister.com/ (Accessed 19 May 2017).

Deutsches Privates Institut für Nachhaltige Immobilienwirtschaft (DIFNI) (2017) *BREEAM.* Available at: http://www.difni.de/leistungen/breeam.html (Accessed 26 May 2017).

Ding, G. (2008). The role of environmental assessment tools. *Journal of Environmental Management*, 86, 451-464.

Dutch Green Building Council (2017) *Over BREEAM*. Available at: https://www.breeam.nl/over-breeam (Accessed 26 May 2017).

Edwards, B. (2003). *Green buildings pay*. London: London : Spon Press.

Education Funding Agency (EFA) (2003) *Building Bulletin 93: Acoustic Design of Schools: A Design Guide.* Available at:

https://www.gov.uk/government/publications/bb93-acoustic-design-of-schools-performance-standards#history (Accessed 19 May 2017).

Elkington, J. (1997) *Cannibals with forks – The triple bottom line of 21st century business.* Oxford: Capstone.

Energy Act 2011. Available at http://www.legislation.gov.uk/ukpga/2011/16/contents/enacted (Accessed: 12 May 2017).

Field, A. (2013) *Discovering Statistics Using IBM SPSS Statistics*. Sage: London

Freeman, C. and Louca, F. (2001). *As Time Goes By : From the Industrial Revolutions to the Information Revolution.* Oxford, GBR: Oxford University Press, UK

Gibberd, J. (2002) The Sustainable Building Assessment Tool: Assessing how buildings can support sustainability in developing countries. *The Built Environment Professions Convention.* Johannesburg, 1-3 May. Available at: https://pdfs.semanticscholar.org/ba1d/c72071e7a4b77884b033a07e892cef55fb02.pdf (Accessed 16 June 2017).

Gomes, V., Gomes da Silva, M., Lamberts, R., Takaoka, M. and Sangoi de Oliveira, M. (2008). Sustainable Building in Brazil. *World Sustainable Building Conference (SB08).* Melbourne, 21-25 September. Available at: www.iisbe.org/sbconferences/Brazil_SB_Report_SB08.pdf (Accessed 16 June 2017).

Government of Hong Kong Special Administrative Region Building Department (2004) *Comprehensive Environmental Performance Assessment Scheme for Buildings*. Available at: http://www.bd.gov.hk/english/documents/index_CEPAS.html (Accessed 26 May 2017).

Gowri, K. (2004) Green Building Rating Systems: an overview. *ASHRAE Journal.* 46 11 p56

Gray, D. (2014) *Doing Research in the Real World*. Sage: London

Green Building Council of Australia (GBCA) (2015a) *Green Star*. Available at: http://new.gbca.org.au/green-star/ (Accessed 20 May 2017).

Green Building Council of Australia (GBCA) (2015b) *Green Star Performance*. Available at: http://new.gbca.org.au/green-star/rating-system/performance/ (Accessed 20 May 2017).

Green Building Council Italia (2017) *LEED Italia.* Available at: http://www.gbcitalia.org/page/show/leed-italia--3?locale=it (Accessed 26 May 2017).

Green Building Initiative (2014) *Green Globes Certification*. Available at: https://www.thegbi.org/green-globes-certification/ (Accessed 20 May 2017).

Guthrie, G. (2010) *Basic Research Methods: An Entry to Social Science Research*. Sage: India.

Guy, S. and Moore, S.A. eds. (2004) *Sustainable Architectures: Cultures and Natures in Europe and North America.* Oxford:Spon Press.

Haapio, A. and Viitaniemi, P. (2008) A critical review of building environmental assessment tools. *Environmental Impact Assessment Review*, (28), pp.469-482.

Haddock-Fraser, J. and Tourelle, M. (2010) Corporate Motivations for Environmental Sustainable Development: Exploring the Role of Consumers in Stakeholder Engagement. *Business Strategy and the Environment,* 19, pp.527-542.

Hakkinen, T. (2012) *Sustainability and performance assessment and benchmarking of buildings.* Espoo: VVT Technical Research Centre of Finland.

Haroglu, H. (2013). The impact of Breeam on the design of buildings. *Engineering Sustainability,* (166) pp.11-19.

Hawkes, J. (2001). *The Fourth Pillar of Sustainability: Culture's essential role in public planning.* Common Ground Publishing: Melbourne

Hayes, N. (2012). The business case for sustainable buildings - Green premium. [Powerpoint] E.C.Harris. November.

Health and Safety Executive (HSE) (2010) *Legionnaires' disease - The control of legionella bacteria in water systems. Approved code of practice and guidance 2000*. HSE: London.

Higher Education Funding Council for England (HEFCE). (1996). *Energy management study in the higher education sector Management Review Guide*. HEFCE: Bristol.

Higher Education Statistics for the UK (HESA) (2013) *Higher Education Statistics for the UK 2015/2016.* Available at: https://www.hesa.ac.uk/data-and-analysis/publications/higher-education-2015-16 (Accessed 20 May 2016).

HMSO (1995) *Approved Document L – Conservation of Fuel and Power, 1995 Edition*. London: HMSO.

Howard, N. (2005). Building environmental assessment methods: in practice. *World Sustainable Building Conference, Tokyo (SB05)*, Vol. 27, p. 29.

Intergovernmental Panel on Climate Change (IPCC) (2007) *IPCC Fourth Assessment Report: Climate Change 2007*. Cambridge: Cambridge University Press.

International Energy Agency (IEA) (2005) IEA Annex 31 - Energy related environmental impact of buildings. Available at: http://www.iisbe.org/annex31/index.html (Accessed 16 June 2017).

Indian Green Building Council (2015a) *IGBC Rating Systems*. Available at: https://igbc.in/igbc/redirectHtml.htm?redVal=showratingSysnosign (Accessed 26 May 2017).

Indian Green Building Council (2015b) *LEED*. Available at: https://igbc.in/igbc/redirectHtml.htm?redVal=showLeednosign (Accessed 26 May 2017).

Institute for Building Environment and Energy Conservation (IBEC) (2017) *CASBEE.* Available at: http://www.ibec.or.jp/CASBEE/english/ (Accessed 26 May 2017).

International Initiative for a Sustainable Built Environment (iiSBE) (2009) *SBTool.* Available at: http://www.iisbe.org/sbmethod (Accessed 20 May 2017).

International Standards Organization (ISO) (2006) *ISO/TS 21931-1:2006 Sustainability in building construction - Framework for methods of assessment for environmental performance of construction works - Part 1: Buildings.* Geneva: ISO.

International Standards Organization ISO (2011) *ISO 21929-1:2011. Sustainability in building construction - sustainability indicators - Part 1*. Geneva: ISO.

Jaeger, W. (2005) *Environmental Economics for Tree Huggers and Other Skeptics*. Washington DC: Island Press:

Johnston, D. Farmer, M. Brooke-Peat, and Miles-Shenton, D. (2016) Bridging the domestic building fabric performance gap. *Building Research & Information,* 44(2) pp.147-159.

Jones, D. (2012) *Who cares wins: why good business is better business.* Harlow: Pearson Educational.

Koepke, K., Portalatin, M., Roskoski, M., Shouse, T. (2010). *Green Building Rating Systems.* Texas: IFMA Foundation.

Koger, S. and Scott, B. (2007) Psychology and Environmental Sustainability: A Call for Integration. *Teaching of Psychology,* 34(1) pp.10-18.

Leaman, A. and Bordass, B. (1999) Productivity in buildings: the `killer' variables. *Building Research and Information,* 27(1) pp.4–19.

Lee, W., Chau, F., Yik, J. and Burnett, M., (2002) On the study of the credit-weighting scale in a building environmental assessment scheme. *Building and Environment,* 37 pp.1385-1396.

Lee, W. and Burnett, J. (2008) Benchmarking energy use assessment of HK-BEAM, BREEAM and LEED. *Building and Environment.* 43 pp.1882-1891.

Lee, W. (2012) Benchmarking energy use of building environmental assessment schemes. *Energy and Buildings*, 45 pp.326-334.

Lidera (2017) Voluntary system for assessment of sustainable construction. Available at: http://www.lidera.info/ (Accessed 23 June 2017).

Lockwood, C., (2008). *The dollars and sense of green retrofits.* Available at: http://www.sustainablecitiesinstitute.org/topics/buildings-and-energy/green-building-101/the-dollars-and-sense-of-green-retrofits (Accessed 9 June 2017).

McElroy (2011) *Re-casting the triple bottom line: Introducing Context Based Sustainability Measurement and Reporting* [Powerpoint]. Available at: www.sustainableorganizations.org/Recasting-TBL.pdf (Accessed 16 June 2017).

MacMillan, S., Editor (2004) *Designing Better Buildings*. Oxford: Taylor and Francis.

Marks and Spencer (2017) *Plan A report 2017*. Available at: http://planareport.marksandspencer.com/ (Accessed: 2013, 13th May).

Menezes, A., Cripps, A., Bouchlaghem, D., Buswell, R. (2012) Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Applied Energy,* 97 pp.355–364.

Miller, N., Spivey, J., and Florance, A. (2008) Does green Pay Off? *Journal of Real Estate Portfolio Management,* 14(4) pp.385-399

Mockett, T. (2012). *Integrating Sustainability in Real Estate Investment.* Available at: www.bre.co.uk/filelibrary/events/40%20Percent%202012/Tim_Mockett.pdf (Accessed 10 May, 2013).

Monfared, I. and Sharples, S. (2011) Occupants' perceptions and expectations of a green office building: a longitudinal case study. *Architectural Science Review*, 54(4) pp.344-355.

Montross, C. and Fraser, M. (1998) Building design for a sustainable future. *1998 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA (US)*, 23-28 August.

National Building Specification (NBS) (2006) *Approved Document L2A – Conservation of Fuel and Power, 2006 Edition*. London: RIBA.

National Building Specification (NBS) (2010) *Approved Document L2A – Conservation of Fuel and Power, 2010 Edition*. London: RIBA.

National Building Specification (NBS) (2014) *Approved Document L2A – Conservation of Fuel and Power, 2013 Edition*. London: RIBA.

National Australian Built Environment Rating System (NABERS) (2017) *NABERS.* Available at: https://nabers.gov.au/public/webpages/home.aspx (Accessed 20 May 2017).

Naik, F.C., Zhao, H., Harrison, T.G. and Phin, N. (2012) Legionnaires' disease in England and Wales, 2011. *Health Protection Report/Respiratory Archives*.

Norwegian Green Building Council (2017) *BREEAM NOR*. Available at: http://ngbc.no/ (Accessed 26 May 2017).

Oehlkers, J. ed., Ebrary, I. (2008) *Emerald architecture case studies in green building.* New York: McGraw-Hill.

Office of Government Commerce (OGC). (2003) *Final Watermark Project Report*. Available at: https://www.coloradowaterwise.org/Resources/Documents/ICI_toolkit/docs/.../uk-final-report.pdf (Accessed 19 May 2017).

Parker, J. (2012) *The value of BREEAM*. London: BSRIA.

Partal, A. (2013) Impact Assessment: A Tool to Assist Cultural Sustainable Development. *People and the Planet 2013 Conference: Transforming the Future,* Melbourne, 2-4 July. Melbourne: RMIT

Pitts, A. (2004) *Planning and Design Strategies for Sustainability and Profit*. Oxford: Elsevier.

Portalatin, M., Koepke, K., Roskoski, M. and Shouse, T. (2010) *Green Building Rating Systems. Oxford:* Oxford University Press.

Pottinger, G., & Tanton, A. (2012). Flooding and commercial property investment - what is the risk? *European Real Estate Society 19th Annual Conference.* Edinburgh. 13-16 June.

Poveda, C. (2011) A Review of Sustainability Assessment and Sustainability/Environmental Rating Systems and Credit Weighting Tools. *Journal of Sustainable Development*, 4(6) pp.36-55.

Preiser, W. and Vischer, J. (2003) *Assessing Building Performance*. Oxford: Elsevier.

Robert, K. (2002) *The Natural Step Story – Seeding a Quiet Revolution.* Canada: New Society Publishers.

Robinson, J. (2004) Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, (48) pp.369-384.

Rose, T. and Manley, K. (2011) Motivation toward financial incentive goals on construction projects. *Journal of Business Research,* 64 pp.765–773.

Royal Institute of British Architects (RIBA) (2017) *Carbon Buzz*. Available at: http://www.carbonbuzz.org/ (Accessed 16 June 17)

Royal Institution of Chartered Surveyors (RICS) (2013) *RICS draft guidance note - sustainability and commercial property valuation.* Available: https://consultations.rics .org (Accessed 26 March 2013).

Royal Institution of Chartered Surveyors (RICS) (2015) *RICS Property Measurement 1st Edition May 2015.* RICS: London

Royal Institution of Chartered Surveyors (RICS) (2017) SKA Rating. Available at: http://www.rics.org/uk/knowledge/ska-rating-/ (Accessed 26 May 2017).

Sayce, S. (2010). *Is sustainability reflected in commercial property prices?* London: RICS.

Scofield, J. (2009) Do LEED-certified buildings save energy? Not really… *Energy and Buildings* 41 pp.1386–1390.

Sev, A. (2009) How can the construction industry contribute to sustainable development? A conceptual framework. *Sustainable Development,* 17(3) pp.161-173.

Schell, C. (1992) *The Value of the Case Study as a Research Strategy,* Manchester: Manchester Business School.

Sonneborn, L. (2007) *The Environmental Movement : Protecting Our Natural Resources*. New York: Chelsea House.

The Standards Institution of Israel (2017) *SI-5281 Sustainable Construction (Green Construction).* Available at: https://portal.sii.org.il/eng/qualityauth/certificationtypes/greenbuild/5281/ (Accessed 26 May 2017).

Stern, N. (2009). *The global deal: climate change and the creation of a new era of progress and prosperity.* New York: Public Affairs.

Sweden Green Building Council (2017) *BREEAM SE*. Available at: https://www.sgbc.se/var-verksamhet/breeam (Accessed 26 May 2017).

Thomas, G. (2011) *How to do your case study*. London: Sage

Turpin-Brooks, S. and Viccars, G. (2006) The development of robust methods of post occupancy evaluation. *Facilities*, 24(5) pp.177-196.

Turner, N. and Arif, M. (2012) BREEAM Excellent: Business Value Vs Employee Morale. *Journal of Physics,* Conference Series 364.

United Nations Environment Programme (UNEP) (2009). *Buildings and climate change - summary for decision makers*. Milan: UNEP.

United Nations Framework Convention on Climate Change (UNFCCC). (1998) *Kyoto Protocol to the United Nations Framework Convention on Climate Change* Available at: https://unfccc.int/resource/docs/convkp/kpeng.pdf (Accessed 9 June 2017).

United Nations World Commission on Environment and Development (1987) *Our Common Future (Brundtland Report).* Oxford: Oxford University Press.

United States Green Building Council (USGBC) (2012) *LEED projects list*. Available at: http://new.usgbc.org/projects (Accessed 12 October, 2012).

United States Green Building Council (USGBC) (2017a) *LEED v4.* Available at: http://www.usgbc.org/resources/leed-v4-user-guide (Accessed 20 May 2017).

United States Green Building Council (USGBC) (2017b) *LEED for homes international.* Available at: http://www.usgbc.org/articles/leed-homes-international-market-update-2016 (Accessed 20 May 2017).

Vanderbilt University (2013) *What is Sustainability?* Available at: http://www.vanderbilt.edu/sustainvu (Accessed 10 May 2013).

Vesma (2016) *Degree Day Data*. Available at: http://www.vesma.com/ddd/ (Accessed 14th Jan 2017)

Wheeler, S. (2004) *Planning for sustainability - creating liveable, equitable and ecological communities.* London: Routledge.

Yin, R. (2014) *Case Study Research: Design and Methods.* London:Sage.

Yudelson, J. (2009) *Green Building Trends: Europe*. Washington:Island.

Appendix A – BREEAM issues and associated themes (BRE, 2006; BRE, 2008)

BREEAM 2008 Reference	BREEAM 2006 Reference	BREEAM issue	Themes
MANAGEMENT			
Man 01	M1	Commissioning	Mechanical ventilation Artificial lighting Natural ventilation Thermal comfort Safe and effective fume cupboards Monitoring of energy use Construction stage site impacts (environmental and social) Energy efficiency of building services Water efficiency in-use Foundation design Building functionality Building aesthetics Traffic impact Community relations Incidence and fear of crime Promotion of sustainable construction Cost effective maintenance and operation Accessibility
Man 02	M4	Considerate Constructors	
Man 03	M5	Construction Site Impacts	
Man 04	M12	Building User Guide	
Man 05		Site Investigation	
Man 06	M8	Consultation	
Man 07		Shared Facilities	
Man 08		Security	
Man 09		Publication of building information	
Man 10	M16	Development as a learning resource	
Man 11		Ease of maintenance	
Man 12		Life cycle costing	
Man 14		Inclusivity	
	M24	Post construction testing - Acoustics	
HEALTH AND WELLBEING			
Hea 01	HW1	Daylighting	Daylighting View out Artificial lighting Natural ventilation External pollutants CO2 levels Mechanical ventilation and cooling Volatile organic compounds Thermal comfort Legionella Acoustics External amenity space Chilled drinking water Safe and effective fume cupboards
Hea 01	HW2	View out	
Hea 03	HW3	Glare control	
Hea 04	HW4	High frequency lighting	
Hea 05	HW5	Internal and external lighting levels	
Hea 06	HW6/7	Lighting zones and controls	
Hea 07	HW8	Potential for natural ventilation	
Hea 08	HW9	Indoor air quality	
	HW10	Indoor air quality (CO2)	
	HW11	Ventilation rates	
Hea 09		Volatile organic compounds	
Hea 10	HW14	Thermal comfort	
Hea 11	HW15	Thermal zoning	
Hea 12	HW16	Microbial contamination	
Hea 13	HW17	Acoustic performance	
Hea 15		Outdoor space	
Hea 16		Drinking water	
Hea 17		Specification of laboratory fume cupds	
Hea 18		Containment level 2 and 3 laboratories	
ENERGY			
Ene 01	E1	Reduction of CO2 emissions	CO_2 emissions (regulated energy) Renewable energy
Ene 02	E2	Sub metering of substantial energy uses	

Ene 03	E3	Sub metering of high energy load and tenancy areas	Monitoring of energy use Energy efficiency of building services Energy efficiency of building fabric Energy efficiency of domestic appliances Energy efficiency of IT equipment
Ene 04	E4	External lighting	
Ene 05	P11	Low or zero carbon technologies	
Ene 06		Building fabric performance and avoidance of air infiltration	
Ene 07		Cold storage	
Ene 08		Lifts	
Ene 09		Escalators and travelling walkways	
Ene 10		Free cooling	
Ene 11		Energy efficient fume cupboards	
Ene 12		Swimming pool ventilation and heat loss	
Ene 13		*Labelled lighting controls*	
Ene 14		BMS	
Ene 15		Provision of energy efficient equipment	
Ene 16		*CHP community energy*	
Ene 17		Residential areas: Energy consumption	
Ene 18		*Drying space*	
Ene 19		Energy efficient laboratories	
Ene 20		Energy efficient IT solutions	
TRANSPORT			
Tra 01	T1	Provision of public transport	Public transport provision and information Proximity to amenities Cyclist facilities Pedestrian and cyclist safety Car parking
	T2	Transport CO2	
Tra 02	T3/4	Proximity to amenities	
Tra 03	T5	Cyclist facilities	
Tra 04	T6	Pedestrian and cyclist safety	
Tra 05	T8	Travel plan	
Tra 06		Maximum car parking capacity	
Tra 07		Travel information point	
Tra 08	T12	Deliveries and manoeuvring	
WATER			
Wat 01	W1	Water consumption	Water efficiency in-use Monitoring of water use Water leak detection/mitigation Water re-use Water for irrigation Water for vehicle cleaning
Wat 02	W2	Water meter	
Wat 03	W3	Major leak detection	
Wat 04	W4	Sanitary supply cut off	
Wat 05	W5	Water recycling	
Wat 06	W6	Water irrigation systems	
Wat 07		Vehicle wash	
MATERIALS			
Mat 01	MW1	Materials specification (Major building elements)	Embodied carbon of construction materials Re-use of building elements Pollution associated with construction materials Building maintenance requirements
Mat 02	MW2	Hard landscaping and boundary protection	
Mat 03	MW5	Re-use of façade	
Mat 04	MW6	Re-use of structure	
Mat 05	MW8	Responsible sourcing of materials	
Mat 06		Insulation	
Mat 07	MW10	Designing for robustness	
Mat 08		*Responsible sourcing of materials - finishing elements*	
WASTE			
Wst 01		Construction site waste management	Monitoring and minimising construction waste
Wst 02	MW7	Recycled aggregates	

Wst 03	MW12	Recyclable waste storage	Use of recycled aggregates for construction Recycling of building waste (in use) Compaction of recyclable building waste (in use) Composting of building waste (in use) Tenant's floor finishes
Wst 04		Compactor/baler	
Wst 05		Composting	
Wst 06		Floor finishes	
LAND USE AND ECOLOGY			
LE 01	LE 01	Re-use of land	Brownfield development Contamination remediation Maintaining / improving site biodiversity External amenity space External educational space
LE 02	LE 02	Contaminated land	
LE 03	LE 03	Ecological value of site and protection of ecological features	
LE 04	LE 04	Mitigating ecological impact	
LE 05	LE 05	Enhancing site ecology	
LE 06	LE 06	Long term impact on biodiversity	
LE 07		Consultation with students and staff	
LE 08		Local wildlife partnership	
POLLUTION			
Pol 01	P1	Refrigerant GWP - Building services	Refrigerant global warming potential NOx emissions Flood risk Light pollution Noise pollution
Pol 02	P2	Preventing refrigerant leaks	
Pol 03		Refrigerant GWP - Cold storage	
Pol 04	P4	NOx emissions from heating sources	
Pol 05	P6	Flood risk	
Pol 06	P8	Minimizing watercourse pollution	
Pol 07	P12	Reduction of night time light pollution	
Pol 08	P13	Noise attenuation	
INNOVATION			
Inn 01		Considerate Constructors	Construction stage site impacts Daylighting CO2 emissions (regulated energy) Renewable energy Monitoring of water use Embodied carbon of construction materials Pollution associated with construction materials Monitoring and minimising construction waste Using a BREEAM consultant
Inn 02		Daylighting	
Inn 03		Office space	
Inn 04		Reduction of CO2 emissions	
Inn 05			
Inn 06		Low or zero carbon technologies	
Inn 07		Water meter	
Inn 08		Materials specification (Major building elements)	
Inn 09		Responsible sourcing of materials	
Inn 10		Construction site waste management	
Inn 11		BREEAM accredited professional	
Inn 12			

Appendix B – Building user survey questionnaire