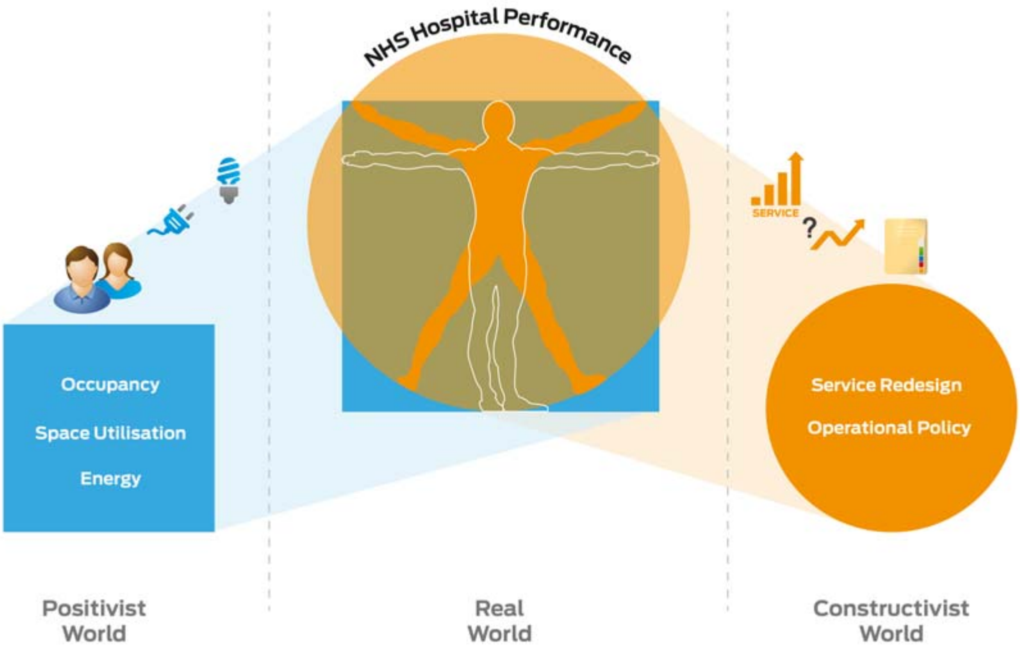
Low energy – low carbon acute hospital engineering design and operation in the UK: Analysis of the impact of In-use



Matthew Bacon

School of Built Environment
University of Salford, Salford, UK

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VOLUME 1: LOW ENERGY – LOW CARBON ACUTE HOSPITAL ENGINEERING DESIGN AND OPERATION IN THE UK: ANALYSIS OF THE IMPACT OF IN-USE 1

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“To me the magic of design is real, important and undoubtedly the province of architecture, but nonetheless capable of being enhanced by scientific understanding of user requirements.”

Dr Frank Duffy PPRIBA writing in Estates Gazette, 18 October 1986

Abstract

This thesis introduces an innovative contribution to the low energy - low carbon design of acute hospitals in the UK. The need for innovation in acute hospital design arises from the consistently poor energy and carbon performance of the health care estate over a period of nearly three decades. This poor performance translates into a situation where overall consumption of energy in the health care estate has remained largely unchanged over that period, despite substantive improvements in the asset specifications of these facilities. With respect to the commitment made by the British Government to reduce carbon emissions under the Climate Change Act (2008) this situation is clearly unacceptable, because that commitment requires an 80% reduction in carbon emissions by 2050. Of equal concern has been the poor predictability of energy forecasts for new buildings, where the apparent difference in performance between design and what is actually achieved In-use can be substantial.

In terms of energy consumption and the associated carbon emissions, the author's research has discovered that the issues of poor In-Use performance and poor predictability of performance in acute hospitals are directly linked. The central causal factor that leads to both is a poor understanding of clinical user practices and the impact of those practices on the design and engineering of the hospital. The research identified that without such an understanding it means that hospital planners, designers and engineers are required to make substantial assumptions concerning In-Use during the design process, most notably concerning occupancy presence and the diversity of occupancy.

The author's investigations found that it would be possible to use simulation to replicate how acute hospitals operate by utilising clinical process information contained in operational policy documents. It was also discovered that the data derived from clinical information systems could be used to run the simulation. It is the unique methods developed by the author that are his contribution to new knowledge. One method developed by the author is called *Occupancy Analytics*. The method enables the author to predict occupancy presence and diversity within a range of probabilities at any hour of the day within the hospital. A second method enables these values to be modelled within another simulation called the *Whole Facility Energy Model*. Using

both models in sequence the author discovered how to directly correlate the impacts of operational policies and working practices to energy consumption and the associated carbon emissions.

Using this new knowledge, the factors that determine occupancy presence and diversity were then investigated. The author reasoned that if these could be managed then it would be possible to optimise the engineering design, and the consequential energy consumption and the associated carbon emissions. Through the use of a case study that is both revelatory and longitudinal (Yin, Op Cit) the author demonstrates how this objective was achieved.

Finally, using the results from both *Occupancy Analytics* and *Whole Facility Energy Modelling* the author also discovered that it would be possible to establish norms for energy and carbon performance based on each patient type using the clinical services of the acute hospital. In the case study, the author demonstrates how this form of analysis could be used to establish the basis for departmental energy budgets, which he envisages could make an important contribution to the future optimisation of low energy – low carbon performance of acute hospitals in the UK.

Chapter 1 - Introduction

1.1 Thesis overview

The focus of this research is to investigate how to achieve low energy - low carbon hospital design and operation through an analysis of In-use. This is a term used to describe the operational phase of a building usually after the construction or refurbishment of it (construction phase). The analysis of In-use policies and working practices is to result in the development of a means to communicate In-use requirements to those that plan, design and operate the hospital.

The starting point for this thesis was founded in two initial research questions. The first question was to understand why forecast energy and carbon performance is significantly different to measured In-use energy and carbon performance in UK acute care hospitals. The second was to understand why UK acute care hospital energy performance has apparently not improved over a period when there has been substantial improvement in the asset specifications of such hospitals as required through regulation.

In seeking to answer these questions the author reasoned that it would be necessary to understand the science of building energy and carbon performance and to understand also the practice of engineering design for low energy – low carbon performance. The possibility exists that whilst the science maybe well understood, the imperfect application of the science may lead to compromised energy and carbon performance.

1.1.1 Expert opinion of engineering design practice

In the development of his research method the author identified the need to obtain expert opinion in order to clarify the application of building engineering science into building engineering design practice. The clarification was required because the author's research identified that codification of the application of the science (knowledge) into practice could be considered to be generally poor in the construction industry, largely because of engineering practices being reluctance to share that knowledge. This raised the question as to the limitations of the Literature Review as an accurate summation of codified knowledge in relation to the science. The author argues that in seeking expert opinion he is seeking to straddle the divide between lack of observed industry consensus as to how to achieve low energy- carbon performance and reliance on the possibly inaccurate (or out of date) codification of knowledge by the institutions that purport to be guardians of relevant knowledge concerning the application of building engineering physics.

The Subject Matter Experts, as the author refers to them, were selected on the basis of their industry reputation. The criteria are that the individual experts would have particular knowledge or skills in the subject, not dissimilar to an expert witness used within a court of law. The specific knowledge and skills sought by the author are in a) The development and application of building engineering physics, and b) Expertise in the analysis In-use (otherwise known as 'post-occupancy' evaluation). Four experts were selected who were not only personally known by the author, but were also recognised experts in the industry. In the Appendix where the transcripts of the structured interviews are set out, the author provides a commentary on the key findings, which provide wide insights into current practice in relation engineering design for low energy – low carbon performance.

1.1.2 Research Objectives

Following the Literature Review, and an analysis of the gaps in our knowledge, the author established a point of departure articulated in a proposition for low energy –low carbon acute care hospital performance (Section 3.5). Arising from this proposition three research objectives were identified:

> Research Objective 1: To make a new contribution to building engineering physics focused on accurately modelling occupancy presence in acute hospitals through an analysis of In-use.
>
> Research Objective 2: Through operational and service redesign to investigate how to achieve low energy – low carbon performance in acute care hospital operations.
>
> Research Objective 3: To make a new contribution to the acute care hospital briefing process, in the form of an 'Energy Efficient Brief', such that this brief

would provide the data required for the engineering teams at an early stage of the engineering design process.

The research methodology was conducted using a longitudinal case study. The subject for the case study was a new acute hospital redevelopment in the United Kingdom[1]. It provided an opportunity to study each of the three research objectives from three distinct perspectives as defined by the units of analysis. These were the analysis of occupancy presence and diversity, the energy and carbon impacts of occupancy and the data required for an effective engineering briefing process for low energy – low carbon performance in response the diversity of use.

[1] Please refer to p23.

1.1.1 - Rationale for the organisation of this thesis

Chapter 2 is designed to set the context for the literature review. In doing so it establishes the justification for the research and builds the case for the research questions. As it is the researchers philosophical position that shapes the research question the author has made his position clear at the outset. However, it is a theme he refers to throughout this thesis.

Chapter 3, comprising the literature review is a major part of the thesis. The literature review is structured around an investigation into both practice and theory, as illustrated in Figure 1. A proposition for low energy – low carbon design of acute hospitals in the UK arose out of this work. It was from this that the author was able to define his research objectives which were informed by a detailed analysis of the Point of Departure.

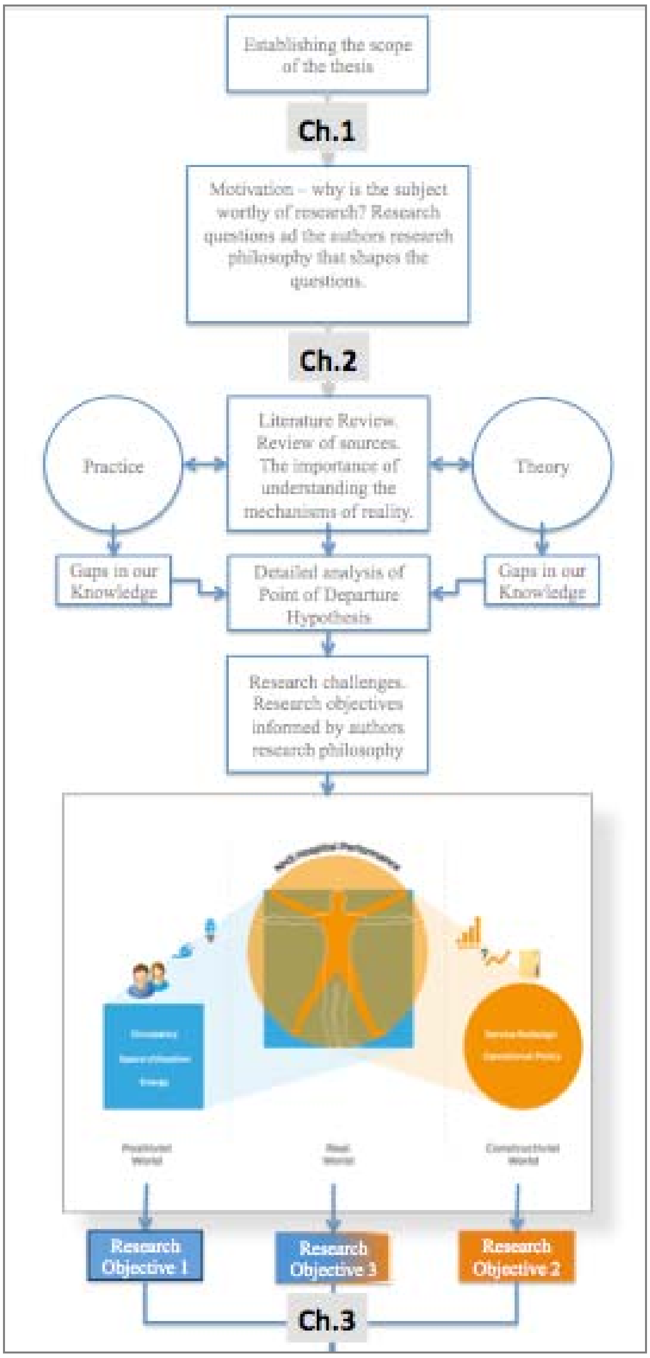

Figure 1 - Thesis structure - Chapters 1-3

In Chapter 4, the author explains in detail his research philosophy in relation to the research investigation to be undertaken. This provides the context for evaluation of the primary research method. A case study methodology was selected and the reasons for this are explained in this chapter.

Chapters 5-7 set out in detail the results of the author's research using a single case study. The results of the In-use experiments using two methods developed by the author are documented in Chapters 6 and & 7. New knowledge is discussed in Chapter 8 where it is used to inform the design of the Energy Efficient Brief.

The author chose to document conclusions and implications for future research within each of these chapters because he considers that this maintains the flow of the sustained arguments. However, these are also summarised together in Chapter 9. Also in Chapter 9, the author discusses the implications of his results as well as the limitations for future research. It is in this chapter also that the author sets out his unique contributions to research.

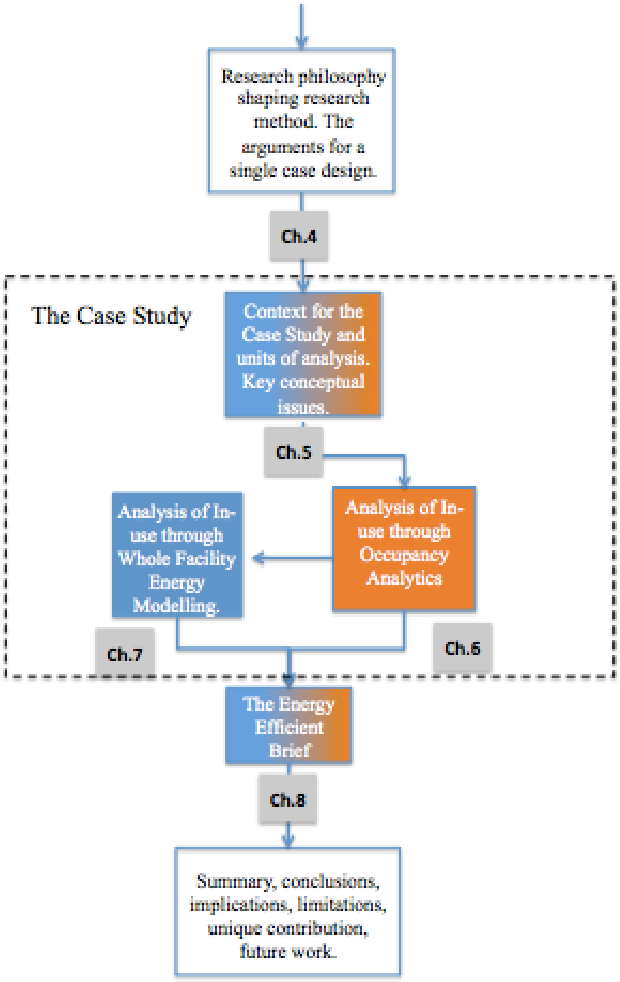

Figure 2 - Thesis structure - Chapters 4-9

1.2 A personal background to this thesis

The starting point for this research arose out of a combination of events for the author, which in 2010 culminated with him being awarded the contract to lead the low energy – low carbon design for the redevelopment of the Brighton & Sussex University Hospitals NHS Trust known as '3Ts'[2]. Significant also, (as will be explained later in greater detail later (p171) in Section 4.3.1), is that this work provided the case study context for the subsequent research. The contract provided valuable data for the research. It is also important to explain that the author played an active role in each of the two stages of the case study, and not that of an independent observer. This role is described in section 4.1.1 Action Research, p151

'3Ts' as the project has become known, involves the redevelopment of a significant part of the County Hospital Site (RSCH), which comprises many Victorian buildings and temporary facilities. The need is to replace these facilities with new facilities appropriate for the provision of 21st century health care.

Teaching, Trauma and Tertiary health care (3Ts) defines the role of the hospital in the south of England. The redevelopment objectives are to modernise the Royal Sussex County Hospital in Brighton, develop and expand the services or the most seriously ill and injured patients, and strengthen its role as the regional teaching hospital.

Two key events led to the author being appointed for this work. Firstly, prior to this in 2006/7 the author had designed a sustainability management system for Pricewaterhouse Coopers (PWC) where the business need was to report on the environmental performance of their estate. This experience provided the author with a valuable insight in terms of the challenges faced by PWC building managers attempting to reconcile building energy performance with the business needs of the users.

Secondly, during the latter part of 2009 the author became aware of the significant environmental performance challenges confronting the UK government as it

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[2] For details please see; http://www.bsuh.nhs.uk/about-us/hospital-redevelopment/

sought to achieve new standards of environmental performance in the public estate. This was given particular focus by the National Audit Office (NAO, 2007) which was highly critical of the estate energy and carbon performance. The magnitude of this challenge was underlined by the Climate Change Act 2008 (DECC, 2007). The carbon reduction commitment legislated in the Act requires a step-change in the carbon performance of the built environment; the extent of which was clearly articulated by the HM Government commissioned Innovation and Growth Team (IGT, 2010) which argued for fundamental innovation and change in process in the way in which buildings are both designed and operated if the required reductions were to be achieved. Further emphasis on the need for innovation was provided by the 2010 report published by the Royal Academy of Engineering: *Engineering a Low Carbon Built Environment* (RAE, 2010) where it also expressed concern about the poor energy and carbon performance of UK construction. It also argued for a new impetus in the development of building engineering physics, which was only just then emerging as a discipline of great importance.

In reflecting on this situation, the author speculated about the apparent disconnect between design and In-use. The author who is an experienced architect in airport design and previously Head of Process and Technology at BAA plc, experienced first hand how this disconnect brought about by failings in process could ultimately impact the eventual performance of a facility. In writing the Design Management Guidelines for the BAA Project Process it provided the author with a unique opportunity to reflect on the impact that poor briefing could have on design outcomes In-use, as much as how inadequate In-Use data could impact the quality of the brief. In the author’s experience the evidence of practice is that inadequacies in one part of the process at key project stages are most likely to ‘ripple’ through the subsequent stages.

To summarise: inaccurate briefing, through lack of knowledge of In-use (how occupiers use the facilities) could result in poor design decisions, which would most likely result in poor building performance. Thus poor flow of information (and thus creation of knowledge) between major phases of the facility lifecycle (Figure 1 refers) was seen as a major barrier to good facility performance.

Figure 3 - Process impact on facility performance.

The evidence at BAA was one of substantial waste: waste of over-specification – waste of design changes because users had not understood the impact of their practices on design requirements and how legislative requirements under which they operated could also impact the design requirements. The BAA Project Process was one that attempted to unite the traditional divide between asset delivery and asset management and In-use, and so remove waste from the process. BAA sought to achieve this through an integrated process that connected all of these phases of the facility lifecycle.

In the wider construction industry, Bordass characterised this poor relationship between design and In-use as the '*Great Divide*'. Whilst he was writing in terms of another process, the sentiment provides a very helpful insight into the wider disconnect that was evidenced in the PROBE studies (Bordass et al., 1997) and (Cooper, 2001). A key reflection of the author has been that because of the 'Great Divide' assumptions become an inevitable part of the whole process. As will be discussed later in this thesis, if designers do not have access to adequate briefing data or information they will often make assumptions in the design and the quality of the design will be compromised as a consequence. This is reminiscent of Llewellyn Davies' assertion (1957):

> *"Knowledge is the raw material for design. It is not a substitute of architectural imagination but is necessary for the effective exercise of imagination and skill in design. Inadequate knowledge handicaps and frustrates the architect, limits the achievements of even the most creative and depresses the general level of design.*

Yet it is across the 'Great Divide' that building engineering physics must operate. In the context of low energy – low carbon performance, building engineering physics lies at the heart (RAE Op Cit).

> *"Building engineering physics...investigates the areas of natural science that relate to the performance of buildings and their indoor and outdoor environments. The field deals principally with the flows of energy, both natural and artificial, within and through buildings. The understanding and application of building engineering physics permits the design and construction of high performance buildings;* ***that is buildings which are comfortable and functional, yet use natural resources efficiently and minimise the environmental impacts of their construction and operation****."*

1.3 Focussing on the domain area for this thesis

As a domain area for this thesis, a focus in any one of the three key process stages, as illustrated in Figure 1 could be investigated, but it is the In-Use phase and the considerations of the 'Great Divide' that inspire to the author to address an area of research that may provide valuable insights into the author's earlier reflections concerning the poor energy and carbon performance in the built environment.

The issue of poor energy and carbon performance is not new. It has seemingly been poor over a period of at least two decades, if not three decades when over that same period asset specifications have been considerably enhanced through legislation. This was a matter emphasised in the RAE report (Op Cit), which stated:

> *"Thus, the construction industry in 2010 is generally still delivering buildings that are little better in real performance terms than they were in the 1990s."*

The evidence of poor performance actually stretches back even further. The work of Dr. Bill Bordass and Cohen (Op Cit) during the 1990's identified that there existed at that time two significant challenges concerning poor energy performance: firstly that measured actual performance of buildings did not appear to have improved to any meaningful extent over the previous 20 years or more, and secondly that of poor predictive performance of buildings, which rarely seemed to achieve the levels of energy performance that the design team aspired to.

There is much evidence to support this argument. It is one that has also been made by the Carbon Trust (Delay et al., 2009) and reflects the same concern expressed by the RAE[3]. The situation in the UK is no different to that in the European Union (EU): (2013). With regards to the European perspective the Commission is concerned that Member States are not making anything like the progress required to achieve its 2020 emissions target. Indeed, over the period from the 1990's to 2010 energy consumption in non-domestic buildings across the EU has risen by 1.5% (Figure 4).

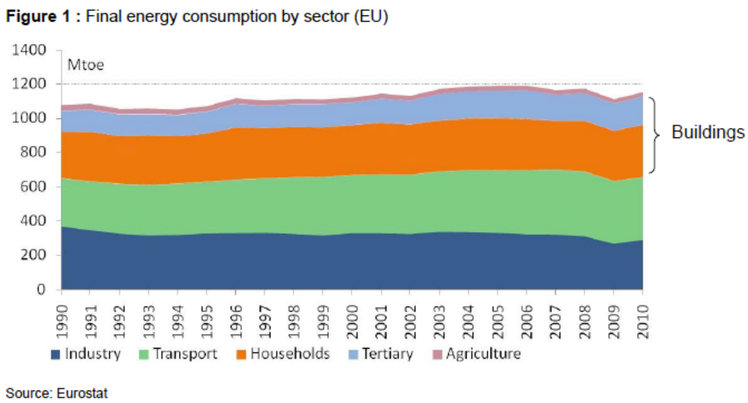

Figure 4 - Energy Consumption in Buildings in the EU ((Lapillone et al., 2012)

The commentary by the European Commission (Ibid) states:

> *"On 28 June 2013, the Commission published a report on progress by member States towards Nearly Zero-Energy Buildings (NZEB), which are to become the norm for all new buildings in the EU by the end of 2020, and two years earlier for public buildings"*

It explains the reason for this need:

> *"The conclusion of the report is that too little progress has been made by the Member States in their preparations towards NZEBs by 2020. Member States have to significantly step up their efforts to implement the requirements regarding NZEBs in the EPBD to ensure that the EU's longer-term climate objectives are not jeopardised and the building sector can take full advantage of the opportunities NZEBs present."*[4]

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[3] It is of course conceivable that both organisation's were referencing the same data.

[4] See: http://ec.europa.eu/energy/efficiency/buildings/buildings_en.htm

With a focus on In-Use and a subject area concerning low energy – low carbon building performance, the question would then arise as to what aspects of In-Use should be investigated? The RAE report goes onto advocate that the clear need is in the development of building engineering physics:

> *"We are at the start of a period when the application of building engineering physics will become one of the principal drivers in the construction of new buildings. In the 21st Century buildings and their construction must evolve rapidly to meet emerging challenges."*

An implication of the foregoing statements could be that building engineering physics has not served the construction industry well if building energy performance has not measurably improved over the last two decades at least. Is this the only reason, or could it be that there are other factors that may have lead to this situation?

Subject Matter Expert[5]: Bellew, who is one the worlds leading exponents of building engineering physics commented that it is only in the last four years since 2010 that energy modelling has became a statutory requirement in the UK (VOLUME 2, p27). (The statutory requirement in the UK is to use the National Calculation Method, using either approved software or an approved tool called SBEM). Whilst this maybe so, the science, knowledge, tools and expertise to understand building performance have existed for over two decades[6]. Perhaps therefore it might be the failure to adequately apply building engineering physics in the engineering for low energy – low carbon buildings, or to adequately inform the physics with appropriate data? If appropriate data were not to be available could it be that poor assumptions are being made at any of the key stages of the engineering design process? If this were to be the case, then no matter how good the building engineering physics maybe, the results could be misleading and result in poor predictive performance at least. Or could it be that engineers have become too reliant on formulaic approaches to design and what are referred to as 'rules of thumb'. Typical of such rules are for example: the assumed requirement litres of hot water per person per day, or the assumption that air changes

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[5] For an explanation of the role of the Subject Matter Experts in this thesis please see p72

[6] For example the UK designed IES software was commercially available in the late 1990's – see http://www.bembook.ibpsa.us/index.php?title=History_of_Building_Energy_Modeling.

per hour for a specific room type will provide sufficient indoor air quality regardless of the number of people in that room. Where did these ‘rules’ emanate from – are they still relevant in buildings of today? Perhaps it is these rules that result in unnecessary energy consumption, because they too are founded in poor assumptions?

Another perspective could concern the role of the building occupant and occupant attitudes towards energy conservation. As it is occupants that largely impact the consumption of operational energy[7] and not buildings, (because buildings serve the needs of the occupants) then it could be argued that it is the use of the buildings that primarily impacts energy consumption. This would raise issues concerning behaviour, culture, education and training; all of which could be areas requiring complex research investigation. But what if the users are disposed to using the building responsibly from an energy perspective, but they are unable to influence the use of the engineering systems to effectively control consumption? The issue here concerns how well the building management systems are designed to achieve control and to support the use of the building. As was noted earlier, the author’s experience in working with PWC in the analysis of building management system data provided an insight into the challenges of managing such systems from an occupant perspective. In analysing these systems the author found that the key challenge was that they were designed more for needs of the engineer, and less so for the needs of the occupant. This was because the systems (at best) were configured to provide the data that only the maintenance engineer could work with. Consequently the user had little understanding of the impact of their use of the building in which they worked.

A further perspective could be that buildings today are far more complex, more intensively used, have highly controlled environments and make substantial use of computing systems and technologies directly associated with use. Perhaps our life-styles lead to this increased consumption? Is it because we have come to expect immediate heating and cooling responses in our workplaces, and that we can be attired in those places regardless of external weather conditions? Could not all of these factors

[7] That part of energy consumption that is distinct from thermal energy consumption used to heat, cool and ventilate a building. A good exposition of operational energy can be found in the CIBSE Technical Memorandum TM54 (see www.cibse.org)

explain why overall building performance has not improved? The author reasons that if it were possible to understand how occupants need to work in the building and to use that understanding to inform the building engineering physics through the design brief, then it might be possible to use ensure a closer fit between design and use – the very issues that Bordass was alluding to in the 'Great Divide'.

It was in discussing these issues with Professor Passman that it became apparent that these issues were of great concern to him. It was though this conversation that Professor Passman asked the author to develop the low energy – low carbon strategy for 3Ts – a strategy founded in developing a new understanding of In- Use energy. The project would establish the means by which the occupants, (namely clinical users) could be directly engaged in a dialogue with the professional team, orchestrated by the author.

It was thus through this project that the author came to consider how to address the aforementioned challenges centred on building engineering physics applied to acute hospital design, and it was through the research for this thesis that the author decided to investigate how low energy – low carbon hospitals could be more effectively designed to achieve this aspiration of performance by bridging the 'Great Divide' – the basis of a new dialogue between the professional team and the clinical users in the hospital.

Chapter 2.0 - Scope of the literature review and the research questions

From the forging introduction the reader will now be aware that domain area for this thesis is the apparently[8] poor energy and carbon performance of the built environment with a potential focus on acute hospitals in the UK. This has been set against a historical trend in the UK (with similar tends in some parts of Europe) of stagnated energy and carbon performance in the built environment over the last two – three decades. This is despite significant improvements in asset specifications over the same period. The possible reasons for this situation were considered. Questions were raised concerning the effectiveness of the application of building engineering physics in the engineering design of this type of hospital, as well as the impact of operational clinical use on the consumption of energy and the associated carbon emissions.

With a view to scoping the research, in this chapter the author will probe further into the domain area of acute hospital energy and carbon performance. In Section 2.1 the author considers the relative importance of the energy and carbon performance of acute hospitals in the UK. In Section 2.2 the investigation then considers the historical context for hospital energy and carbon performance and places the performance into the relative context of European hospital performance. The author discusses the impact of the growth in the intensity of use and considers how this impacts poor performance. This develops the discussion introduced in the previous chapter. In Section 2.3 the author then moves the focus of discussion from considerations of In-use to the poor predictive energy and carbon performance of these facilities by engineering designers. Having considered the issues in further detail that were outlined in the previous chapter the author then considers in Section 2.4 why these issues should be worthy of research. This discussion then leads to a further refocusing of the scope of the research. To provide an analytical framework for this, in Section 2.5 the author considers how scientific theories are tested. The author reasons that as one of the areas of investigation is concerned with the science and application of it in the design and operation of buildings, then reference to a formal framework for theory testing should

[8] A qualification that will be explained later in this chapter.

help to provide an objective focus for the research questions. In Section 2.6 the author then identifies the research questions, and in doing so introduces his philosophical position. The author believes that this is important to state at this early stage because the philosophical context should inform the rational for the research question as much as the research strategy and methods (Bergman, 2008). Finally in this section the author sets out the scientific sources that were identified as providing the key texts for the literature review.

2.1 The context for low energy – low carbon hospitals in the UK

It was explained earlier that UK Government policy in relation to carbon emissions in the public estate has been centred on its obligations to the Climate Change Act 2008 (Op Cit). Directly associated with the requirement to reduce carbon emissions is the need to reduce energy consumption. This is because it is the consumption of energy in buildings that directly leads to carbon emissions from In-use.

Within the built environment sector the UK government has established clear policies to reduce energy consumption and the associated carbon emissions. The policy is achieved through regulation: the Energy Performance of Buildings Regulations 2007, which forms part of the final implementation in England and Wales of the European Directive 2002/91/EC on the Energy Performance of Buildings. The regulation requires owners of buildings to meet specified criteria and to publish Display Energy Certificates (DEC's). These certificates are to display the energy performance of the building. The authors of the Carbon Trust report: *Building the future, today* (Op Cit), point out that the government then made a commitment to get carbon emissions in all buildings close to zero by 2050 (technically an 80% reduction). This means that not only must the asset specification (as measured by the EPC) be 'close to zero', but the operational performance (as reported by the DEC) must be too.

The Department for Communities and Local Government (DCLG) are responsible for overseeing the implementation of Energy Performance of Buildings Directive. They state that non-domestic buildings are responsible for almost 20 per cent of the UK's energy consumption and carbon emissions (DCLG, 2008). With the chosen context for this thesis as low energy – low carbon hospitals, (a building type that is categorised as 'non-domestic') how significant is the contribution of this building type to these emissions? The answer to this question is that in relative terms for the whole of the government estate the carbon emissions from the health estate are responsible for 25% (the largest proportion) of all public sector carbon emissions. In other words the NHS Estate is responsible for about 5% of all non-domestic building emissions. However, in contrast in the European Union (EU) (BPIE, 2011) the share of all non-domestic emissions is 10%, where hospitals account for 7% of the total non-domestic building area. In comparative terms within the EU, Hotels and Restaurants represent 12% of all emissions, and 11% of total non-domestic building area, and Educational buildings represent 12% of all emissions, and 17% of total non-domestic building area. From these statistics it can be seen the carbon intensity of hospitals is much greater than these two other building types, which is understandable given the 24-hour use.

Building type	kWh/m^2 year	Ratio
Dwellings	147	1
Retail	233	1.6
Schools	262	1.8
Offices	293	2
Hotels	316	2.1
Supermarkets	631	4.3
Hospitals	786	5.3
Restaurants	814	5.5

Year 2003. Source: EIA.

Figure 5 - Relative intensity of energy use of different building types. (Source: Perez-Lombard et al, Op Cit)[9]

These differences are illustrated in Figure 5 for the relative intensity of use of different building types. It can be seen that hospitals have one of the highest intensities of energy uses of any building type. Reason would thus suggest that between different hospital types and different countries, intensity of energy use could also be different? Whilst it is possible to find differences at national level, the author was unable to find differences between different types of acute hospital.

[9] A later study that was carried out in 2010 identified an almost identical distribution. Refer to Figure 8.

From a UK perspective 70% of the health care estate in 2011 performed with a DEC rating (Op Cit) at a D Rating or worse (Bryan et al., 2011). This would suggest that there is an on-going need to upgrade the built estate, yet as will we discussed later in this chapter, the reasons for this poor performance are probably less to do with poor asset performance (the building envelope and engineering system specifications) and probably much more to do with how these buildings are used.

Source of emissions	Total floor area (m^2)	Total CO_2e emissions by buildings (tonnes/yr)	Total CO_2e emissions by owned vehicles (tonnes/yr)	Total CO_2e emissions by Business travel (tonnes/yr)	Total CO_2e emissions (tonnes/yr)
Central Government (exc. prisons)	10,976,115	580,716	249,826	66,325	**896,868**
Central government (MoD specific)	89,870,000	1,450,226	2,341,622	8,423	**3,800,272**
Central government (prison specific)	3,650,699	377,721	-	-	**377,721**
Health	28,379,463	3,737,659	128,482	-	**3,866,141**
Local Authorities (exc schools and police and fire)	17,795,804	1,941,588	99,647	-	**2,041,234**
Local Authorities (schools)	44,538,706	2,439,586	-	-	**2,439,586**
Local Authorities (police, fire and rescue)	2,734,059	335,398	235,550	-	**570,948**
Further Education Institutions	8,713,282	719,774	-	-	**719,774**
Higher Education Institutions	21,731,720	1,983,962	-	-	**1,983,962**
Subtotals (exc, MoD)	**138,519,848**	**12,116,402**	**713,505**	**66,325**	**12,896,233**
Total	**228,389,848**	**13,566,629**	**3,055,128**	**74,749**	**16,696,505**

Figure 6 - Relative carbon emission from the public sector estate in 2011 (Source: Bryan et al, Op Cit)

The pattern of poor performance of UK buildings is also reflected in the NHS performance. Although energy is being used more efficiently, consumption has risen 40% since 1990, and increased by 2 Mt between 2008 and 2009. This was highlighted in report from the Sustainability Development Unit, (SDU, 2009) which states:

> *"The NHS has a carbon footprint of 18 million tonnes CO2 per year. This is composed of energy (22%), travel (18%) and procurement (60%). Despite an increase in efficiency, the NHS has increased its carbon footprint by 40% since 1990. This means that meeting the Climate Change Act2 targets of 26% reduction by 2020 and 80% reduction by 2050 will be a huge challenge. This strategy establishes that the NHS should have a target of reducing its 2007 carbon footprint by 10% by 2015.* ***This will require the current level of growth of emissions not only to be curbed, but the trend to be reversed and absolute emissions reduced. Interim NHS targets will be needed to meet the government targets."***

2.2 Consistently poor overall energy and carbon performance.

It is clear from the foregoing that despite the stated need to reduce absolute emissions, typical acute hospital energy consumption in the UK has not improved. Indeed there is further evidence that clearly demonstrates that over last three decades hospital energy performance remains in the region 400-500kWh/m^2. The empirical evidence to support this position can be explained by Figure 7 and Figure 8.

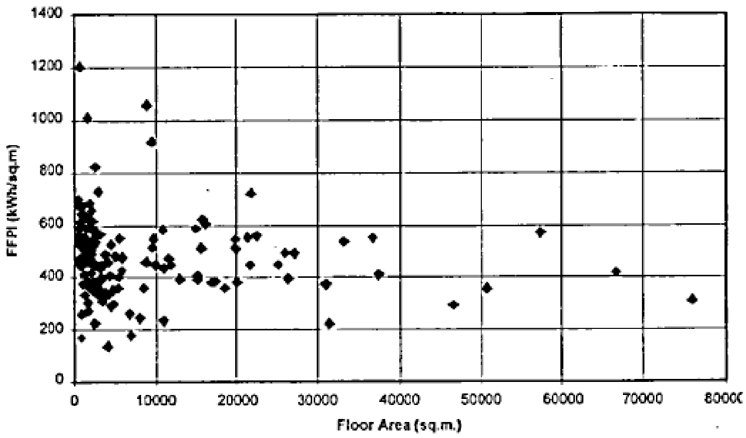

Figure 7 - Thermal energy consumption of UK acute hospitals - 1994/1995

In Figure 7 it can be seen how the energy consumption performance of UK acute hospitals was typically in the region of 400- 500kWh/m^2. This is the earliest scientific record that the author has been able to source. The energy consumption performance illustrated in the Figure should now be compared that of UK hospitals during 2011 in Figure 8 over page. Typically the average performance is a little over 400kWh/m^2. A further benchmark for contemporary acute hospital performance can also be found in the Chartered Institute of Building Services Engineers (CIBSE) Guide F (CIBSE, 2004) where benchmark energy performance is advised as 500 kWh/m2.

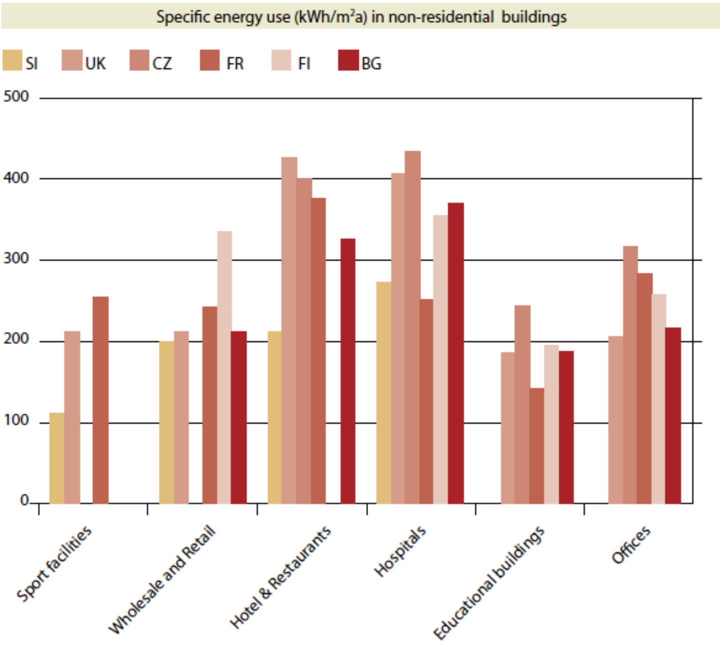

Figure 8 - Comparative European hospital performance – 2011 (BPIE, Op Cit)

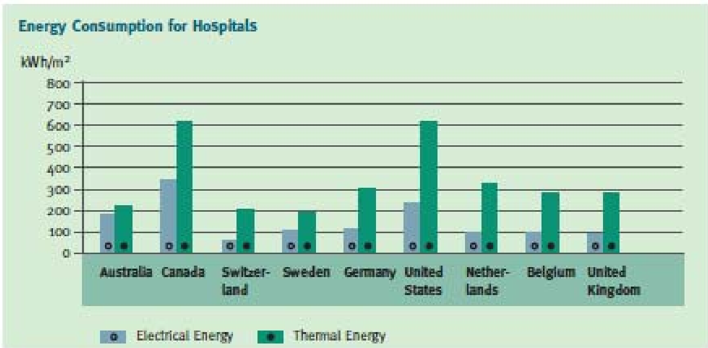

Figure 9 - Comparative energy consumption between European hospitals (Environment Science Center, 2003)

Figure 9 illustrates very similar In-use energy consumption in hospitals across Europe. Notably Switzerland was lowest in 2003, matching those results reported in 2011 (see Figure 8). However, as was explained in the Introduction (p29) it should also be recognised that intensity of use could be a factor in the comparative results between hospital energy performance in different countries. It is thus conceivable that UK hospitals are more intensively used than two or three decades ago, and furthermore, it could also be the case that UK acute hospitals are more intensively used than some other EU countries. Why is this important? It is because for each square metre of hospital space, should it be subjected to a greater intensity of use, then it would be reasonable to expect the operational energy consumption for each square metre to be higher than one with a lower intensity of use. Comparative intensity of use analysis could help to develop understanding as to why similar hospitals perform differently and also help to focus on what the operational differences are. By this means it would provide improved insights as to how to reduce hospital energy consumption.

The author argues we need to understand the intensity of use of all resources that may impact energy consumption. In a hospital this could mean the intensity of throughput as suggested above, intensity of use of equipment (which would be related to the foregoing), hours of use – for example 3 Session days[10] as distinct to 2 Session days, and the relative mix of diagnostic functions using energy intensive equipment. Whilst differences concerning intensity of use maybe important distinguishing factors in hospital performance across Europe, sourcing accurate data has not been possible. Does this invalidate the intensity of use argument when attempting to understand the trend in acute hospital energy and carbon performance? The author would argue that this should not be the case.

Another measure of the intensity of use might be reflected in the rate of admission and discharge of patients, where it could be argued that the higher the rate, the greater the intensity of resources being used. Of particular note is that compared to both Sweden and Switzerland, the UK's apparent intensity of use is about 80% of those two countries, yet our overall energy consumption is about 25% greater.

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[10] A 'Session' is defined by the period in which an Outpatient clinic is scheduled. Typically clinics operate two-session days, being a morning session and an afternoon session. For each session a clinician will have a 'List', this being the list of patients that are scheduled for each session. Consequently a 'Session' will comprise one or more 'Lists' depending on how many clinicians have been assigned to each Session.

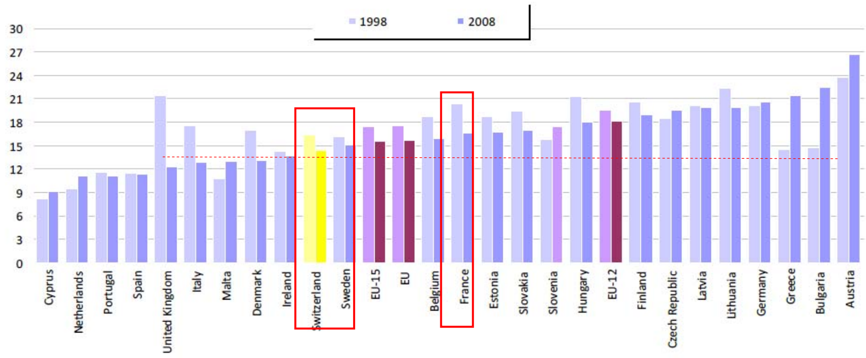

Figure 10 - Rate of acute care hospital admissions and discharges (percentage) Source: (HOPE, 2011)

Explaining the data in Figure 10, it can be seen that the UK has what could be interpreted as a smaller rate of intensity of use (12%) when compared to France (16%), Switzerland and Sweden where the rate is 15%. Comparing these results with the energy consumption profile illustrated in Figure 8 and Figure 9 shows that despite the apparently higher intensity of use of hospitals in France, and Switzerland they have lower significantly lower operational energy consumption than typical hospitals in the UK. Reason would suggest that the opposite should be the case, but perhaps there are other factors that explain the UK's higher energy consumption?

Perhaps the size of UK hospitals is greater per patient served than comparable hospitals in Europe? This could be relevant because the larger the building volume to serviced, then the larger the amount of energy that is likely to be consumed (L.Perez-Lombard et al., 2008). Without available data to make such a comparison, this can only be considered a possibility, a point that shall be returned to later in this section. Another factor could be the difference in engineering standards, particularly those for mechanical ventilation systems. These differences are discussed later in this thesis, but of particular relevance in the UK is that ventilation standards are based on air changes per hour, whereas in other parts of Europe (particularly in Scandinavian countries, that generally perform better than the UK in energy consumption terms) use ventilation standards based in litres per person per second. The impact of the UK standard is that spaces are more likely to be ventilated regardless of use, whereas in Scandinavia they are more likely to be served according to use. Typically heating, ventilation and cooling (HVAC) systems account for at least half of all energy consumption in buildings, (Perez-Lombard et al, Op Cit) and because of this the differences in ventilation standards between the UK and Scandinavian countries may account for some of the difference[11]. A critical observer may propose that it is differences in asset specifications achieved through better thermal transmittance standards that may explain this situation. However, the argument presented here is focused on intensity and efficiency of operational energy consumption and not on asset energy consumption.

Figure 10 also illustrates how the rate of admission and discharges has reduced in the majority of European countries over a ten year period. The reasons for this reduction are no doubt complex, but the progressive move to day cases and outpatient treatment along with the progressive expansion of primary care has led to a corresponding reduction in bed spaces. Improved clinical efficiency has substantially reduced length of stay (Hensher and Edwards, 1999) (J.Farrington-Douglas and Brooks, 2007)and would probably have contributed to this situation as well. How might this change impact the energy and carbon performance of UK hospitals over a 20-30 year period? Perhaps it could be expected that the reduction of bed spaces and length of stay would to lead to smaller hospitals and thus reduced energy consumption? However with the growth in day cases and outpatient services perhaps a larger part of the potential reduction has been nullified? Again without empirical data to inform this debate concerning the changes in size of hospitals the reasons can only be speculated upon.

As was explained earlier, without comprehensive data, reliable indicators of different intensities of use, or differences in engineering standards, are unlikely to be forthcoming and consequently achieving an accurate comparison between the UK and other European countries is unlikely to be possible. The lack of accurate data constraining accuracy of benchmarking is an argument that is offered by CIBSE (CIBSE, 2011). In their report the authors argue against including intensity of use considerations because:

> *"We conclude it is not sensible to allow any adjustments for occupancy density at this stage because – even in offices - there is not enough evidence available to support this adjustment. Allowing such adjustments could also undermine*

[11] See also p198 for a further examination of these issues.

the whole DEC process because they are so open to abuse. However, to start to establish an evidence base, the DEC process should enable assessors to attempt to collect data on density of occupation and to record these data…"

However, despite these concerns the author argues that the rejection of understanding of In-use through occupancy means that construction industry is denied knowledge as to how In-use has impacted the DEC rating. Consequently, the author argues we need to understand the intensity of use of all resources that may impact energy consumption. In a hospital this could mean the intensity of throughput (as discussed earlier), intensity of use of equipment (which would be related to the foregoing), hours of use – for example 3 session days[12] as distinct to 2 session days, and the relative mix of diagnostic functions using energy intensive equipment. As previously stated, whilst differences concerning intensity of use maybe important distinguishing factors in hospital performance across Europe, sourcing accurate data has not been possible. Does this invalidate the intensity of use argument when attempting to understand the trend in acute hospital energy and carbon performance? The author would argue that this should not be the case.

This foregoing reasoning suggests there to be a strong argument that a measure of kWh/m^2 is misleading for comparative benchmarking because of the different intensities of use. From a UK perspective the data would suggest that it is the growth of intensity of use that has resulted in no discernable improvement in overall energy performance of UK hospitals. The summary of this situation is illustrated in Figure 11 over page.

[12] A 'Session' is defined by the period in which an Outpatient clinic is scheduled. Typically clinics operate two-session days, being a morning session and an afternoon session. For each session a clinician will have a 'List', this being the list of patients that are scheduled for each session. Consequently a 'Session' will comprise one or more 'Lists' depending on how many clinicians have been assigned to each Session.

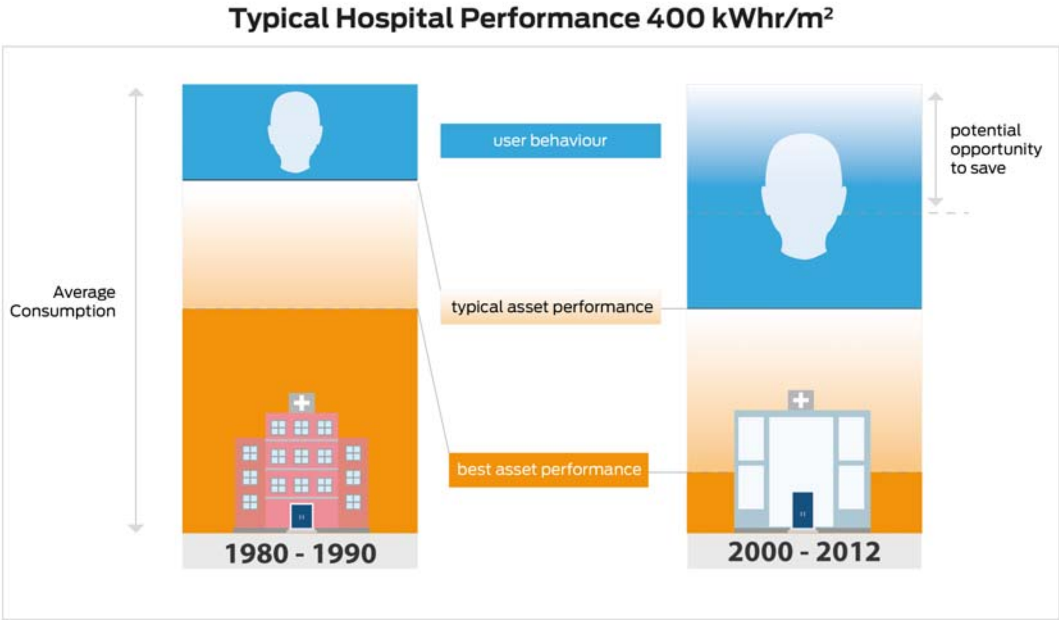

Figure 11 - Comparison between 1980's and contemporary energy consumption

Figure 11 summarises the situation of the stagnation of energy consumption over a thirty year period in the UK. Empirical comparative energy consumption data in the healthcare sector across Europe is scarce. As Perez-Lombard et al (Op Cit) point out:

> *"Energy consumption of buildings in developed countries comprises 20–40% of total energy use and is above industry and transport figures in EU and USA.* ***However, available information is clearly insufficient and not proportional to its importance. It is not considered as an independent sector and there is a lack of consistent data that makes it difficult to understand the underlying changes that affect energy consumption in this sector".***

Whilst there certainly appears to be a lack of knowledge of the impacts of use on energy consumption in hospitals there is some evidence of the impact of In-use generally as illustrated in Figure 12. It clearly illustrates how In-use (Activity effect) has effectively nullified all the energy savings from improved asset specification.

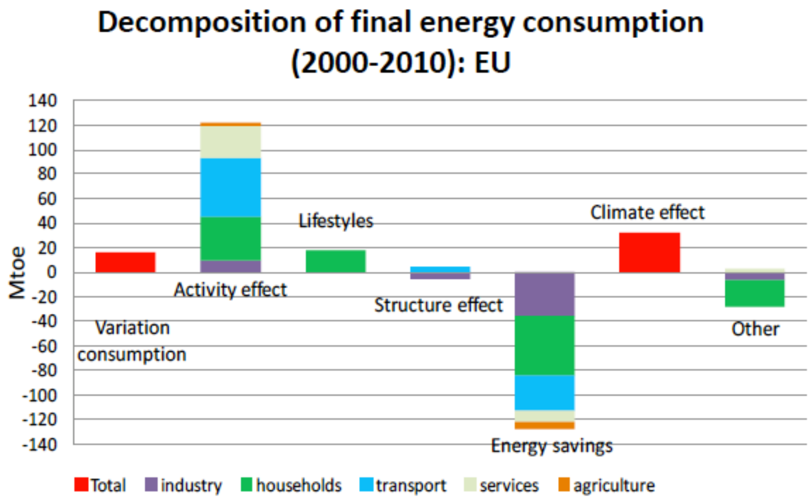

Figure 12 - Energy Efficiency Trends in Europe. Source: (Lapillone et al., 2012)

Thus far the discussion has focused on energy consumption, and it is now appropriate to specifically consider carbon emissions in acute hospital design and operation.

From a carbon emissions perspective the empirical evidence of historical emissions is harder to find, however the NHS Sustainability Development Unit has been publishing carbon updates since 2009 (SDU, 2009). In their forecast, (SDU, 2012) illustrated in Figure 13 it clearly demonstrates a steady rise in carbon emissions, with building efficiency at best leveling off and at worst rising. This is directly opposite to the requirements of the CRC (Op Cit), which requires carbon emissions to fall in absolute terms.

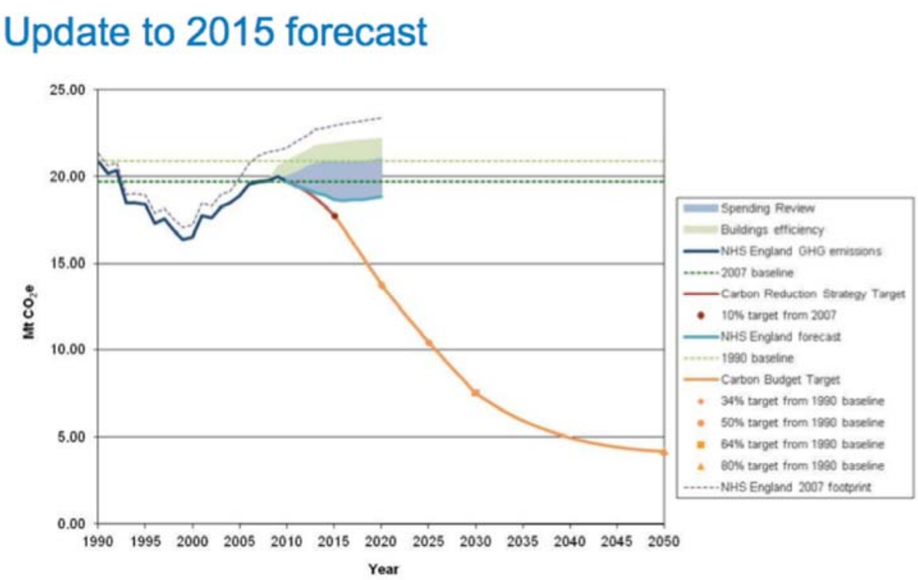

Figure 13 - Carbon Forecast from the UK's NHS Estate (SDU, 2012)

As acute hospital energy consumption translates directly into carbon emissions (but not all emissions) it is necessary to consider how energy performance standards impact carbon emissions. The Department of Health has committed to achieving a maximum target of energy performance of 55GJ/100m3 (approximately 473kWk/m^2 [13]) for all new capital development and 55-65GJ/100m3 for all refurbishment projects. (Short et al., 2010) comment that in 2004/5 the Department of Health reported that the energy performance of NHS Trust acute hospitals in England was in the range of 44.8-98 GJ/100m3. The authors of the report emphasise the imperative for reducing energy consumption to reduce carbon emissions. Yet it is clear from the historical perspective of energy consumption (as discussed earlier) that as these have not reduced since the 1990's, then neither can have carbon emissions from buildings have fallen. Consequently one can conclude that the energy targets as recommended by the Department of Health will not lead to the reductions in carbon emissions that are required by the CRC.

Then what should be targeted? Perhaps best practice in Europe should be referenced, where energy performance and the associated carbon emissions, superficially appear to significantly exceed UK performance? If we were to seek a

[13] Assimilated from a study at the 3Ts redevelopment at Brighton.

basis for such a target the data would have to be normalised against three key factors (Singer et al., 2009):

- Intensity of use
- Mix of use
- Degree heating days[14]

Considering the first factor, this was discussed earlier, and without comprehensive data and analysis of In-use the reliability of data will be of concern. This should be the subject for further research. With regard to the second factor it would be illogical to attempt to compare acute hospital performance, where for example, one contained surgery facilities and the other did not, or one contained an imaging suite and the other did not. In both examples the energy demand profile would be quite different. As far as the second factor is concerned then there is reliable European data for which comparisons can be made. In a preparatory study for 3Ts the author and the energy modeling team normalised Finnish acute hospital performance with the UK (through an analysis of heating degree days: UK (Brighton) has 53% fewer heating degree days that in Finland). The basis of this analysis was on the premise that if the hospital could be both designed using comparative asset standards, and operational energy controlled as would be in a Finnish hospital, what energy performance could be expected? The study concluded that in comparative terms 3Ts could potentially perform in the region of 30-35GJ/100m^3 (approximately 280kWh/m^2). Notable also is that the intensity of use of Finnish hospitals appears to be higher than that of the UK, which reason would suggest should result in a lower target. Regardless of this, the study suggests that the performance range for 3Ts should be in the order of 250 – 300kWh/m^2 – approximately 50-60% of the current recommendation.

Yet as far as the European Commission (2013) is concerned even this target would not be acceptable. The EC is seeking to achieve Nearly Zero Energy Buildings (Public sector) (NZEB) by 2018. In reviewing each Member State NZEB the EC reports the following:

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[14] For an explanation of degree heating days please see here: http://degreedaysforfree.co.uk/pdf/TM41.pdf

> *"Where a numerical indicator is set, the requirements range rather widely from 0 kWh/m2/y to 220 kWh/m2/y. It may be questioned whether the higher levels of energy consumption are compatible with the definition of NZEBs as given by the EPBD."*

Whilst a common standard remains to be set, it does suggest a need for significant improvement for the UK.

What impact such a change in performance would have on the carbon forecast for the NHS would be very difficult to predict. Given that most acute hospitals now operating in the UK will meet foreseeable patient demand, reason would suggest that it is In-use where focus needs to be applied to energy reduction and the associated carbon emissions. The author's proposition runs counter to the observations of the SDU report in Figure 13 where it is salient to note that the report states that where emissions are expected to fall, (and thus to achieve a leveling off of emissions) this is due to the HM Government's Spending Review, (which has substantially impacted the funding of capital investment projects), in other words not as a consequence of improved acute hospital energy efficiency.

This is also the justification for the European Commissions' stance on 'Near to Zero' building performance explained earlier and which places significant emphasis on the need for behaviour change in achieving low energy – low carbon building performance. This is more evidence of the need for change and to understand the impacts of In-use on both energy consumption and carbon emissions.

2.3 Poor predictive energy and carbon performance

With the UK governments objective to drive for absolute reduction in energy consumption and associated carbon emissions, in the case of acute hospital it would be reasonable to expect new and refurbishment projects to demonstrate clear <u>overall</u> performance improvement. Notably it should demonstrate an absolute improvement in line with the performance identified by the SDU (Op Cit).

As was explained earlier. Energy Performance Certificates (EPC) are required for all new buildings and refurbishments (DCLG, Op Cit) and these are designed to demonstrate compliance with asset performance standards relative to the legislation in force at the time of the project submission under Part L2A of the UK Building Regulations. Yet despite this all the evidence suggests that the potential to achieve predicted performance as measured by the EPC is not achieved in practice.

It could also be correctly argued that the EPC (forecast of notional asset performance) was never intended to be compared to the DEC rating. Not least because the EPC only measures what are defined as ‘regulated loads’, in other words loads not associated with the operation of the facility, which are defined as ‘unregulated loads’. Whilst this is certainly true, it is misleading because clients believe (albeit mistakenly) that they will receive a high performing building if it has an Outstanding or Excellent BREAM rating, which the EPC performance is part of. Yet it is also the case that when considered in terms of overall performance, a building with such a rating (EPC, A or B) will invariably perform with a DEC rating of F or G. This is certainly the case for the new award winning Children’s Hospital at Brighton and Sussex University Hospitals Trust, with an EPC rating of B, performs with a DEC rating of between an F and G. Another example of the disparity is illustrated by a comparative study to understand the difference in this calculation methodology for an airport building (Parker et al., 2012). The issues were explained as follows:

> *“Anecdotal feedback provided by the Airport Energy Manager confirmed that at the corporate board level the disparity between the two ratings raised questions over the operation and design of the building. In the worst case scenario, this could prejudice decisions to invest in energy efficient buildings in the future. From an economic perspective, the airport energy budget is the second largest after staff costs and reducing building energy consumption is a priority for the airport operators. They also have a commitment to reduce their carbon footprint and this perceived poor DEC rating caused further discontent regarding the quality and design of the facility. It is possible that the reason for this is the use of the same A-G rating scale which may lead non-building professionals to assume the rating systems are complementary.”*

The disparity between the predicted energy performance of health care buildings in the UK (not just acute hospitals, which is the focus of this Thesis) and the actual performance has been reported by a Technology Strategy Board funded project called: Carbon Buzz[15] The project references the CIBSE Guide TM46, and the current summary (April 2013) is illustrated in Figure 14.

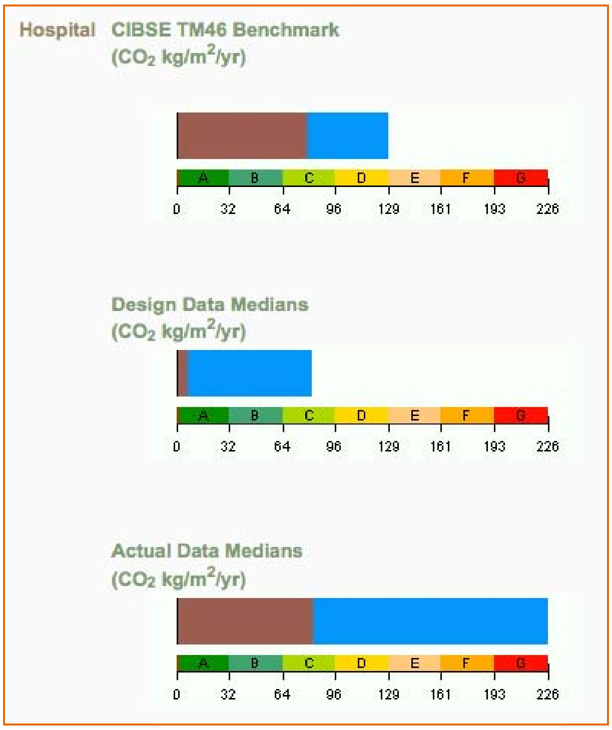

Figure 14 – Comparative analysis between CIBSE Benchmark, Design forecast and actual carbon performance.

The disparity between benchmarks and actual performance is significant, but more so is the disparity between design aspiration and actual performance, which from the data illustrated in Figure 14 has a median inaccuracy of a factor of three. Other commentators have suggested that the disparity could be as much as a factor of five (Menezes, 2012).

The author further argues that despite the intention of the EPC to inform the energy performance potential of a building the rating is an inaccurate indicator of the potential asset performance because it takes no account of how the building was set up to perform irrespective of how it is to be used. For example, in the case of an acute hospital the specification may require for certain spaces, that over a 24 hour period a minimum number of air-changes is required, regardless of use. Another example would be that of a building management system that allows no user intervention and is

[15] See: www.carbonbuzz.org

configured to condition the building regardless of use – in other words potentially creating a predilection for poor energy performance. It seems to the author quite illogical that the EPC should control plant infrastructure efficiency, and yet ignore the efficient control of it. In part this discrepancy will be due to the differences in modelling using static models such as SBEM and sophisticated dynamic energy models, which should provide better accuracy. However, without realistic operational input data even a more sophisticated dynamic model will produce compromised results, a fact that will be discussed later in this Thesis.

Perversely also, in acute hospitals completed over the last decade in the UK there has been little or no incentive to strive for improved energy and carbon performance beyond that which is required by regulation, which as has been demonstrated by the author (p43) will not deliver the absolute reduction in consumption required by the Change Act 2008 (Op Cit). This is because the majority of hospitals that have been delivered in the UK over the previous decade at least, have been funded through the Private Finance Initiative (PFI). Only design and construction risks are usually managed by the PFI whereas operational risks have usually been excluded. Consequently, specifications that establish a clear onus of responsibility on the supply chain can be so constructed that they ignore the needs of sustainability, and in particular the operational energy impacts of the PFI specification.

The author discussed this perspective with Subject Matter Experts[16] when he sought to verify opinion. All the experts were of the same opinion, and that is regardless of what an EPC may forecast, if the client is not prepared to fund an energy model, then accurate forecasts of energy performance will not be possible. Subject Matter Expert, Bellew explains that few clients are prepared to pay for energy modelling because they see little value in it. He also made the point that without substantial sub-metering it is impossible to establish the reasons for poor performance. However in order to achieve at least a ‘B’ rating for the EPC energy modelling will be required. Subject Matter Expert, Bordass, takes a somewhat sceptical view (VOLUME 2, p86), in that engineers can always provide the ‘answer’ that is required:

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[16] For an explanation of how Subject matter Experts have been used by the author please refer to p72.

> *"…and we know about the tweaks that can done on all models. Consequently if somebody wants a particular design solution, a model will be found which shows that it meets the regulations. So you get all of these glass buildings which is a perverse issue – despite the regulations."*

> *Whether or not EPC's are being manipulated or the basis of the calculation is misleading, expert commentators agree that better quality input data is required, for both EPC calculations and DEC benchmarks. This situation is explained succinctly by the UK Green Building Council (Op Cit) report, which stated:*

> *"The most significant development in building science over the last thirty years has been the development of computer models to assess the energy and environmental performance of buildings. These models are now regularly used to assess the potential impact of energy efficient technologies in the design and refurbishment of buildings.* ***However, when buildings are refurbished or new buildings built, they can use up to twice the theoretical energy performance. This is a serious problem, which can significantly impact on the potential for the world to achieve carbon reduction targets."***

The report then goes on to state:

> *"As things stand, the building industry is unlikely to achieve model-based targets in reality and this problem needs to be addressed at a national level.* ***The causes of the discrepancy between model predictions and actual building energy use must first be understood, then incorporated into model structure, input data requirements and the ways models are used. These methodological improvements need to be based on sufficient empirical data rather than further modelling.*** *The tools used in design consultancies need to be able to predict real building energy use, and national policy needs to enable the design process to do that and mandate that it does."*

The need is clear: "*methodological improvements need to be based on sufficient empirical data*". This will be a task for the literature review – to understand what '*sufficient empirical data'* means in practice.

It should now be clear that the acute hospital estate in the UK is under performing relative to the requirements of the Climate Change Act 2008. It also underperforms in energy consumption terms relative to comparable acute facilities in the EU, although why this is the case is not yet clear.

It could be argued that EPC forecasts are unreliable because they provide the client with an unreliable estimate of predictive performance, because it is now well understood that operational performance will usually be very different and usually much worse than the performance potential inferred by the EPC. Yet in the author's opinion a reliable forecast of performance is absolutely necessary if the built environment is to make its contribution to reducing carbon emissions. Without such a forecast how can design and In-Use be coupled so that step-changes in the energy performance of UK hospitals can be achieved – step changes advocated by the previously cited reports from the Royal Academy of Engineering, the National Audit Office and the Innovation and Growth Team?

2.4 Why should these issues be worthy of research?

The author has previously explained that:

1. The health care estate in England is the largest sector of the public estate, representing 25% of it (p33).
2. The sector also contributes to the largest volume of carbon emissions from estate (p33).
3. Government policy is directed towards achieving the requirements of the Climate Change Act 2008 to reduce greenhouse gasses relative to 1990 levels, by 34% by the year 2020, and 80% by the year 2050 (p32).
4. All the indications are that carbon emissions from the public estate are rising and not falling (p43).
5. In overall terms, over the previous three decades, overall energy consumption (which directly translates into carbon emissions) in hospitals in the UK has remained largely static (p41).

These are compelling reasons to understand how this trend could be reversed and absolute emissions from acute hospitals in particular could be reduced. They are worthy of study if one believes, as the author does, that society must embrace a sustainable existence if we are to preserve the future. Worthy too, if one also believes, as the author (who is an architect) does, that uncontrolled energy consumption and carbon emissions resulting from the way in which we use of buildings, has a significant impact on carbon emissions.

This situation was analysed by Swiss RE, reinsurance brokers, studying the risk impacts of global warming: *Building a Sustainable Future, Risks and Opportunities* (SWISS-RE, 2013), the authors illustrate the potential abatement ‘levers’, that should lead to reduced carbon emissions. These are illustrated in Figure 15 below.

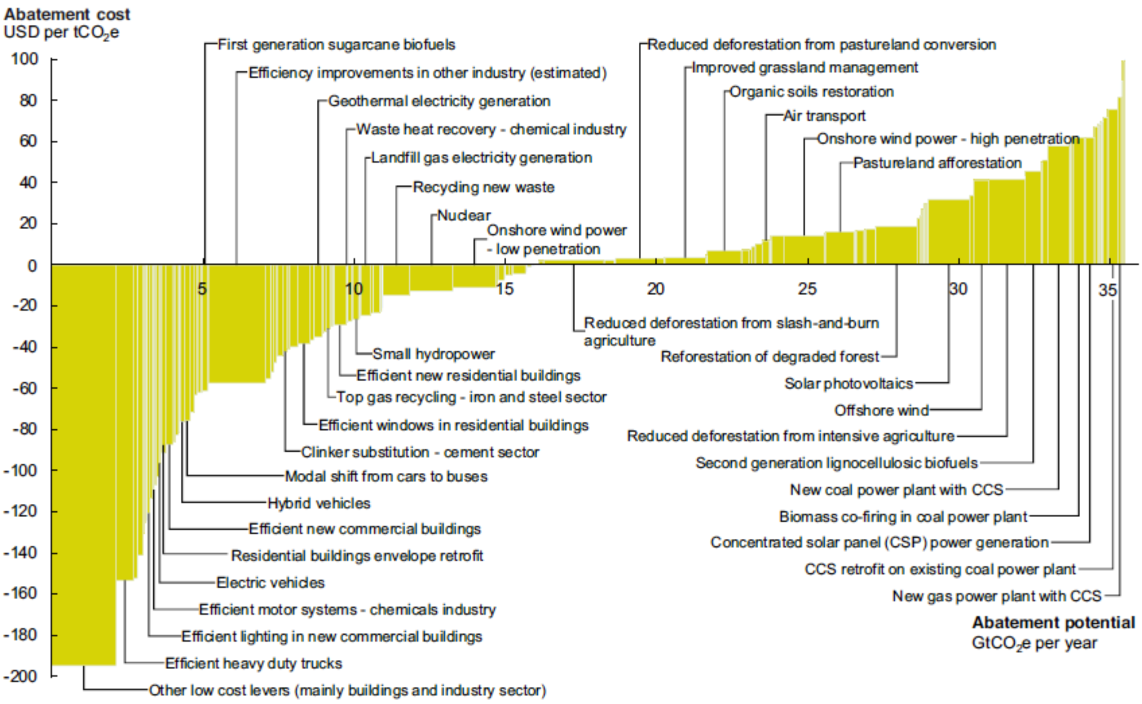

Figure 15 - Global Greenhouse Gas Cost Abatement Curve 2030 (Source: Swiss RE, Op Cit)

Studying the table of abatement measures in Figure 15, six of the fourteen abatement measures relate to the built environment. It is salient to note that none of the levers would appear to focus on how buildings are used, but focus largely on improved asset specifications, which as has been demonstrated by the author, has had little measurable impact in the healthcare sector on overall building energy and carbon performance over the previous three decades. A report by McKinsey & Company (through an international collaboration between industrial companies and academic institutions): *Pathways to a Low Carbon Economy (2009)* emphasises like the Swiss RE report the importance of 'Technical levers' to reduce emissions, suggesting that 38% reduction in emissions could be achieved by such measures, and that only a 4% reduction could be achieved in a lever referred to as: "User behaviour". Whilst the author's qualify their statement:

> *"The estimate of behavioural change abatement was made after the implementation of the technical levers; the change would be higher if modelled before the implementation of the technical levers."*

Even with this qualification the evidence presented earlier in this chapter would suggest substantial potential for behavioural change abatement beyond the 4% anticipated by the report. The author's argument is supported by the Carbon Trust, which in its strategy for 2020 emphasises the importance of "*Better buildings, used better"* (Delay, Op Cit). However, it states that a significant barrier to achievement of this objective is:

> *"Lack of motivation due to transaction costs, **lack of awareness and information, or lack of transparency in building performance."***

Given the findings of In-use, notably those illustrated earlier in Figure 12, the potential to make In-use savings should be substantial – if transparency of building performance can be improved. The DEC data also confirms this potential as was illustrated earlier in Figure 14. The author argues that it will be transparency of In-use that will facilitate this change. Consequentially, one of the outcomes of this Thesis should be to demonstrate an improved understanding of In-Use in order to improve absolute carbon emissions and improved predictability of the forecasting of energy consumption. It follows that the value of this research should also be to demonstrate the importance of understanding the In-use as a lever to improve the energy efficient design of acute hospitals.

How would this be of value to those that commission and design acute hospitals? Would such an understanding, if it were possible to achieve, encourage a change in design and operational practices? How should these benefits be explained? Would translation of them into potential environmental benefits be sufficient? In their book: *Ecology, Economics and Ethics, The Broken Circle,* (Bormann and Kellert, 1991) argue that society:

> *"Must have a better knowledge of the science underlying our environmental problems,* ***we must understand their causes and consequences in relation to our economic and political systems****, and we must recognize that an effective response will require a shift in a technologically oriented society's ethical attitude toward the natural environment."*

Bormann and Kellert argue that considerations for a sustainable environment (Ecology) cannot be separated from Economy and Ethics. In this regard, if this thesis could inform the need for change then it also has the potential to help "*promote a shift in a technologically orientated societal attitude towards the natural environment*". Furthermore, if this thesis could not only seek to understand what needs to be changed in the design and operational processes to achieve improved low energy and low carbon performance, but to demonstrate the economic benefits of such changes as well, perhaps this work could provide an insight into the repair of 'The Broken Circle' as it relates to low energy – low carbon acute hospital performance. Certainly such an argument should also resonate with the public sector at least. (Ullah and Shields, 2011) drafting the final report of the Sustainability Development Commission, (before it was abolished when UK government funding was withdrawn) emphasised the need for a strategy and vision which is:

> *"A public statement of the Government's priorities (i.e. how it will deliver its core business for the long-term in order to achieve better and mutually reinforcing social, economic and environmental outcomes) and principles (i.e. the central organising principles through which all activities are viewed to limit adverse effects and maximise efficiency), which will enable an improved quality of life for all now and in the future, while living within environmental limits."*

Consequentially a larger societal need emerges from this work. Clinical users in acute hospitals in the UK must come to recognise that they have an important role to perform in the efficient use of energy and reduction in carbon emissions. The author argues that the '*a technologically orientated societal attitude'* to deliver improved asset specifications has been at the expense of failing to understand the impact of In-use. Clearly if the technology is not used effectively or is implemented ineffectively, failing to recognise the needs of users, then it follows that our buildings will continue fail to perform to their full potential. As Ulluah and Shields (Ibid) advocate we need to find mutually reinforcing social, economic and environmental outcomes. In acute hospitals the author would translate this into the close coupling of clinical practice, facility use and building engineering physics (Figure 16 refers).

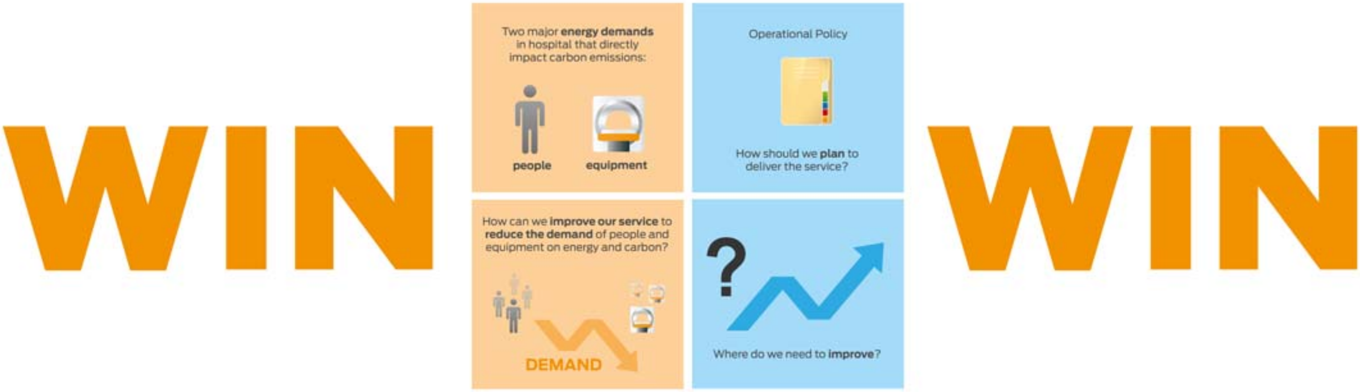

Figure 16 - Coupling of clinical practice facility use and building engineering physics

2.5 Scope of research

Thus far the author has established a scope for the research focussed on two observations a) That energy performance of acute hospital's in the UK has not measurably improved over nearly three decades, and b) Predictions of energy performance in acute hospitals is very often different to actual performance, and usually much worse than was predicted by the supply chain. The research needs to understand the factors that cause these situations to arise. It must consider the building engineering physics that informs the engineering design as much as the working practices over which the science is applied. As previously explained (p19), it is important to understand these issues because of the possibility that the application of the science maybe at fault. Should this be the case then it raises the possibility of the need to enhance our understanding of how the application of building science needs to be improved such that the predictability of outcomes, if not better outcomes, could be achieved. If the application of the science were to be at fault, where might the deficiencies lay? If we cannot isolate these issues, how can they ever be addressed?

In examining these issues the author has considered them from the perspective of theory testing. There is a direct parallel in simulation model testing, (often used in building engineering analysis) as such the same essential methodological components also exist (Judkoff and Neymark, 2006).

Runeson and Skitmore (2008) discuss theory testing and identify the key process factors that have the potential to cause distortions of the predictions in theory. As building engineering physics is founded in the theory of thermodynamics, architecture and engineering it would seem logical to examine these questions through theory testing. The author's identify the following possibilities:

1. Applicability of model
2. Logical validity
3. Measurements
4. Transformations of theoretical concepts
5. Unrepresentative samples
6. Exogenous variables.

Judkoff and Neymark discuss process factors in terms of 'internal' and 'external' error types, but the causal factors remain essentially the same. Considering the possibilities posed by Runeson and Skitmore, it would be logical for the research investigation to investigate the possibility that any one of these process factors is either incomplete or absent from the engineering design process. For example are measurements of In-Use building energy performance so incomplete such that the application of building engineering physics is pre-destined to fail due to inaccurate or inadequate data on which to operate a thermodynamic computation? Or is it because the transformation of the theoretical concepts of thermodynamics to acute hospital design is failing in some way? This could imply that it is the transformation process that is either incomplete of not properly applied. Considering 'unrepresentative samples', could it be that the data sets used in forecasting the thermodynamic performance of the acute hospital are so incomplete that the application of the building engineering physics would then lead to erroneous forecasts and ultimately erroneous results? Alternatively are the 'exogenous variables' so great that they lead to results far removed from the real world experience? If were to be the case, (and the evidence from the early discourse suggest that it might be), then the research would need to consider the sensitivities of those variables in terms of the impact of them on the energy performance outcome of the acute hospital design.

It would thus be reasonable to postulate that it is one or more of the aforementioned process factors concerning In-Use that lead to the poor energy performance and prediction of UK acute hospitals, and in scoping the research, the author proposes that it is these factors that warrant deep study. The author argues that gaining such an insight into these factors may well help society to understand how to achieve improved energy and carbon performance in acute hospitals in the UK. The author's aspiration is that from this new insight it maybe possible for a new contribution to building science to emerge: one that would not just substantially impact low energy-low carbon acute hospital performance, but would also result in the improved predictability of such performance.

Support for this argument is provided by (Underwood and Yik, 2004):

> ***"Incomplete knowledge about the characteristics of system components is a barrier to the development and use of mathematical models that are based on fundamental principles.*** *…Hence if one can derive a rigorous and detailed model, there remain difficulties in finding appropriate values for some of the input parameters for the model, rendering the model not practically usable…"*

This challenge appears to so characterise building engineering physics: the lack of availability of 'appropriate values' resulting in the science unable to make use of mathematical models based on fundamental principles. This issue is central to this thesis, in that the author postulates that the alternative is for engineering designers to establish alternative methods of setting up these mathematical models in the application of building engineering physics. It is here where generalisation, formulaic approaches are often used. Underwood and Yik (Ibid) describe the situation in these terms:

> *"An alternative way of setting up mathematical models for* ***systems is to establish equations to numerically relate the output of the system interest (e.g. cooling capacity or energy demand) to the influential input (e.g. operating conditions) while the systems itself is regarded as a black box****…Obviously, application*

of such a model is subject to restrictions, e,g. it cannot reflect the effects of any factors the influence of which was omitted in the model derivation; and the predictions will be unreliable when the model is applied to situations outside the set of conditions that it was based upon or from where it was derived."

This explains how inadequate data impacts the engineering design process and thus has the potential to lead to misleading results, when mathematical models based in formulaic methods are applied beyond the scope of the intended application[17].

However, would addressing these issues be sufficient to bring about an improvement in these two areas of performance relating to the scope of this thesis? As discussed in the Introduction to this thesis the author has decided to consider the research from the engineering design perspective *informed* by the requirements of the clinical user during the In-Use phase of the building life-cycle. Yet if clinical users chose not to operate the building In-Use as they had briefed the engineering team, then would that not completely undermine any new contribution to building engineering physics? Should not the scope of the thesis seek to understand user behaviour?

The author argues that whilst doubt remains as to the proper application of building engineering physics, then considering user behaviour would add a complex variable into the research before the foundations of building engineering physics had been properly understood. The author wishes to expose the key factors that impact the forecast In-Use energy performance and thus make them transparent through the engineering design process. At present the evidence suggests that they are not transparent (the 'black box suggested by Underwood and Yik (Op Cit). This transparency should, (after the intervention of the enhanced building science) lead to an improved understanding of the causal factors that impact poor energy consumption and carbon emissions.

Consequently, the author expects new knowledge to be created through the testing of the theory of building engineering physics using new data concerning In-use. The author also expects new knowledge to be created through a comparative study of the current application of this science into practice. This will be the scientific endeavour that the author intends to pursue – the merging of theory with practice.

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[17] The work of Underwood and Yik will be reviewed in greater detail in the next chapter.

2.6 Initial Research questions

From the forging analysis in this chapter the author expects it to be possible to provide explicit data to facilitate the development of a comprehensive understanding of In-Use energy and carbon performance. Reason would suggest that without such data users would be 'flying blind' (Bordass, 2001). The inference in the UK GBC report (Op Cit) is that there is a lack of accurate input data for predictive energy modelling:

> *"The causes of the discrepancy between model predictions and actual building energy use must first be understood***"**

Could it be that the same lack of data to inform In-Use operations is what also impacts accurate prediction from the design and engineering teams?

Consequently there are two research questions that are central to this thesis:

a) Why hasn't energy consumption in acute hospitals improved during a period where legislation has sought to improve building energy consumption and the associated carbon emissions?

b) Why is there such a significant disparity between the design aspiration and the actual performance?

In considering these two questions it is important to consider both the ontological and epistemological position of the author. Both research questions are founded in '*how*' and are constructed with the objective of seeking out a new understanding of the factors that impact building engineering physics.

The assumption of the author is that informed with such an understanding new insights might be derived that could provide an improved, if not new basis, for building engineering physics – a science that the author believes is a construct of reality. The author maintains an epistemological perspective bounded by a positivist view of the world.

Yet it is also important to state that the author's assumptions behind these questions that they are consciously not related to a constructivist position where for example, users attitudes, cultural disposition, education even morality in relation to energy consumption and / or carbon emissions – reality which is subjective and thus does not exist independently of us. The is further support for the author's argument that surely it is of prior importance to investigate the proper application of building engineering physics first, and then only after we fully understand these issues pertaining to this do we then attempt to address the reasons of why users might adopt behaviours in the way that they do. This is what the author believes is behind the UK GBC statement quoted above.

How does the author substantiate a positivist position? If building engineering physics is a means by which to describe a conception of reality, logically therefore a measure of building energy performance is measure of reality as interpreted from the laws of thermodynamics. Whilst such 'laws' might be challengeable through science, they exist as interpretations of reality that hold true until they are disproven. That a 'law' might be disproven does not in itself question reality, but surely it only disproves our understanding of the mechanisms of reality? So for example our understanding of heat loss (reality) mechanisms through a solid material at a point in time might change, but it does not change the objective reality that heat loss does occur. An example of this was situation was explained by Subject Matter Expert, Bordass (p**Error! Bookmark not defined.**). He explained that a phenomenon discovered in 2007 (Lowe et al.) referred to as the '*Cavity wall by-pass*', where researchers found that insulated terrace houses were loosing more heat than detached houses. The investigation showed that whilst the building physics was correct, it was the application of it through construction that was incorrect. This arose when the cavity wall was not sealed to the roof space, and as a consequence warm air was able to rise up inside the cavity wall and escape through the cold roof space. In other words it was the mechanisms of reality that were incorrect not our measure of reality in terms of the laws of thermodynamics.

This argument was expressed in these terms (Smith, 2004):

> *"Good ontology and good modelling in support of the natural sciences can, we conclude, be advanced by the cultivation of a discipline that is devoted precisely to the representation of entities as they exist in reality."*

Returning to the first question, informed by the foregoing reasoning, the author contends that we need to understand the mechanisms (reality) of acute hospital energy and carbon performance before we attempt to overlay the role of the user and their attitudes towards energy conservation for example. The first question has a premise based in the science, which is to seek out the scientific understanding of all the factors that impact energy and carbon performance. The second question has a premise based on *'how'* hospital use impacts such performance, but not why users behave the way that they do.

2.6.1 -The research questions in relation to the author's philosophical position

The grounding of both questions in quantitative analysis would be a logical consequence of the aforementioned arguments, if it were not for the fact that how energy is consumed as a consequence of use may involve questions concerning the subjective reality of the efficacy of clinical processes. As noted earlier, the second question has the potential to raise a subjective epistemological perspective, based on user behaviour, and their predilection to conserving energy. Nevertheless the author's concern is that once such subjective decisions have been made, it is then a question of developing a correlation of the impact of those process decisions on the eventual energy and carbon performance of the acute hospital. Consequently the perspective of the author is an objectivist one founded in a quantitative methodology.

Referring to the arguments put forward by the author in Section 2.5 the central issue for research investigation is the enhancement of knowledge (input parameters) applied to the engineering design process in the forecasting of energy performance. Such investigation would lead to a quantitative research methodology and which could provide the accurate input parameters for the model advocated by Underwood and Yik (Op Cit).

The second research question also raises an obvious line of enquiry concerning how well the engineering science applied in the engineering design process is informed by the users requirements? This presupposes that the engineering profession fully understands what types of requirements are needed to properly inform the building engineering physics. This is not to suggest that it does not, but perhaps it does not implement the science rigorously enough? This must be an area of investigation in the next chapter: Literature Review.

Despite the somewhat ‘polarised’ view of the author, there could remain potential for a ‘negotiation across the positivist – constructivist divide, where there is a place for a critical reality, that enables users to be informed by the consequences of their value judgements? Perhaps in considering the second research question there is the possibility to elicit users’ opinions of energy consumption and carbon emissions (perhaps through validation of data) and so use that knowledge to inform the design and engineering process?

It is here where the objectivist ontological arguments arise. This is because the question of how users carry out their working practices has both an ontological constructivist perspective: i.e. working practices arising out of social interaction, or an objectivist ontology where social actions are subsumed in practices concerned with achieving pre-specified clinical outcomes that are both measurable and objectively evaluated and thus potentially devoid of social interpretation. Whilst the reality of practice maybe somewhere between these two positions, the author wishes (for the purpose of quantitative data extraction) to focus exclusively in an objectivist ontological methodology.

In seeking to understand the issues relating to the research questions the author will summarise current knowledge and then investigate the gaps in our knowledge that lead to this situation. New research questions may then emerge, and it will be from these that the potential contributions to knowledge could then emerge.

2.6.2 - Investigation into the research questions: Literature review

Developing the arguments set out in the opening paragraph of this chapter, in seeking to understand current knowledge the author suggests that there are two obvious perspectives:

- Engineering practice relation to the analysis and the forecasting of In-Use hospital energy performance.
- Theory relating to the analysis and the forecasting of In-Use hospital energy performance.

Concerning the former, the engineering practice perspective would seek to understand building engineering physics and the implementation of it through best practice, design guidance, and standards. The latter, from a theoretical perspective would seek to understand current theory, testing of theory, and research into new knowledge.

The author argues that it would only be through a study of the literature from both perspectives that a complete understanding of current knowledge could be obtained. This is also consistent with the arguments developed by the author in the Introduction, in that the reasons for poor forecasting and poor in-use energy performance may indeed be related. The relationship may conceivably be either through poor application of building engineering physics (practice) or it maybe related through inadequacies of building engineering physics (theory), where science fails to address the precise needs of low energy – low carbon acute hospitals. These are the challenges for the literature review.

2.6.3 - Literature review methodology and key sources

The key sources for the literature review with a focus on the science and on practice of building engineering physics would be:

- Journals
- Specialist books
- Peer reviewed conference papers
- Institutional publications
- Government publications
- Web sites

Both research questions imply the key need is to understand building engineering physics, as well as the challenges for practice in the application of the science.

Journals. The initial literature scan identified the following journals as providing relevant scientific papers for the literature review.

- Automation in Construction
- Applied Energy
- Building and Environment
- Building Services Journal
- Energy and Buildings
- Journal of Building Performance Simulation
- Journal of Building Research and Information
- Journal of Building Physics
- Journal of the Operational Research Society
- Journal of Operations Management
- British Medical Journal

Books. The author has selected two key works in order to understand the science.

- **Building Performance Simulation for Design and Operation.** Authors: Hensen and Roberts, 2011.

  The book provides detailed analysis of all types of simulation from the perspectives of:

  - The arguments for the use of simulation and the risks associated with it.
  - Explanations of the different forms of simulation that are possible and they have been applied.
  - Examples of the application of simulation in the application of building engineering physics.

  The book is particularly relevant to this thesis because it provides wide reference to all forms of building performance analysis, and which would enable a comprehensive understanding of the practice of energy modeling. This contrasts with the second book, where the focus is on the theory of energy in buildings and the application of building science using computational analysis.

- **Modelling methods for Energy in Buildings.** Authors: Underwood and Yik, 2004.

The authors provide a detailed explanation of the science of thermodynamic principles as well as how the science can be applied in practice. They explain the constraints of the science as much as the constraints of the simulation and analytical models that are used by engineers.

The book discusses the principles of thermodynamics in buildings. It explains how heat transfer takes place and then discusses the modelling implications based on how the science is applied.

At the outset of the book the author's explain how the science should be applied in practice. A key statement relevant to this thesis is:

> *"**Quantification of the annual energy use in buildings requires the predication of the space cooling loads of individual rooms in the building that would arise at different times in the operating periods throughout the year.** This involves determination of the heat and mass transfer through the buildings envelope that are significant parts of the heat and moisture gains or losses of an indoor space. The other sources of heat and moisture gains include occupants, equipment, and appliances present within the air-conditioned spaces and infiltration."*

This statement is significant because it serves to emphasise how the science should ideally be applied from an analysis of all spaces and not from an estimation based on formulaic principles. The book is of particular relevance to this thesis because it studies in detail a major aspect of building engineering physics, which is concerned with the buildings energy performance. It discusses the impact that different assumptions (explicit or implicit) could have on the results.

Peer reviewed conference papers

- The two most notable conferences where the issues of low energy- low carbon building performance and the use of computational and simulation technologies is discussed are:
    - Building Simulation
    - Building Simulation and Optimisation

Institutional publications. The most notable reference sources are:

- The Chartered Institute of Building Services Engineers (CIBSE). They provide technical guidance for engineering practice.
- Royal Institute of British Architects (RIBA). They provide guidance for practice and the RIBA Plan of Work.
- Publications from Europe such as HOPE – European Healthcare and Hospitals Federation and the World Health Organisation (WHO).

Government publications. The most notable reference sources are:

- Department of Health. They provide Health Technical Memoranda (HTM's) and Health Building Notes (HBN's).
- National Audit Office. They provide a valuable source of critical review of UK Government policy and performance. The most notable publication was titled: Sustainable Construction and Refurbishment of the Government Estate (NAO, 2007)
- Sustainability Development Unit (SDU). The Unit provides regular carbon updates for the health sector. Their most notable publications are their Carbon Footprint Reports (SDU, 2012)

Web sites. These are relevant because they can be important sources of papers and links to other information sources.

- Building simulation.
  - UK site for the International Building Performance and Simulation organsation: http://www.ibpsa-england.org
  - US site for the International Building Performance and Simulation organsation: http://www.ibpsa.us/publications.shtml
- Healthcare planning and improvement.
  - Healthcare without Harm: http://noharm.org/

- UK research centre for health improvement: http://www.nihr.ac.uk/research/Pages/default.aspx

- Low energy – low carbon building and hospitals.
    - UK Green building Council: http://greenbuildingcouncil.net/
    - Carbon Trust: http://www.carbontrust.com/home
    - Sustainability Development Unit: www.sdu.nhs.uk
    - Green hospitals: www.greenhospitals.net

1. Engineering design and standards for low energy performance
    - Whole Building Design Guide: www.wbdg.org
    - Usable Buildings (post occupancy studies focused on building performance): www.usablebuildings.co.uk
    - CIBSE: www.cibse.org.uk
    - ASHRAE: www.ashrae.com
    - CIBSE Engineering Design Process: http://www.cibsedesigncompass.org.uk/public-health

Chapter 3.0 - Literature review

3.1 Chapter overview

From the foregoing chapter the reader will have understood that the author suggests that there are two perspectives of In-use energy and carbon performance: one related to application of theory in practice, and one related to the development of theory. For these reasons the literature review is structured from these two perspectives.

In Section 3.2 the author commences the discussion with a focus on how knowledge is codified in professional practice. The reasoning for this is because there is a question in the author's mind as to how reliable perspectives of practice are for the purpose of the literature review, which is to understand current knowledge. For this reason the author then discusses the introduction of Subject Matter Experts – people that the author considers possess unique insights into the area of study, and with whom he has had the privilege of working. The transcripts of the authors semi-structured interviews are included in the Appendices, and apart from verification of key findings the interviews, the qualitative information provides a valuable insight into current practice of low energy – low carbon performance in the built environment.

By way of an introduction to practice, the author introduces the key aspects of building engineering physics. This is important because without a basic understanding of the physics, how could the application of the physics in practice be properly understood?

In both this section (Practice) and the following section 3.3 (Theory) the author takes two key works for reference – one for each section, and analyses them with regards to the focus of each section. It is through this analysis that the author seeks to synthesise established current knowledge. Through discussion the author attempts to identify the gaps in current knowledge, and seek verification of these gaps from the Subject Matter Experts. Section 3.2 concludes with a discussion as to how uncertainty is managed in practice. The author has framed the investigation in this way, because it is apparent from the research that much uncertainty exists in practice and the way that uncertainty is managed can directly impact the energy and carbon performance of the building. In the same way, the author concludes Section 3.3 with a discussion as to how uncertainty is managed in theory.

In Section 3.3 the author commences with a discussion on the role of computational simulation in helping researchers to understand how simulation is being used to advance the acquisition of knowledge, particularly with regards to the causal factors of energy consumption and carbon emissions in the built environment. Section 3.3 concludes with an analysis of building engineering science. This work leads into the application of theory in research. It is here where the knowledge gained from understanding the physics in Section 3.2 is used as a basis for understanding how research has sought to investigate the causal factors of energy and carbon performance.

In Section 3.4 the author then summarises the gaps in knowledge, and these are synthesised into three themes. It is these three themes that are carried though in the remaining chapters of this thesis. In this section the author provides a detailed reasoning, based in the review of literature, as to the justification of these gaps. Verification of these gaps is also sought from the Subject Matter Experts. The Section final part of this section sets out the author's proposition for low energy – low carbon acute hospital performance. This Section then leads into a detailed discussion as to the point of departure, and a conceptual analysis of the three themes expressed as research challenges. The author then summarises these into three research objectives.

3.2 The practice of engineering design in relation to energy forecasting and associated carbon emissions in buildings (with emphasis on acute hospital buildings)

The reader will now be familiar with the author's line of enquiry that it maybe the inadequate application of building engineering physics that leads to poor energy and carbon performance, as much as poor predictability of that performance during the engineering design process. This section of the literature review is thus focused on engineering design practice with particular emphasis on the application of the science through the briefing and engineering design process. This raises a question: whilst the application of the science can be appreciated for the engineering design process, it not so evident why it is applicable to the briefing process? The answer to this challenge is as identified by Underwood and Yik, (see p56) in that it is possible that 'appropriate values' are not gleaned in the briefing process such that they could be used to inform the early stage analysis for the engineering design. The literature review must then seek to inform the chosen line of enquiry through a review of practice. However, to be clear, the review of practice is not concerned with opinion as to how engineering designers typically execute practice, but what the professional standards or guidance requires for practice. Consequently, the basis of this section of the literature review is to understand how practice has been codified into actionable knowledge.

3.2.1 - The challenge of accessing codified knowledge (relevant to the research questions)

Knowledge requires codification if it is to be reusable, (Nonanka and Takeuchi, 1995. Kamara et al., 2002. Bacon, 2008.). However, Kamara et al (Ibid) also acknowledge that commercial organisations in the construction industry find it very difficult to effectively manage knowledge. They point to the fact that knowledge management tends to be predominantly project focused and consequently less concerned with the generation of new knowledge. Ideally it would be the creation of new knowledge that would be codified by institutions for reuse by their associated professions. It is apparent therefore that there are two key sources of knowledge in the industry concerning practice: that which exists within commercial organisations, and that which has been codified by professional institutions or membership organisations.

The need to capture and codify new knowledge in a fragmented construction industry was discussed by the UK Government sponsored Innovation and Growth Team (IGT, Op Cit). The report asserted that there was a poor understanding of best practice as well as wide diversity of opinion as to what knowledge is required to achieve low carbon performance in the built environment in the UK. It stated:

> "This will require innovation – ***new ways of working and the acquisition of knowledge and skills*** *that will provide competitive advantage at home and internationally, building on the United Kingdom's reputation as a world leader in sustainable design."*

The challenge would be to either identify sources of codified knowledge (desirable) or to codify knowledge though survey and interviews of practice (least preferable). With divergence of opinion as to how to achieve low energy – low carbon performance in the industry a survey of practice would in all probability confirm that divergence of opinion. Recent evidence (Kershaw and Simm, 2014) (albeit with the focus being low carbon school design) confirms the findings of the IGT report. The author's lists reasons for obstacles to low carbon performance such as: increased equipment in modern schools, complexity of building systems and the perceived extra cost of low carbon design and technologies. Interestingly and of particular relevance to this thesis the authors suggest that most barriers could be overcome by improving communication between the design team, client and end users, and that truly integrated design teams are the key to mainstream low carbon school design. The very challenges that are identified by the author's research questions.

The argument thus leads to the need to investigate codified knowledge i.e. that which is embodied in standards and codes of practice. Yet even this has its limitations, the criticism being concerned with how it has been interpreted (Guzman and Trivelato, 2007). They cite what amounts to a constructivist predilection as a reason for this by using examples such as: assumptions, context and tacit elements as being limitations of codified knowledge. The risk here is that even codified knowledge has limitations, not least of which is its currency. The author suggests that it is commonly understood that institutions tend to lag behind industry in codifying knowledge. This presents another risk concerning the relevance of that knowledge to current practice. It is also a risk to this thesis in that it could throw doubt onto what the author would have analysed as gaps in current knowledge.

3.2.2 - Codified knowledge

Accepting the limitations of codified knowledge within institutions and membership organisations, (because it is the best that is available) the most obvious focus of study into the practice of engineering design in the UK would be the governing institute for the profession, which is the Chartered Institute of Building Services Engineers (CIBSE). Like all professional institutes it should be expected that this institute is the focus of current knowledge too. The CIBSE web site states that its role is to[18]:

> *"…support the Science, Art and Practice of building services engineering, by providing our members and the public with first class information and education services and promoting the spirit of fellowship which guides our work."*

It also states that it is:

> *"…the standard setter and authority on building services engineering. It publishes Guidance and Codes which are internationally recognised as authoritative, and sets the criteria for best practice in the profession."*

Whilst other sources such as BSRIA will also provide commentary on practice CIBSE has attempted to codify knowledge into guidance and best practice. A good example of this is the CIBSE Technical Memorandum 54 (Cheshire and Menezes, 2013). In this document the authors set out to explain current knowledge concerning the performance gap, that which explains the poor forecast performance of new buildings. Considering the author's earlier comments in this chapter, Subject Matter Expert, Bordass explains (Volume 2, p97) that codification of knowledge is often imperfect, because 'what the industry does know' has not been translated into the guidance – indeed he asserts that it can take years before it is consolidated:

> *"In the UK, we have not understood with the 'roll back' of the State, the role professional institutions should play and how to put sufficient horse-power into creating and revising standards and Guides"*.

TM54 written in 2013, is an example of the concern expressed by Bordass when he claims that the 'credibility' gap has been understood through case studies for many years (B. Bordass et al., 2004). Another obvious institutional source of codified knowledge will be from the Royal Institute of British Architects. From a study of its web site, it is apparent the institute considers its role as a facilitator of research, and less concerned with codification of architectural knowledge, and in particular the achievement of low energy – low carbon performance. However, the significant

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[18] See: http://cibse.org/index.cfm?go=page.view&item=37

exception to this concerns the investment in the RIBA Plan of Work, which received a major update in 2013. This will be discussed later in this thesis.

3.2.3 - Subject Matter Experts

For these reasons the expert opinion sought by the author from known experts on specific statements in this thesis would serve to identify leading knowledge, not yet codified by institutions. This was achieved through semi-structured interviews and these are set out in the Appendices.

Concerning a Subject Matter Expert for building engineering physics in the UK one of the most respected engineers in the industry is Professor Patrick Bellew, Royal Designer for Industry (RDI), one of only a few professionals in the construction industry that have achieved this status. As a founder of the Green Building Council and Visiting Professor at Yale University in the United States he operates at the forefront of building engineering physics. His wide international experience would provide a breadth of opinion that would challenge the author’s statements should they be deemed to be invalid.

The second Subject Matter Expert is Mr. Stephen Runicles, Engineering Director for the Building Design Partnership and also responsible for the engineering design for the 3Ts Redevelopment, which has provided the case study for this thesis. The author argues that application of building engineering physics in the project provides an objective basis for validation of the author’s findings in the literature review. Indeed as will be demonstrated later in this thesis, the case study will provide a detailed explanation of the challenges of current practice in implementing building engineering physics to achieve low energy – low carbon performance for an acute hospital.

Concerning the Subject Matter Expert for In-use, one of the most recognised experts in the UK concerning In-use is Dr. Bill Bordass who was a principal investigator in the PROBE studies carried out during the 1990’s and early years of the following decade. He was significantly involved in the research projects that led to the definition of operational rating for non-domestic buildings and now known as Display Energy Certificates. He was also co-author of the Soft Landings Framework, which helps design and building teams to focus their projects more on performance In-use.

A final consideration in the use of Subject Matter Experts was that of the ethical considerations. By including the full transcript of the interviews in the Appendices, there will be concerns of informed consent addressing such matters as anonymity, confidentiality and data protection. The author's proposal was subject to the university Ethics Approval Process and thus the rights of the individual's concerned were addressed through this process.

3.2.4 - Engineering design practice: application of the science

The application of the building engineering physics in practice as it applies to the energy performance of buildings is set out by (Olesen, 2007). The paper establishes the requirements for compliance with the European Directive for Energy Performance of Buildings (EPBD). Olesen (Ibid) establishes a fundamental principle at the outset:

> *"The energy consumption of buildings depends significantly on the criteria used for the indoor environment, which also affect health, productivity and comfort of the occupants…*
>
> *There is therefore a need to specify criteria for the indoor environment for design, energy calculations, performance evaluation and display of operation conditions of the building."*

Not only are the criteria for energy consumption clearly established – particularly pertinent given the research questions, but also at the outset it establishes the need for briefing criteria. Where would an engineering designer find guidance on such criteria?

As has been explained in the UK, CIBSE has codified best engineering practice and theory into design guides. In seeking to understanding the impact of users on energy consumption in buildings, the most relevant of these is set out in CIBSE Guide F Part 2, *Energy Efficiency in Buildings*, (CIBSE, 2004). It describes three key factors that affect energy consumption in buildings. These are:

a) Building Services,

b) Building Fabric and,

c) Human Factors.

These factors combine in the building system, as described in Figure 17.

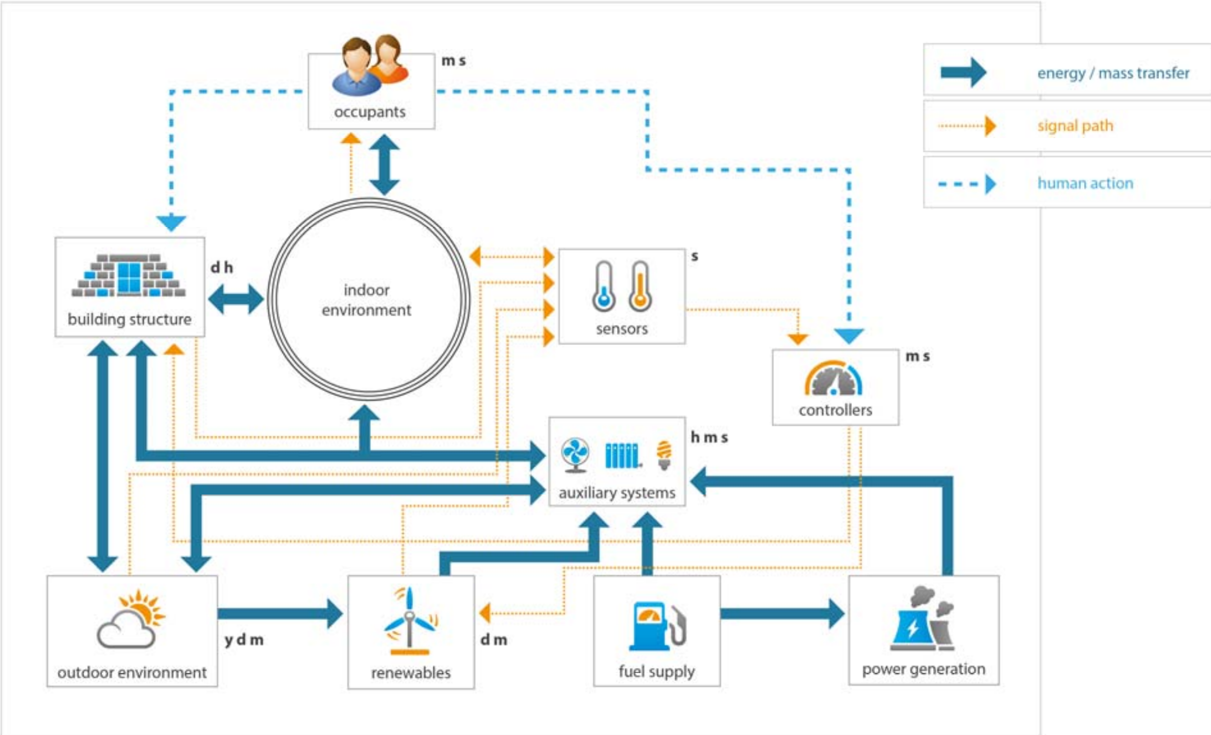

Figure 17 - The building as an integration of energy systems – based on Hensen (2000)

In studying the illustration the ‘Internal environment’ it will be observed that it is impacted by a number of factors, which are:

- The role of the occupant, which can be in terms of the number of occupants, the activity of the occupants and their physiological tolerance for example, to heat, humidity and pollutants in the air.
- This tolerance impacts their interaction with the ‘Building structure’, such as the need for fresh air, through the opening of windows for example. This action will be influenced by the ‘Outdoor environment’.
- The ‘Occupants’ will react to the ‘Internal environment’ by placing demands on the systems that condition it, and in doing so they will interact with ‘Controllers’ that will send instructions to the engineering systems to modify the ‘Internal environment’ to provide a level of comfort appropriate to their needs.

- The ‘Controllers’ can also be activated by ‘Sensors’. These detect changes in the ‘Internal environment’ and which result in them transmitting instructions to the ‘Controllers’ to modify the ‘Internal environment’ such that it is now within acceptable comfort limits that were configured in the ‘Sensor’.
- ‘Auxilliary systems’, such as fans, radiators and lighting also impact the ‘Internal environment.’ These make demands on ‘Power generation’, ‘Fuel supply’ and ‘Renewables’.

The most significant message of this illustration is that it is the needs of Occupants that places demands on the Internal environment – in other words it is not buildings that consume energy per se – but it is the users of buildings (Janda, 2011). Clearly users have basic needs for comfort, but our expectations as users is that we have been conditioned for many years by the expectations of the consumerist society in which we live. Part of that conditioning is that we take for granted that the ‘Internal environments’ of the buildings in which we live and work can be controlled automatically with little or no occupant intervention and little regard for our actual needs. The conditioning leads us to have expectations on the systems that deliver the ‘Internal environment’ to be highly responsive (or even immediately responsive) to our ‘wants’ as distinct from our needs. For example users may want the room temperature to be 24 deg C, but we only need to it to be 21 deg C, if we were to wear appropriate clothing. Users may want hot water to be delivered at the spout within 3 seconds of turning on the faucet, but the need maybe more like 10 seconds. Both examples impact energy consumption. In their work on adaptive thermal comfort Nicol and Humphreys (2002) suggests that the human needs for thermal comfort are universal. They compare studies carried out between the UK and Pakistan to substantiate this observation. Whilst this may be so for many building types, in a hospital where patients thermal regulatory functions are compromised this cannot be the so. Indeed the wide variances of patient types suggest that the comfort range can be wide as well. A study in Swedish hospitals emphasised these distinctions through quantitative analysis techniques (Skoog and Jagemar, 2005) and also (Verheyen et al., 2011) where they carried out a study of thermal comfort of different patient types in Belgium hospitals.

In each case the sensible and latent heat gains will be different. Anecdotal evidence suggests that renal dialysis and chemotherapy patients for example are much more susceptible to variances in room temperature than healthy people. Likewise there will be variances in thermal tolerance between sedentary users and active users, and the elderly user compared to the younger user, where in each case, the former is more likely to be acutely aware of variances in temperature than the latter, a point emphasised Nicol and Humphrys (Ibid), and supported through detailed analysis (Collins et al., 1977)

Returning to Olesen (Op Cit) the author sets out the standard design criteria to be used for different types of accommodation and different types of use, based on activity. This immediately raises a question: In an era of energy conservation, how much do these ‘standards’ impact energy consumption? Olesen has already made the point that the criteria have a significant impact on consumption, and it thus follows that if those criteria could be refined (even optimised) then surely this it could be expected for forecast consumption to fall? How might this be achieved?

The ‘Sensors’ have been set up to monitor typical parameters for the ‘Internal Environment’ that are acceptable to the needs of most ‘Occupants’. These monitor the environmental parameters of what is known as Indoor Air Quality (IAQ), and are configured for heat, humidity and pollutants as described earlier. The ‘Sensors’ may or may not be configured to detect occupants in a space. They may only be configured to condition a space within the preset parameters – the very parameters cited by Olesen (Op Cit). If Sensors and Controls were not to be accurately configured for use, it would result in spaces being conditioned regardless of the occupant presence, and thus the building being effectively ‘preconditioned’ to use much more energy than is actually required. How could this situation arise? The engineers that specify the ‘Sensors’ and the ‘Controllers’ may do so in ignorance of how the building will be used. Consequently they might make assumptions concerning use, and it is these assumptions that set the operational parameters for the ‘Sensors’ and ‘Controllers’.

However, Part L2A of the UK Building Regulations 2013 Edition (NBS, 2013) sets out the requirements of control engineering services to prevent this situation arising.

In section 2.43 of the regulations it states:

> *Systems should be provided with appropriate controls to enable the achievement of reasonable energy efficiency in use.*

It then defines what is 'reasonable':

> *The systems should be sub-divided into separate control zones to correspond with each area of the buildings that has* ***significantly different pattern of type of use****; and*
>
> ***Each separate control zone should be capable of independent timing*** *and temperature control and, where appropriate, ventilation and air recirculation rate; and*
>
> ***The provision of the service should respond to the requirements of the space it serves****. If both heating and cooling are provided, they should be controlled so as not to operate simultaneously and*
>
> *Central plant should operate only as and when the zone requires it. The default position should be off.*

The Building regulations are emphatic as to how the engineering systems design should be controlled. In this literature review the author will seek to understand how the engineering design briefing process implements these requirements, and how guidance from the Department of Health, Health Technical Memoranda relating to engineering services design also ensures compliance with the legislative requirement of the Building Regulations. The legislative requirement raises an important question: how does engineering practice seek to understand the impact of the building occupant on the engineering design? It is important because the legislative requirement clearly expects the use of the facility to be clearly understood as emphasised by the bold text in the above listed extracts from the Building Regulations Part L2A.

3.2.5 - The impact of the building occupant on building engineering design

(Kwok and Lee, 2009) describe how these factors (illustrated earlier in Figure 17) combine in an office building:

> "*In an office building occupants may use diverse electrical appliances as well as lighting appliances tending internal heat gains and the consumption of electricity. In parallel to*

> *consumption, occupants produce waste, both in the form of solid and vapour. All of these effects resulting from occupant behaviour collectively play an important part in determining the extent of single building's need for cooling, heating and ventilation, as well as the amount of the electricity and water consumed and the quantity of the solid waste and wastewater produced within it."*

These same factors apply to the majority of building types, including acute hospitals. Concerning Human Factors (occupants needs), the CIBSE Guide F, (Op Cit) identifies the following:

- Comfort requirements
- Occupancy regimes
- Management and Maintenance
- Activity
- Access to controls

The Guide F explains that (Op Cit, Section 2):

> ***"The most significant influence in energy efficiency is often the way the building is used by the management and occupants.*** *Hence, the principles of energy efficiency at the front of this guide place great emphasis on management issues.* ***Activity, hours of occupancy, control settings etc. all vary enormously and represent the greatest unknown at the design stage. Designers need to take account of this variability and promote better building management through improved design.*** *A good management regime, which is responsive to the needs of the occupants and fully in control of the building, can have a major effect on energy consumption."*

In this short paragraph the essence of what is required for briefing is set out. There is no ambiguity and emphasis is established in '*management issues'*. In terms of these issues as they relate to hospital operations the author will demonstrate that none of these are unlikely to be known at this stage, not least because hospital operations are one of the most explicitly managed of any building type. Later in Section 2 the guide then sets out the requirements for the 'Energy Efficient Brief'. It identifies the following key aspects of this brief:

- *The client's intentions, requirements and investment criteria*
- *Energy targets for each fuel and individual end uses e.g. based on benchmarks from Section 20*

- *Environmental targets e.g. BREEAM[19] credits*
- *Life cycle costs*
- *The intentions to include energy efficient equipment, based on certified performance information where available*
- *A requirement to undertake integrated design.*

It could be considered surprising that there is no mention in the "Energy Efficient Brief" of anything concerned with In-Use, particularly with respect to Occupancy, given the importance of understanding:

> *"The most significant influence in energy efficiency is often the way the building is used by the management and occupants."*

How significant is the impact of use and indeed of user behaviour on building performance? Referencing CIBSE Guide A (CIBSE, 2006b) it states:

> "*In the design of air-conditioning systems the internal heat gain may contribute a significant part of the total cooling load and it is therefore important that all such gains be included...**over estimating internal heat gains may result in over-sizing of plant leading to higher capital costs of plant, poor part load performance and increased running costs**."*

The guide states that the internal heat gains in buildings primarily arise from four sources:

- Lighting
- Equipment
- Occupants
- Electrical motors

The essential science concerning the impact of occupants on the internal heat gains is well understood (CIBSE Guide A, Ibid). It is understood, for example that, occupants contribute to the heat gains to the buildings either directly (sensible gains) or indirectly (latent gains).

[19] Building Research Establishment Environmental Assessment Methodology

Figure 18 - Human thermal plume (SETTLES)

The illustration in Figure 18 illustrates the rising heat (thermal plume) from a human body (sensible gains) and the vapour emitted through exhalation (latent gains), it is through the latter that heat as moisture is added to the space into which it is emitted. In considering these issues the engineer will seek to ensure that the occupant serviced spaces produce comfort conditions (appropriate Indoor Air Quality) through appropriate heating, cooling and ventilation. In an acute hospital environment the amount of heat gains to a space will be determined by both the quantum of occupancy as much as the type of occupancy (CIBSE Guide A, Op Cit). As explained earlier on p76, heat gains from inpatients will be different to those from outpatients, where in the former, the patient is likely to be sedentary whereas in the latter they are likely to be more mobile. Referring to CIBSE Guide A, the differences between occupancy types are summarised in Figure 19 over-page.

A question then arises at this stage. How does the engineer in practice quantify these potential heat gains (which are then translated into a cooling load or a reduced heating load) and over what duration would each space in the building be subjected to these gains?

Table 6.1 Heat emission (W) from an adult male body (of surface area 2 m²) and average heat emission per person for a mixture of men, women and children typical of the stated application

Activity	Typical application	Occupancy density (m²/person)	Total, sensible and latent heat emission (W) for stated application and dry bulb temperature (C) for adult male (and average for mixture of men, women and children)										
			Total	15		20		22		24		26	
				Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent
Seated, inactive	Theatre, cinema matinee	0.75–1.0[2,3]	115 (100)	100 (87)	15 (13)	90 (78)	25 (22)	80 (70)	35 (30)	75 (65)	40 (35)	65 (57)	50 (43)
Seated, inactive	Theatre, cinema evening	0.75–1.0[2,3]	115 (105)	100 (91)	15 (14)	90 (82)	25 (23)	80 (73)	35 (32)	75 (68)	40 (37)	65 (59)	50 (46)
Seated, light work	Restaurant	1.0–2.0[2,3]	140 (126)	110 (99)	30 (27)	100 (90)	40 (36)	90 (81)	50 (45)	80 (72)	60 (54)	70 (63)	70 (63)
Seated, moderate work	Office	8–39[4–6], 14[4,7]*	140 (130)	110 (102)	30 (28)	100 (93)	40 (37)	90 (84)	50 (46)	80 (74)	60 (56)	70 (65)	70 (65)
Standing, light work, walking	Department store	1.7–4.3[2,3]	160 (141)	120 (106)	40 (35)	110 (97)	50 (44)	100 (88)	60 (53)	85 (75)	75 (66)	75 (66)	85 (75)
Standing, light work, walking	Bank	—	160 (142)	120 (107)	40 (35)	110 (98)	50 (44)	100 (89)	60 (53)	85 (76)	75 (66)	75 (66)	85 (76)
Light bench work	Factory	—	235 (209)	150 (133)	85 (76)	130 (116)	105 (93)	115 (102)	120 (107)	100 (89)	135 (121)	80 (71)	155 (138)
Medium bench work	Factory	—	265 (249)	160 (150)	105 (99)	140 (132)	125 (117)	125 (117)	140 (132)	105 (99)	160 (150)	90 (85)	175 (164)
Heavy work	Factory	—	440 (440)	220 (220)	220 (220)	190 (190)	250 (250)	165 (165)	275 (275)	135 (135)	305 (305)	105 (105)	335 (335)
Moderate dancing	Dance hall	0.5–1.0	265 (249)	160 (150)	105 (99)	140 (132)	125 (117)	125 (117)	140 (132)	105 (99)	160 (150)	90 (85)	175 (164)

* Recommended

Notes:

(1) Figures in parenthesis are adjusted heat gains based on normal percentage of men, women and children for the applications listed. This is based on the heat gain for women and children of 85% and 75% respectively of that of an adult male.

(2) For restaurant serving hot meals add 10 W sensible and 10 W latent for food per individual.

Figure 19 - CIBSE Guide A - Heat emissions from a human body

Referring back to the quotation from CIBSE Guide F:

> *"Activity, hours of occupancy, control settings etc. all vary enormously and represent the greatest unknown at the design stage."(CIBSE Guide F, Op Cit)*

This is because the nature of occupancy in buildings is not well understood. Wang et al. (2011a) observes that:

> *"Occupant behavior, as a basic factor in building performance, still remains a big issue because of its stochastic nature in time and space."*

Consequently, whilst the contribution of the occupant in terms of heat gains that they make to the environment around them is understood, understanding the specifics of occupancy density in any space at any time of the day is not well understood as explained by the citation above. It is the stochastic (variability) of occupancy, related to activity (CIBSE Guide F, Op Cit) that is the key understanding that needs to be developed. Hence being the guidance by CIBSE that this is the '*greatest unknown at the design stage*'.

It is at this juncture that some of the theory of use needs to be discussed. It will be the brief examination here of the theory that will help place the practice in context.

Whilst the nature of occupancy in many building types will be largely stochastic (variable), within heavily process related building types it could be argued that occupancy could be more predictable, because it would be impacted by those processes. Acute hospitals and airport terminals are obvious examples of the latter, because they are largely managed by sophisticated organisational processes. Certainly Degelman (1999) alludes to this when he states that energy analysis is only capable of accurate predictions if the use of the building is predictable and routine. For buildings that do not conform to '*predictable and routine processes*' there would be a clear challenge, a point that shall be returned to in the next section. Studies by Haymaker and Clevenger (2006) show that predicted energy consumption changes by more than 150% using all high and low values for what experts believe reasonably represents occupant behaviour.

The difficulty in predicting occupancy impacts, without comprehensive briefing data, inevitably results in the need to make unreliable assumptions which can have large implications on building performance design (P. Hoes et al., 2009). Could it be that it is these assumptions concerning occupancy is a reason for the substantial inaccuracy in forecasting energy consumption that was raised in the UK Green Building Council report (Op Cit)? An attempt to understand occupancy patterns in office buildings (and so enable assumptions to be challenged) was carried out by Chan and Hong in open plan offices (2013). They studied the stochastic variability of switching lights in open plan office cubicles, and reasoned that this could provide a reliable basis for occupancy. They then used the data from this study to ascertain the probability of occupancy in this type of space.

Returning to practice, the engineer will invariably use guidance to estimate the internal heating loads (or indirectly through the use of thermal modelling software), and may reference guides such as CIBSE Guide A (Op Cit) and specifically the data from the chart illustrated in Figure 19. Yet as pointed out by Subject Matter Expert, Bellew (VOLUME 2, p35):

"There are ways of designing without having to analyse occupancy."

Nevertheless, Bellew also accepts that the alternative is to make large assumptions, the size of which will vary according to what In-use data concerning occupancy or knowledge of the heating and cooling loads of the internal environment that an engineering designer has access to. It is the difference between engineering design based in the application of building engineering physics, or based on the 'formulaic' and 'rules of thumb'[20].

Returning to the application of the science in practice, is an understanding of '*predictable and routine'* processes as advocated by Degelman (Op Cit) sufficient to predict the impact of the building occupant on energy? Certainly being able to predict occupancy profiles throughout the day would be important as has already been observed. However, can the use of lighting and equipment be treated in the same way? As has already been explained, both of these uses contribute to the internal heating load of the spaces.

Could lighting and equipment use be predicted with any certainty, such that the heating and cooling loads arising form this use can be reliably predicted, or this another area where assumptions need to be made in the forecasts of energy consumption? Certainly M. Donn et al. (2009) believed so:

> *"However, what is crucially missing from the input data to these models is anything but the most crude estimates of many of the factors that are critical influencers of energy performance...there also needs to be better data on assumptions for internal heat gains from occupiers' equipment, e.g. not just the name plate and Energy Star ratings of appliances in the workplace but their true energy consumption, both during standard test cycles and in actual use. Similarly, there is a need to establish real data on the use patterns in terms of occupancy rates, user expectations of performance, user interaction with controls, and user preferences for environmental space quality…"*

With a paucity of understanding as to the impact of the occupant on demand for lighting practice tends to fall back on another 'rule of thumb', which suggests that lighting and other small power loads could be forecast in terms of an allowance per square metre of floor area. In terms of equipment loads it will be shown in Stage 2 of the case study, how the engineers were obliged to make large assumptions concerning the use of equipment, which bore no relation to In-use because they had no data to inform them otherwise.

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[20] The impact of these assumptions on the engineering design process will be discussed later in this thesis in the chapters investigating the case study.

To further illustrate the need identified by Donn et al, in their study of existing acute hospital facilities (Short et al, 2010, Op Cit) studied lighting levels in south-facing hospital wards. They noted that wards in these areas received daylight significantly in excess of recommended illuminance levels (100-150 lux in bedded areas, CIBSE 1989). In the study they measured illuminance levels of 11,000 lux behind the glazed elevation, and at the back of a four-bed ward it was in the order of 1200 lux, which were well above recommended illuminance levels. The authors comment that this contrast is likely to induce a perception of gloominess within the ward, and therefore it was not surprising that the users made use of near-permanent artificial lighting.

The literature review identifies that all internal loads used in the calculation of heating, cooling of the building will be significantly influenced by occupant behaviour, as much as the processes that they are involved in as they work in the building. It is clear too that whilst the building physics of occupancy is understood, it is the lack of a sophisticated understanding of In-Use that would appear to represent a significant gap in our knowledge. It follows that the principles of In-use are all to often not taken into account in the engineering design, because of the lack of empirical data concerning use and In-use processes (B. Bordass et al., 2004), (Hanninen. R et al., 2007). This is also evidenced in the public estate through numerous studies, in addition to that for the DCLG, referred to above. The seminal report in 2007, published by the NAO (Op Cit) concluded that 88% of the buildings analysed failed to achieve the required energy efficiency (and therefore carbon emission) standards advocated by government statute. It also observed that a common lack of empirical data concerning In-use in the two years prior to the publication of the report, resulted in a lack of accurate input data for subsequent developments. A later House of Common Select Committee report in 2008 found little evidence of change in the intervening period (Leigh, 2008):

These factors, notably the variability of use, activity and hours of occupancy as explained by Donne (Op Cit) and specified in the CIBSE Guide F, are the key data inputs required for the accurate engineering of the building, based in building engineering physics. But there is an essential dichotomy, which is that without the empirical data from In-Use as outlined above, how do engineering designers develop *informed* engineering requirements? It might be reasonable to expect the engineer to ascertain activity, hours of occupancy and such like as part of the briefing process, but does this happen? Could it be that the poor-predictability of forecast energy consumption arises because this aspect of the 'Energy Efficient Brief' mentioned in CIBSE Guide F (Op Cit) is all too often silent on these matters (Bacon, 2013)? Could this be another reason why assumptions concerning occupancy need to be made?

It is in relation to this question that the process that establishes the basis of engineering design needs to be understood. From a process perspective, engineering designers may follow one, such as that set out in the CIBSE Design Framework[21]. The framework recommends the use of CIBSE Knowledge Series publication: KS8 (Race-CIBSE, 2006).

Figure 20 - CIBSE Design Framework

It is pertinent to note that whilst the CIBSE Design Framework references a briefing process, there is no reference to it in the CIBSE Guide F (Op Cit). This is surprising because of the emphasis that KS8 places on engineering designers to ensure a proper foundation for the design process through comprehensive analysis of the brief.

3.2.6 - Critical analysis of KS8: CIBSE Design Framework

In this analysis the author analyses the briefing and design process for a heating system in non-domestic buildings, which of course would include acute hospitals. It is analysed for critical review because the author wishes to use it to expose key issues concerning the engineering design process that expose firstly the importance of briefing in relation to the communication of In-use and secondly to expose design

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[21] For further information please refer to: http://www.cibsedesigncompass.org.uk/cooling

assumptions that can have critical impact on the resultant energy performance of the facility. The guide introduces the challenge as:

> *"Whilst heating systems may seem relatively simple, in practice there are many factors to be considered during the design process, in order to achieve a well-designed system that delivers both the required comfort conditions and level of control whilst still minimising energy consumption."*

The author will consider these two objectives – what the factors are required for a well-designed system and how these will lead to the optimisation of energy consumption.

Key findings from the author's critical analysis are set out over page.

▪ The guide identifies the engineering design process (Figure 21). It reflects many of the process issues identified by Underwood and Yik (Op Cit)[22]

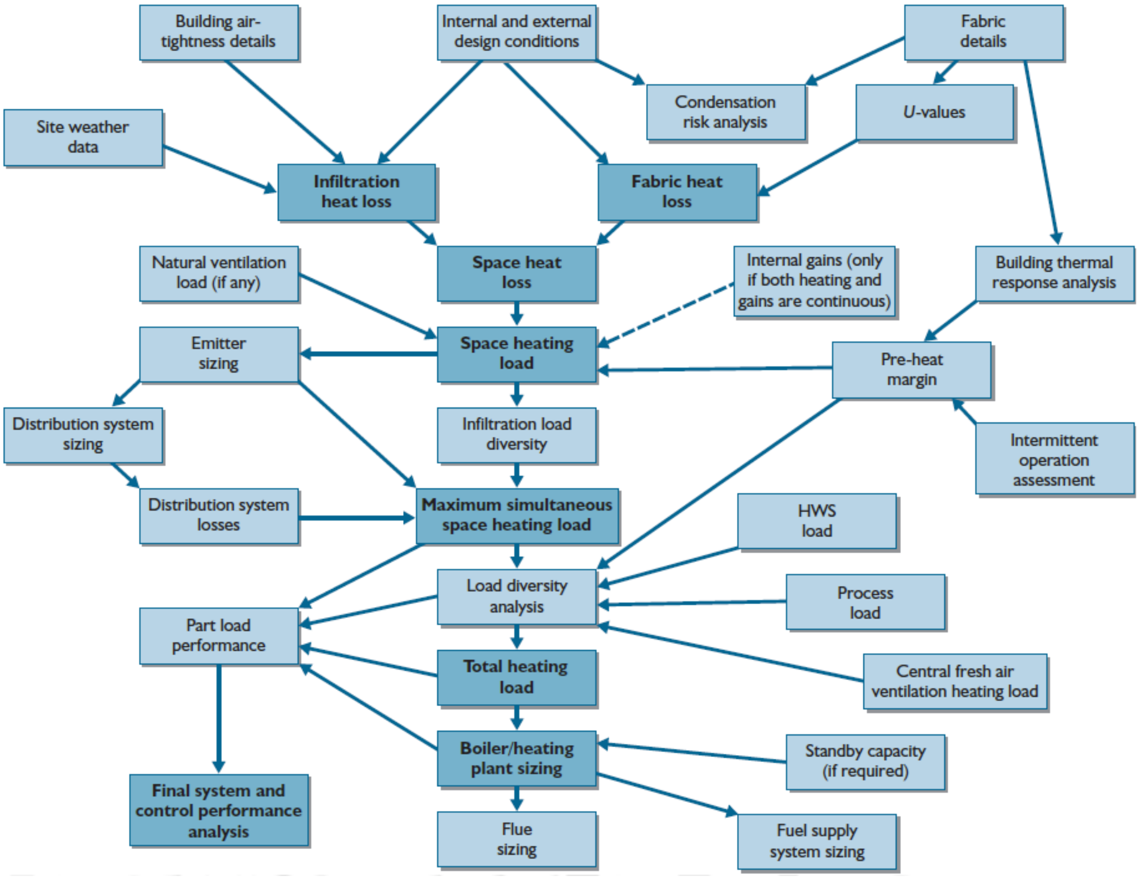

Figure 21 - Engineering design process (from KB8, Op Cit)

▪ The reader should note that the sequence of considerations in the process described in Figure 21, is one that in theory should not require assumptions to be made, *if* the engineering design brief is complete. This point will be returned to later.

▪ Section 3 identifies the key design steps and in particular it documents the briefing input requirements. It mentions the need to document the energy and controls strategies. However it also states that the brief '*can include*' details of

▪ [22] See p119 of this thesis for a critical analysis of this work.

occupancy and use. This is confusing because it documents in detail the need to understand both internal loads and load diversity.

- On p11 a detailed schedule of data and information requirements is specified. It specifies in some detail the need to understand the operational strategy for the building, which includes occupancy hours, activity and density.
- Further in Section 3 it discusses the importance of design conditions:

> *"The design conditions selected can have a substantial impact on both system loads and subsequent system performance and therefore care must be taken to select appropriate values."*

- The guide then advocates the need to use CIBSE Guide A (Op Cit) for design guidance concerning internal design conditions and comfort. The basis of this Guide is clearly one of establishing 'bottom-up' or 'white box' design (Please refer to p123 for an explanation of these concepts).
- Section 3 further details the 'white-box' analysis that is required. There is no suggestion at this stage that engineering designers should resort to 'rules of thumb' and 'formulaic' guidance. To emphasis this point it states:

> *"CIBSE Guide A, chapter 5 provides details of the required calculation procedures for heat losses, covering both a steady state heat loss approach and a dynamic approach which can provide more detailed analysis if required, including modelling of building and system thermal response. Section 5.6.2 of CIBSE Guide A provides a worked example for the steady state heat loss calculation."*

- The significance of an engineering designer selecting to carry out the basis of design using 'steady state' and 'dynamic approaches' is not discussed. However as will be discussed in Underwood and Yik (Op Cit), these decisions can have a fundamental impact on the accuracy of the energy forecast. In the author's opinion the basis of design at this level should be agreed with the client in terms of the level of uncertainty that they would be prepared to tolerate in the energy forecast. The impact of this was highlighted by Parker (Op Cit) and discussed on p46 of this thesis.

- The guide then contradicts its earlier guidance:

> ***"Normally no allowance would be made for internal gains in establishing space heating loads as a worst-case scenario is always considered****, i.e. to bring the unoccupied building up to temperature. However, exceptionally, if the heating will be operating continuously and there are constant heat sources such as electric lights and occupants in a continuously occupied building, then the steady state heat requirement can be reduced by the amount of the constant gains.* ***However the risks of this should always be made overt to the client as if any gains are removed or reduced or the building is operated intermittently then the system may not be able to achieve the design temperatures."***

- The significance of these assumptions must not to be underestimated. Having advised the designer to methodically calculate internal heat gains AND stressed the importance of determining the accuracy of these gains it states that these should not be allowed for, '*as a worst case scenario is always considered*'. Why should this be so? Why is this not discussed and agreed with the client and specifically to explain the subsequent impacts on the system performance? This point is also discussed with Subject Matter Expert, Bellew (VOLUME 2, p7), where he explains how guidance such as this can lead to substantial system over-sizing, but considers that this is not such an issue when the plant can be controlled.

- Building pre-heat requirements are then discussed. The need to establish optimised pre-heat time is explained. The significance of this requirement is that the shorter the pre-heat time the larger the capacity of the system that will be required, the more energy that will be consumed to respond to this requirement. This point was discussed by Subject Matter Expert, Runicles (VOLUME 2, p75) when he explained that this is another area where the client may be advised to understand the impact of system tolerance. For example a one-hour pre-heat time would be appropriate, but scenarios for different requirements could be investigated. This is an example of where a client decision could lead to a compromising of energy consumption performance.

- The guide further advises the methods for load calculations. It states:

> *"For individual spaces the maximum heat loss is always required to size any emitters for that space.* ***However when considering the total space heating load for sizing central plant, some diversity can be applied to infiltration, to allow for the fact that infiltration of outdoor air will only take place on the windward side of the building at any one time, with the flow on the leeward side being outwards.*** *This suggests that the total net infiltration load is usually about half of the summation total for the individual spaces, although the infiltration patterns for individual building configurations should always be considered carefully."*

The statement: 'some diversity can be applied' could lead to further assumptions being made. The science concerning air infiltration is well understood (please refer to the critical analysis of Underwood and Yik, p120.) The correct approach, to avoid the unnecessary assumptions made in the guide, would be to analyse the infiltration loads as explained by Underwood and Yik. Should assumptions be made, then the impact of these assumptions on the forecast energy consumption for the building should be made clear to the client (Parker, Op Cit).

- The guide then discusses the need to consider 'load diversity analysis'. It is here where the whole rationale for occupancy analytics comes to focus:

> *"An analysis of load diversity is needed as the maximum demands for each separate part of the overall load are unlikely to coincide. In addition to the infiltration diversity within the total space heating load, there can be zone diversities, perhaps due to differing hours of occupancy. Process loads could be intermittent and the HWS load could perhaps peak at the middle or towards the end of the occupied period, rather than the beginning.*
>
> *The individual and zone space heating loads should be reviewed to check when the peak demand occurs. While it is most likely that the worst case scenario will be for all spaces to require heating at the same time it is possible in certain buildings that there could be spaces or zones which only have very occasional use and do not coincide with the main demand times from other areas."*

Clearly without any understanding of occupancy profiles (an issue raised by all of the Subject Matter Experts) how can a reasonable diversity analysis be calculated? In office buildings an investigation into energy consumption diversity analysis was studied in an ASHRAE report (B. Abushakra et al., 2004). The report studies data from existing buildings to estimate typical load diversity, presumably as a consequence of In-use. The approach taken was to use a day-typing method that uses a percentile statistical analysis. In the percentile analysis the 50th percentile was used to calculate the diversity factors and the typical hourly load shapes. For the analysis they developed an MS Excel template, which could then be imported into an energy modelling application. Whilst this study investigates load diversity it does not directly answer the question concerning occupancy diversity. Nevertheless the study does introduce the concept of statistical probability as a means for understanding diversity and this method could equally be applied to occupancy diversity.

It has been clearly explained earlier in the guide as to how critical internal load assessments are to the proper design of the system. The inference in the statement at the top of this page could be to design for the worst-case scenario? However, without understanding the occupancy diversity what would be a 'reasonable' worst-case scenario? Clearly this is another issue to be analysed through risk-assessment should occupancy profiles not be available. The client should understand the consequential impacts on energy consumption of not making 'reasonable assumptions' at this stage'. A critical reader might argue, that any inaccuracies at this stage could be managed through effective control. This is reasonable, but at the commissioning stage, would a controls engineer know what the occupancy profile of the building would be? Furthermore, as discussed with Bellew (Op Cit) these assumptions can lead to substantial over-sizing.

- The guide then explains the need for a 'sense check' for system sizing and to ensure that part-load performance is acceptable. It stresses the need to ensure that design margins have not unacceptably over-sized the system.
- The control strategy is the considered to ensure that the system will respond to the needs of the occupants and the functionality of use. Here again is another reason why occupancy analytics is so important to ensure that the system design can respond to the known functional in-use requirements.

- Finally the guide recommends a design review is carried out, a key objective of which is to ensure that the energy forecast remains valid. It also emphasises the need to re-check ‘design margins’ and also to ensure that all assumptions are validated.

The relevance of these findings to this thesis is:

1. The guide is very relevant because it explains in detail a typical engineering design process. It highlights many of the areas where briefing inputs are required that are essential for accurate engineering design which responds to the needs of the users.

2. It is clear from this analysis that the engineering process would ensure a close coupling between the requirements of In-use and the system design is well understood. The challenge that remains concerns how to set out the In-use requirements such that the significant assumptions that are typically made (as evidenced by the Subject Matter Experts) are avoided.

From that analysis the following evidence is pertinent to the engineering design process. There is a clear requirement for engineering designers to:

1. Gather design information, such as occupancy hours, activity and density of occupancy (p11).
2. Document a design brief: “which can include occupancy” (p15)
3. Analyse the impacts of occupancy and activity in order to assess internal heat gains (p32)
4. Analyse internal design conditions for the assessment of intermittent operation, internal loads comprising small power and lighting (p19)
5. Perform a load diversity analysis to establish peak demand (p30)
6. Understand the impacts of oversizing heating systems (p36)

It must also be recognised that the briefing process for engineering design, as set out in KS8, does not take place independently of any other process, because it is conceived to take place in the context of the RIBA Plan of Work briefing stages. However, the latest version of the RIBA Plan of Work (RIBA, 2013) makes no reference to KS8, and as such the author argues that this is an important omission. Neither does the Plan of Work document requirements to the same level of detail for the briefing process as KS8. Instead it references the 'Green Overlay', which establishes the sustainability strategy for projects (RIBA, 2011b). Yet, neither does this document in any detail the relevant briefing issues and instead focuses on the strategic interventions that are required. It is also relevant to note that in the RIBA Climate Change Toolkit: *04 Low Carbon Standards and Assessment Methods* (RIBA, 2009) there is no mention of assessment of In-use. This is not to criticise the toolkit but to emphasise the gulf between what the Building Regulation Part L2A requires and what is documented in advisory standards.

The critical analysis of KS8 set out in the foregoing section is central to understanding how engineering science is applied in practice. In the Introduction to this thesis the author questioned whether it is the application of building engineering physics that might be the reason for both poor predictive and poor In-use energy performance. From the evidence of KS8 it would suggest that the ideal process recommended by CIBSE is not so much at fault. Perhaps it is the application of the process that is the reason for this situation arising? [23]

KEY ISSUE

What evidence is there which would suggest that this maybe the case? Earlier in this section the author produced substantial evidence to demonstrate that despite the requirement, as outlined above, for engineers to develop a comprehensive understanding of the internal loads of the building, this is frequently not carried out. On the contrary it is 'crude estimates' that are used (M. Donn et al, Op Cit). Furthermore the evidence suggests that these failings in the briefing and engineering design process have been understood since at least the year 2001, although there is evidence prior to this from the PROBE reviews (Bordass et al., 1997) that a common failing in the buildings studies (and identified as a 'Key Design Lesson') were assumptions concerning internal heat loads, observing that:

> *"This has led to higher plant costs, problems with comfort and operation, higher energy use, and sometimes even unnecessary*

[23] The use of Key Issue statements throughout this thesis is part of the evidence used by the author to define the scope of the Energy Efficient Brief in Chapter 8.

installation of air-conditioning”.

Since the time of the PROBE reviews there is very little recent evidence of anything like the depth of analysis of In-use that was undertaken in the UK. (Cooper, 2001) observes that nearly 20 years ago the RIBA removed reference to what was known as Part M to the Plan of Work, because it ceased to form part of the RIBA Fee scales.

In this sense there exists another ‘Broken Circle’ (thinking of Kellert and Herbert, Op Cit) in that from the evidence of the literature review the following conclusions could be drawn:

1. Infrequent and inadequate In-Use data collection and building performance evaluation (which is often referred to as: Post-Occupancy Review).

Resulting in inadequate understanding of the factors that lead to low energy and carbon performance, and conversely the factors that lead to poor energy performance.

2. Lack of correlation of briefing requirements between Building Regulation Part L2A, HTM 03-01, KS8, RIBA Plan of Work and Green Overlay.

Resulting in lack of ‘joined up’ guidance to achieve low energy – low carbon performance in non-domestic buildings. Given the discussion concerning the reasons for poor energy and carbon performance in the UK, and the need for Subject Matter Experts (p72), it is now appropriate to report on their opinions of this conclusion.

The opinions of these experts were gleaned through semi-structured interview. The format of these interviews is explained in the Appendix to this thesis. However, to briefly explain the process that was adopted, the author assembled all key observations and particularly the Gaps in Knowledge section arising from the literature review, and used these as a basis for discussion with the Subject Matter Experts. Each of them being separately interviewed, were asked the same questions.

Returning to the aforementioned conclusions above concerning lack of In-use data, both this and the conclusions that follow were put to the Subject Matter Experts:

> Bellew (VOLUME 2, p19)*: “So yes we do lack this…we have none of this… it is simply not available.”*

> Runicles (VOLUME 2, p68)*: “I would say ‘insufficient’ as*

> *well as 'poor' because it is out of date – a lot of it is out of date."*

> Bordass (VOLUME 2, p91)*: "The other perspective is that there are inputs, outputs and outcomes. Historically we have been talking about inputs. Now certain things get to outputs – pressure testing – commissioning and such like. But there has been very little investigation into outcomes. So what you often find is that you do the inputs based on flawed models and flawed assumptions (as you state), but until recently the outputs have seldom been verified and the outcomes are hardly ever looked at. So there is a whole situation, I wrote in that 2001 paper: 'Flying Blind', where the people who are getting this stuff done have little understanding of the impact on outcomes."*

3. Inadequate communication between those that design and those that operate facilities.

Resulting in the briefing process remaining inadequately implemented because the evidence of poor low energy and low carbon performance are not made explicit through In-use data collection and operational review, with the consequence that engineering designers are susceptible to repeating the same mistakes that lead to this poor performance.

The Subject Matter Experts expressed the issue in these terms:

> Bellew (VOLUME 2, p10): *"Our experience is pretty mixed – for us it is left open to what the operational characteristics will be…the problem with our industry is there is little enough data to provide information even on basic statistics…never mind for demand modelling."*

Even were it to be available, Bordass (VOLUME 2, p91) adds:

> *"…we do not have the institutional mechanics for capturing and using that data."*

4. Engineering designers obliged to make assumptions that are insufficiently validated In-Use.

Resulting in buildings that fail to perform as expected.

> Runicles (VOLUME 2, p59): *"Models need to be validated. If you build a simulation model – validation against actual consumption is essential. In the mid 90's CIBSE carried out a comparative study of a thermal modelling programme and found that not one programme gave the same answer because*

of differences in the way that modellers used the software and made assumptions."

(Jones and Davies, 2003) ref[24]er to this situation as the 'Great Divide':

"Designers and operators should at least work together even if they are not one and the same person. Designers don't seem to talk to operators and few operators get to even meet the designers. Even PFI projects seem to draw a line between the two phases of work. A great divide has opened up in our industry that is detrimental to the product that we supply - buildings. One of the key performance indicators this has a big effect on is energy efficiency."

3.2.7 - Managing uncertainty in practice

With a fragmented process between design/ construction and operation, where there is a 'Great Divide', and with poor data from In-use, (certainly in the public sector), and a heavy reliance on assumptions in the engineering design process, the risk of under-performance of the engineering systems has to be considered. The most significant risk is that of not achieving acceptable Indoor Air Quality (IAQ). (Reid, 2007) suggests that on the occasions that project teams to attempt to assess the risks they will tend to the following:

"To account for uncertainty in probability estimates and to promote confidence in the results of probabilistic risk assessments, conservative (safe) estimates of probabilities are sometimes used instead of expected values. However, an objective basis for this approach has not been established and the choice of an appropriate confidence level for the estimation of probabilities (i.e. the level of confidence that the 'true' probability is no worse than the estimated value) is essentially subjective."

If risk is not being objectively evaluated engineering designers will often address the risks by selecting perceived 'worst-case' scenarios and/ or safety factors to

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ensure that this does not happen (F.Dominguez-Munoz et al., 2010), leading to a tendency to over-size the systems (Crozier, 2000). As has been clearly demonstrated by the PROBE studies (Op Cit) this is one of the factors that leads to poor energy performance. As Bellew points out (VOLUME 2, p18):

> *"If there is nothing in the brief that the client is prepared to share the risk with the design team of either over-sizing or under-sizing, are you ever going to create an environment where an engineer would make anything smaller?"*

What would provide the objective basis for such an assessment? It would be information and data to inform the risk. But without sufficient information and data the default position would be make assumptions and accept that over-sized systems provide tolerance for the unknown elements of the brief. But whilst there are conscious assumptions it is possible that there also exists 'unconscious' assumptions. These are assumptions that have become embedded in standards and best practice guidance, or they have become embedded in modelling software[25]. Evidence of this comes from Wang et al (Op Cit), and Underwood and Yik (Op Cit). Both hold very similar views and also comment that assumptions needing to be made concerning the highly stochastic inputs due to building users are less well developed[26]. They provide an example of assumptions concerning occupancy analysis noting that various assumptions are made in practice-based patterns of discreet switching events. The author's suggest that users activity will usually exhibit strong repeating patterns. Is this observation also an assumption – does this mean that this understanding can be applied to all contexts?

Underwood and Yik (Ibid) also highlight contemporary challenges. An example of a contemporary challenge concerns how to treat transitionary laminar-turbulent flow for the difficult problem frequently encountered in building ventilation – the conjugate heat and fluid flow at a low Reynolds number. They state that this is important because in plant and control, and the stochastic influences of the user the answer to this challenge remains illusive. This observation raises the question: how important is 'transitionary laminar-turbulent' flow to the engineering design of acute

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[25] All of these issues will be discussed in the case study later in this thesis.

[26] This issue will be discussed in the next section of the Literature Review.

hospitals? If it is, what is the potential severity of the impact on the forecast of energy consumption and should assumptions need to be made? This would be an example of where the science is understood, but the practice is compromised for some reason, possibly because computational analysis does not exist or it is because of the inadequacies of modelling software.

Specific to the design of ventilation systems in hospitals it has been found that substantial assumptions are made concerning ventilation rates in hospital ward ventilation, particularly as they might control the airborne spread of infection. (Beggs et al., 2008) outline the problem in these terms:

> *"Although the merits of ventilating operating theatres and isolation rooms are well known, the clinical benefits derived from ventilating hospital wards and patient rooms are unclear. This is because relatively little research work has been done in the ventilation of these areas compared with that done in operating theatres and isolation rooms. Consequently, there is a paucity of good quality data from which to make important decisions regarding hospital infrastructure. This review evaluates the role of general ward ventilation to assess whether or not it affects the transmission of infection."*
>
> *"… ward ventilation systems are generally specified in terms of providing patient comfort and minimizing energy costs, rather than for clinical reasons. In short, ward ventilation is perceived as having little impact on the transmission of HAI and thus is not rigorously specified".*

This uncertainty raises the question; why are UK standards for ward ventilation so onerous when compared to standards in other EU countries[27]? What assumptions have been made in the Health Technical Memoranda that provide the guidance on ventilation in hospital wards? As Beggs et al also point out:

> *"However, the lack of sufficient data on the specification and quantification of the minimum ventilation requirements in hospitals, schools and offices in relation to the spread of airborne infectious diseases, suggest the existence of a knowledge gap. Our study reveals a strong need for a multidisciplinary study in investigating disease outbreaks, and the impact of indoor air environments on the spread of airborne infectious diseases.''*

[27] This issue is discussed in detail on p304 of this thesis.

The author argues that it is the uncertainty (through lack of data) of the effect of ventilation rates on airborne spread of infection that leads to the potential over-specification of ventilation rates in certain areas of acute hospitals in the UK. The potential over-specification leads to unnecessary additional fan power to move the additional quality of air and this in turn leads to greater energy consumption than would otherwise be required.

The issue of air-change rates in hospitals is also based on another assumption that the author does not believe has been sufficiently considered in hospital design. It is that if air-change rates are largely specified for occupant comfort as was note by Beggs above, then why is no limit put on occupancy within the space? Surely it must be the case that the greater the number of occupants in the conditioned space, the greater the amount of pollutants, and thus the greater the need for fresh air? This would be an important consideration where ventilation design is based solely on air-change rates and thus does not take occupancy profiles into account. It should also be noted from Olesen (Op Cit) in the analysis of EN1521 that in terms of ventilation rates for occupants the standard defines the requirement in terms of $L/S/m^{2.}$ As Olesen comments:

> "*The people part depends on the density and the building part depends on the type of building*."

In doing so the standard clearly recognises density of occupants, which the Department of Health HTM 03-01 (DoH, 2007)for ventilation based on air change rates per hour does not. This maybe one reason why the energy consumption in acute hospitals in the UK is relatively poor compared to similar hospitals in Europe where ventilation rates are based on occupant density.

It is also relevant to note that HTM 03-01 only make one reference to the Building Regulations Part L (not L2A as was current in 2006), and furthermore in Section 6.8 (Controls) none of the control requirements of the Building Regulations are referenced. This creates a potential contradiction between the legislative requirement and the advisory standard.

KEY ISSUE

3.2.8 - Summary

If UK society is to achieve low – energy - low carbon hospitals and sustained performance then this suggests that current practice in the UK has to fundamentally change, a point that was examined earlier with regard to the IGT report: Low carbon construction (Op Cit).

Lack of appropriate data results in uncertainty that impacts the engineering design process. The natural response by practice is to manage the risk that arises from that uncertainty by using formulaic approaches that ultimately results in systems over-sizing (Crozier, Op Cit). The lack of appropriate data arises because the needs of building engineering physics have not been properly understood in an industry that tends to be reliant on standards and guidance, much of which remains to be validated from studies of In-use. As Subject Matter Expert, Bellew points out: "we *do not know as much as you think that we do*", or as Subject Matter Expert, Bordass adds: "*We do not know an awful lot, and what is known is not tuned into the little that is known…*" As much as there is uncertainty because of a lack of appropriate data for effective application of building engineering physics there appears to be uncertainty by those that are responsible for briefing acute hospital facilities. The Subject Matter Experts are of the opinion that many public clients neither have the knowledge nor the skills to adequately brief and the anecdotal evidence that they provide suggest that it is rare for there to be any articulation of requirements beyond the essential physical requirements. This is probably a subject area that requires further research.

Subject Matter Experts, Runicles and Bellew point out that obtaining a client's to agreement to carry out energy modelling is very difficult. This too has been recognised within the research community (Hensen and Lamberts, 2011). However the reasons for this are less clear. Runicles and Bellew contend that their clients often do not appreciate the need for it, and with scant performance data to prove the value of it, there becomes a cycle of compromised performance. The anecdotal evidence from Runicles and Bellew is confirmed in research (Morton et al., 2011):

> "*However, many respondents also indicated that clients attitudes would also need to change (either by force or persuasion) and reflecting the fact that the most salient costs associated with action*

of climate change were money and time, both things that clients were not perceived as being willing to bear."

Again this is probably another subject area that requires research, perhaps through qualitative analysis to ascertain how lack of briefing skills ultimately compromises acute hospital energy and carbon performance. However, this study would be beyond the scope of this Thesis.

A concern emerges from the foregoing discussion: Simply because those from practice perceive a gap in our knowledge – largely that concerned with lack of knowledge of occupancy, does this mean that this gap in our knowledge also exists in the science? Citing a question posed earlier in this Thesis: Is it that science is imperfect or the application of it? Perhaps we could also consider if the science is so far in advance of practice that practice in the UK is unable to effectively implement it?

It is now appropriate to consider the theory of In-use in relation to energy consumption and the associated carbon emissions in buildings.

3.3 The theory of In-use in relation to energy consumption and associated carbon emissions in buildings (with emphasis on acute hospital buildings)

The reader will now have an insight into the principals of building engineering physics as it impacts the practice of engineering design of buildings and particularly the impact of key design decisions related to In-use on energy consumption and associated carbon emissions. The second research question remains concerning the robustness of the theory of In-use and the science that is the foundation of it: Is the theory sufficient and is it adequately supported by science? Only through investigation of the theory and the science can this question be answered. This is the objective of this next section.

Understanding the theory of In-use in relation to energy consumption requires understanding the causes of energy consumption from In-use. The author has discussed earlier in this thesis some of those causes (please refer to p77) and in this section the author will discuss the science behind these causes.

It became clear in the literature review that understanding the theory of In-use requires the use of simulation tools. This need arises because in attempting to understand the causative factors that impact energy consumption performance in buildings, researchers have been obliged to model complex inputs to the analysis. This is where simulation can be of great benefit and is thus an important tool in the analysis of building performance (Augenbroe, 2011). In doing so this potentially enables the user to gain wider insights into the significant complexities 'real world' problems, probably more so than other forms of computational analysis and mono disciplinary tools (Hensen and Lamberts, 2011). For these reasons, the literature review commences with an investigation into the principles of simulation, particularly as it relates to the study of the theory of In-use and the science that supports it. It is important also because there still remains the question as to how the science can be most effectively leveraged in pursuit of optimised building performance.

3.3.1 - Overview – the role of simulation

The literature review identifies that a substantial body of knowledge is emerging focused on working with a significant number of variables that impact the energy consumption of buildings In-Use. A consistent feature of the wider range of studies considered for the literature review concerns the impact of the building occupant on energy consumption. In other words research is focused upon the *causative* impacts of occupancy on consumption - in particular to understand the relationship between the metabolic nature of occupancy and engineering system dynamics. The author will demonstrate evidence of the need to understand the factors that cause occupancy presence in space and time as much as the quantum of occupancy

The practice of simulation to understand the impacts of occupancy on energy consumption is a common feature of research in this field. Simulation enables complex systems involving multi-dimensional/ disciplinary interrelationships to be understood. In the engineering design process simulation will often be used as a decision support tool as illustrated in Figure 22 the following page.

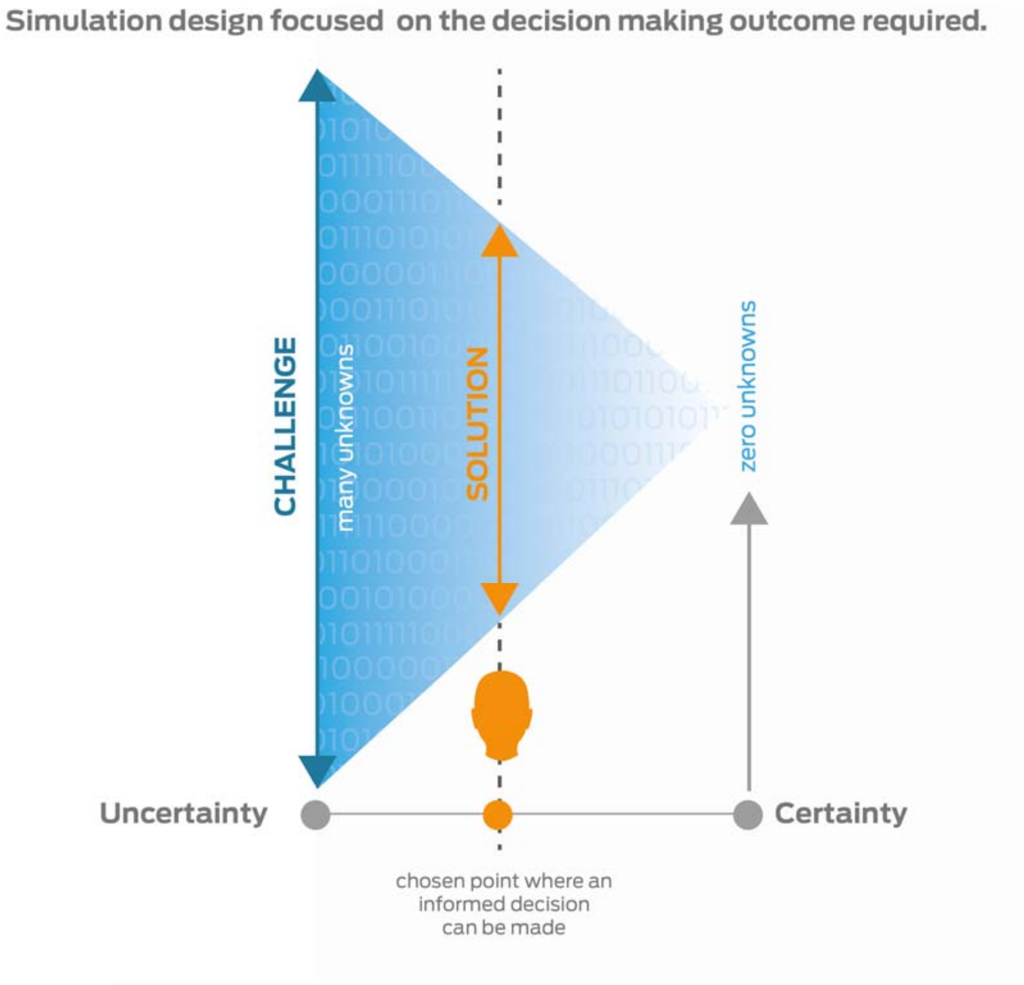

Figure 22 - A benefit of simulation: to enable deep understanding of the impact of input variables, or assumptions, on outcomes

The literature review identifies the use of simulation in:

1. Whole building simulation during the design phase. (P. Hoes et al., 2009), (Short et al., 2010).
2. Whole building simulation during the In-use phase. (Short et al., 2009), (Claridge, 2011)
3. Specific areas of a facility requiring detailed analysis. (Beggs et al., 2008), (Khan et al., 2012)

4. In-use operational analysis[28] (Jun et al., 1999), (T. McNulty and Ferlie, 2002) (Hall, 2006), (M.M. Gunal and Pidd, 2010)

The practice of simulation enables the users to reduce the number of variables[29] in analysis, and consequently reduce uncertainty in the outcome of the design and engineering process. This presupposes that the building will have been constructed, commissioned and calibrated according to the assumptions of the engineering designers. Short et al (Ibid) report on post-occupancy evaluation of a naturally ventilated office building with complex controls making substantial use of natural ventilation. Despite sophisticated modelling, including Computational Fluid Dynamics (CFD) the building failed to respond as designed. Indeed the building suffered from failures identified in the PROBE studies some 10 years earlier, most notably in the inability of contractor and subs-contractors to design and install according to the specification.

In the examples identified above, they can be divided into two categories of study: a) Predictive and b) Causative. Predictive analysis is often applied in the engineering design process to predict how the building environment would respond to a given set of parameters. The simulation facilitates a decision making process, in terms of establishing specific target values that should result in predictable performance In-use. In research it will be demonstrated how predictive analysis enables researchers to understand the sensitivity of values that lead to certain results. However, if the results were not to be predictable, then causative analysis would be required, to establish the reasons for the poor predictability of the results. Referring back to the study by Short et al (Ibid) had the designers learned the lessons from the PROBE studies, they may have predicted the impact of failures in critical parts of the system. Whilst this has little relevance to the pure science of building engineering physics, it does point to the need to consider building engineering not just from the application of the science but also in terms of how other engineering systems can

[28] The literature review identifies a long history of simulation in healthcare service design. Evidence goes back to the mid 1960's where simulation was carried out using Fortran.

[29] In other words to establish fixed values, or specified tolerances.

impact the environmental balance of the building. For example, the authors make reference to the simulation model failing to consider the impact of revolving doors on the air flows and uncontrolled infiltration within the building, and they explained how this lead to a failure in performance. Did this arise because the science was unclear, or because of the inadequate application of the science? The science is very clear as to the impact of revolving doors on the energy balance in a building (C. Younes et al., 2011). The modelling method is also examined in Underwood and Yik (Op Cit, pp122-126). It would appear that it was the poor application of the physics that led to the failure.

The analysis of the reasons for failure was seeking out the causative factors that led to those failures. In-use studies such as those carried out by Short et al, would provide essential criteria to identify these 'what-if scenarios'. This suggests that in studying the building engineering physics and the application of it in simulation studies, failure analysis needs to consider the impact of assumptions both during the design phase as much as during the construction and commissioning phases.

Within certain bounds the greater the complexity of the model then the less the potential for error contained in it. This is not to suggest that models cannot be too complex, because that is certainly a danger for simulation. Nevertheless, the opposite is also true that the simpler the model, possibly the more assumptions that are made and the fewer the number of variables that are considered the less potentially reliable the simulation. Hensen and Lamberts (Op Cit) make the point that:

> *"The aim should be to keep the model as simple as possible to meet the objectives of the simulation study."*

So to reduce the aforementioned uncertainty it typically requires a corresponding increase in data complexity and input parameters reflecting the 'real-world', but in doing so the simulation team must recognise the level or resolution required to enable an appropriate level of understanding to be achieved from the simulation, such as *causative* or *predictive*. But what if the data does not exist such that it could provide the required values for the input variables and parameters? Even if it does, can it be modelled such that it can be processed? If it does not, then the investigators would need to develop analytical models that substitute the complexity of the data or inherent uncertainty in it.

This is where theoretical constructs can be deployed, such as Markov Chains: a stochastic method in which future states of a system are dependent on its current state. The implementation of such models requires a clear understanding of current performance so that the stochastic nature of the system (in this case user behaviour) can be transformed into a set of transition states, thus simplifying the inherent complexity of a large data model. This implies extensive survey in order to understand current performance (*causative analysis*). However it also assumes that low order states are subsumed into higher order states which studies have proven does not necessarily reflect the 'real world' (Gillespie, 1992). Logically it could be reasoned that because such analysis is in effect 'bottom-up' and the model attempts to encompass all behavioural states (higher and lower order), then such models could become very large and complex. In the context of the research question being explored in this thesis the use of Markov Chains might be used to predict users behaviour (*predictive analysis*) in terms of the probability that they would consume certain resources when in specified states or in transition states. The need for bespoke analysis to provide appropriate value for a simulation was discussed in an overview of the subject (V. Fabi et al., 2011), who concluded that:

> *"Moreover, software packages are not nowadays capable of adequate evaluation of scenarios explaining the influence of occupant behaviour, but this is a crucial point in the efforts to minimize energy consumption."*

The inference here is that whilst it is certainly possible to *predict* through simulation as to where/ when users will be in a particular space and so potentially cause energy to be consumed, the question would remain as to the probability that they would cause consumption of one type or another. This would be the role of a bespoke analysis and is what has been defined as 'activity recognition' (Duong et al., 2006)

Other types of analysis using simulation technology can be used: a) Agent-Based Simulation (ABS), alternatively known as Agent-Based Modelling (ABM), or b) Discreet Event Simulation (DES) in predictive analysis, or c) System Dynamics (SD). In his review of 15 years of application of ABM, Squazzoni (Squazzoni, 2010) defines the purpose of it as a computational method to create, analyse and experiment with model composed of agents that interact with the environment. Whereas DES is defined as another computational method focused managing discrete events in systems. Applied to healthcare it is defined as an operational research technique that allows researchers to assess the efficiency of healthcare delivery systems and to ask 'what-if' questions (Jun et al., 1999). Simulation is a technique to predict reality or at least to predict certain insights on reality. Where the DES is designed to measure state or elucidate rules at a system level of abstraction, ABS is the means by which the measured state or rules can be understood at an entity level of abstraction.

DES is ideal where the context for the research question involves complex organisational process involving for example occupants as part of a networked system need to be investigated. The research question is likely to be process-orientated, and thus the need is to understand the system operation (top-down, or a '*Birds eye' view as it has often been referred to*). This would be useful where the system as whole needs to be modelled rather than the entities within it. For the context of this thesis, it is here where the presence of users in the hospital could be identified, because they will be modelled as part of the system, and not as entities with individual behaviours within the system. It is where the probability of events is sampled at each discrete event in the simulation. (Siebers et al., 2010) suggest that this is an ideal application of DES.

SD is primarily used to understand how a system works. It has been described as deterministic and not stochastic where SD models a system as flows, akin to a fluid. SD is usually applied at a strategic level of abstraction, unlike DES, which is applied at a tactical level within a system (S.C. Brailsford and Hilton, 2001). For this reason it has often been used to inform policy decision making.

Siebers et al (Op Cit) argue that the application of ABS is ideal where the research question is focused, for example, on developing a 'bottom-up' understanding of the impact of a behavioural model where the individual roles of agents within a system is pre-determined. ABM applies this understanding to study the impact of agents on other agents acting within that system. In the context of this thesis, the use of ABM could be required where the research questions are directed to understanding how an individual user type (agent) of groups of user types (agents) could interact with the engineering systems. More generally ABM has been defined in these terms, where Siebers et al (Op Cit) state:

"…is the process of designing an ABM of a real system and

> *conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operation of the system. In ABMs, a complex system is represented by a collection of agents that are programmed to follow some (often very simple) behaviour rules."*

"…To follow some (often very simple) behavioural rules" is the key issue here. How could it be possible to define all the human behavioural rules that might be reasonably evidenced in a systems or interacting systems? If they have to be 'simple', what scientific value can such models provide, beyond the 'simple'? How could such a simulation be calibrated? The challenge has been described in these terms by Squazzoni (Op Cit), in reflecting on 15 years of attempts to use ABM successfully in social sciences:

> *"A first critical point is the lack of a common methodological standard on how to build, describe, analyse, evaluate and replicate an Agent Based Model."*

Squazzoni quotes Gintes (2007) who observed that:

> *"This lack has seriously penalised the wider recognition of ABM in standard science."*

In the healthcare environment such as the author will be studying, there will be a larger number of variables that need to be considered in the design of the engineering systems, and these will interact directly or indirectly on the simulation. As such these could impact behaviour rules, and make the operation described by Siebers et al very complex. For example, referring to the author's diagram in Figure 22, a key variable, which could also be an assumption in a simulation of the impacts of the user on the engineering system of the building, would be the extent to which the user intervened in the control of the building automation system. This example was considered by Zimmermann (2010). Zimmermann proposes that the agent specification needs to consider user roles, user process and behaviours, all of which Squazzoni and Gintes (Op Cit) dispute are capable of being accurately modelled.

The use of simulation in healthcare has a long history. Jun at al (Op Cit) is the most widely referenced. It is important to study this area of literature because it is from the perspective of clinicians rather than from the perspective of engineering designers.

In this regard a more recent survey of literature (Fone et al., 2003) comprising in excess of 2000 abstract and 900 full articles found extensive use of DES, and Markov Chain analysis, but there was no reference to ABM. Of particular importance to this thesis was the conclusion of the authors of the paucity of outcomes measured through evaluated implementation. This suggests that the work of McNulty and Ferlie is of particular importance as a point of reference to this thesis because it does at least provide an evidence base for analysis of implemented change. From the analysis of practice in Section 3.1 it suggests two principal research objectives in the theoretical analysis of the In-Use characteristics of the building. Referring back to Figure 17 and the discussion on p73:

1. Seeking to understand the impact of occupant behaviour and building performance. The impact will be concerned with opening windows, and doors, and the management of controllers for heating and cooling systems and the activation of auxiliary systems such as lighting, small power and equipment.
2. Seeking to understand occupant presence and distribution and in particular to understand the potential impact of occupant presence on the design of building engineering systems.

Robinson and Haldi (2011) characterise the relationship between these two fields of occupant analysis in the following terms:

> *"…in general the predictive accuracy of a model of occupants' behaviour is contingent on the accuracy of the model predicting their presence; likewise, the estimation of associated metabolic heat gains. This is so in all of the above cases. It is thus of primordial importance that these models be theoretically sound and rigorously validated. But this task is complicated by the difficulty in reliably detecting the number of occupants within a building zone throughout the period of interest or, better yet, tracking occupants' movement throughout a building whilst present."*

Even reason would dictate that predicting occupant presence in buildings must be a first order priority over understanding how users may or may not interact with it. Clearly the interaction can only take place when an occupant or occupants is/ are present. A point emphasised by Page et al. (2008). Yet this is not to discount the importance of behaviour, only that in order to effectively develop reliable models of such behaviour, the matter of occupant presence must also be understood if holistic understanding of the impacts of occupancy is to be reliably forecast. This is what CIBSE Guide A (Op Cit) encompasses when setting out the requirements for calculation of internal heat gains. Mahdavi and Proglhof (2009) emphasises the importance of both perspectives:

> *"Accordingly, many recent and ongoing research efforts attempt to construct models for passive and active occupancy effects on building performance…* ***Specifically, long-term high-resolution empirical data on people's presence and control-oriented actions in buildings can support the generation of general patterns of user control behavior.****"*

It is from this reasoning that there is a focus in research on understanding the combined impacts of both perspectives. (Bourgeois, 2005), (Page et al., 2007), (Virote and Neves-Silva, 2012).

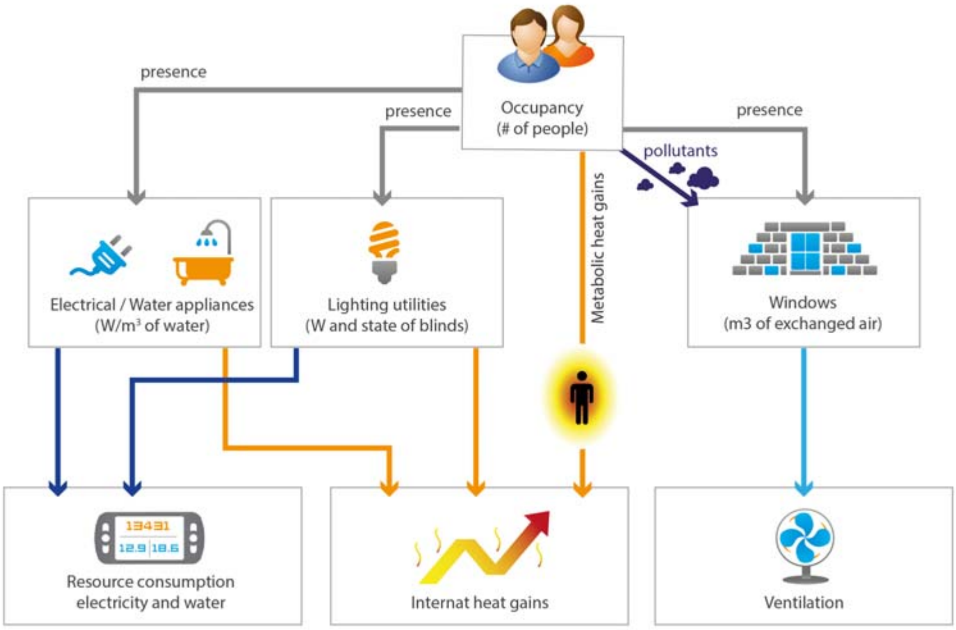

Figure 23 - The relationship between building occupant and energy / resource consumption (redrawn from Page et al, 2007)

Page (Op Cit) illustrates the interactions between occupant and energy impacts in Figure 23. The diagram clearly shows the primordial position of occupancy presence in relation to occupancy behaviour in the use of the systems described in the author’s diagram in Figure 17 (p74). The European Environment Agency report: *Achieving Energy Efficiency Through Behaviour Change*, (A. Barbu et al., 2013)states:

> *“A growing body of evidence in academic literature demonstrates that there is potential for energy savings due to measures targeting behaviour…*
>
> ***…There is, however, one issue that has not been covered by previous studies**, and which the EEA report directly addresses, **namely the distinction between consumer behaviour and consumption practices**. Most recent academic literature argues that it is the consumption practices themselves that need careful scrutiny as they tend to lock consumers into patterns that are more and more energy intensive and they involve a wide range of actors”.*

It would also be logical to conclude that an integration between a DES model that defined the occupant presence in the system and an ABS model that defined the occupants behaviour in the system might be a means of determining the impact of users on the building. Such a combined approach (albeit for different reasons) was also suggested by Siebers et al (Op Cit). Regardless of whether this is even desirable, or achievable (given the well documented limitations of ABS), the EEA report does point to a potentially significant issue – that of *consumption practices*. This is an issue that will be returned to later in this thesis.

All the methods that have been described so far share a common basis, which is to understand the stochastic nature of occupancy. This is the challenge observed by Wang (Op Cit). All methods will use to a varying extent, assumptions influenced by survey or patterns of behaviour derived from established data sources. However, the author has yet to find a method based in the functional processes that take place within certain building types; a need emphasised by Degeleman, 1999 (Op Cit). This certainly appears to be a gap in current knowledge, appoint that shall be returned to later.

3.3.2 - Application of the theory of In-use in research

i) Stochastic methods: Markov Chains

The application of the use of Markov Chains has already been described. The literature review has sought to understand the application of the Markov Chain method in the impact of users in energy in buildings. Page et al (Op Cit) hypothesised that the probability of occupancy at a given time step depends only on the states of occupancy at the previous step. In this way, he proposed the application of Markov Chains toward occupancy prediction and energy use as a consequence of time and place. Page's model is based on predicting occupancy behaviour in a single person office, and this avoided the complexity of a much larger model comprising multiple spaces and high occupancy variance. In the author's opinion a key limitation of the Markov Chain approach is that in practice there are a substantial number of variables that would influence use, (and some of which are not so obvious). These complexities lead to 'crude assumptions; as discussed by Donn et al, 2009 (Op Cit) and further analysed by Short et al, 2010 (Op Cit). Virote et al (Op Cit) also acknowledged the complexity of modelling human behaviour, but offered no alternative other than using Markov Chain theory. Yet in another domain, that of Applied Behavioural Analysis, researchers have developed the concept of the 'Behaviour Chain', which is defined as:

> *"A specific sequence of discreet responses, each associated with a particular stimulus condition. Each discrete response and the associated stimulus condition serve as an individual component of the chain. When the individual components are linked together, the result is a behaviour chain that produces a terminal outcome.*
>
> *(Cooper et al., 2007).*

Considering the concepts of the Markov Chain method which considers the probability of certain behaviour taking place (R. Fritsch et al., 1990), based on the state of the system at a particular time, then the Behaviour Chain could be the task analysis that provides the basis for the Markov Chain analysis, and so avoid the 'crude assumptions' referred to earlier. The Behaviour Chain considers physical needs of individual termed as '*Respondent Behaviour*': The need for ventilation, cooling or heating as distinct from learned '*Operant Behaviour*', the acquired knowledge that if I open a window I will receive fresh air. The author can find no evidence that these two methods of analysis (Markov and Applied Behavioural Analysis) having been brought together in a cross-domain application, and yet it could provide a valuable insight into understanding of human behaviour in terms of In-Use energy consumption. A literature review in the Journal of Applied Behavioural Analysis[30] identifies the use of ABA in managing occupant behaviour with regards to energy consumption, but no research into the potential for correlation between Behavioural and Markov Chains.

ii) Occupancy presence

A review of the application of these theories in the research identifies an increasing awareness of the importance of user behaviour as it impacts both the design and operation of buildings. However the techniques deployed are inevitably relevant to the questions being asked. These questions can be typified by the following examples:

1. What is the frequency that occupants use lights, open windows and make demands on heating, cooling or fresh air? For example through the changing of heating or cooling set points.
2. What frequency do occupants use equipment and when during the hours of the day do they do so?

The premise behind these questions is a need to understand how the demand from occupants would result in energy consumption, and then to develop predictive models that could become the basis for energy forecasting. Examples of this analysis can be found in (E. Azar and Menassa, 2012), (Mahdavi, 2011) and even earlier in the work of (P. Hoes et al., 2009), but there are numerous other studies deploying different forms of analysis in addition to these. In the 2012 study for an office building the team executed a sensitivity analysis to understand the impacts that different factors (model input parameters) had on the resulting energy usage (outputs). The work considers scenarios of use both within and outside working hours. They explain that the goal of this work is to determine different energy usage patterns. The work is based on substantial assumptions, most notably classifying users based on their typical usage profile, which is based on their attitude to energy management programmes. Another significant assumption was that they assumed 'average occupancy' derived from the

[30] See: http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1938-3703

US DOE’s buildings database. This is why the issue of occupant presence is so important. Occupancy presence assumptions can be very inaccurate.

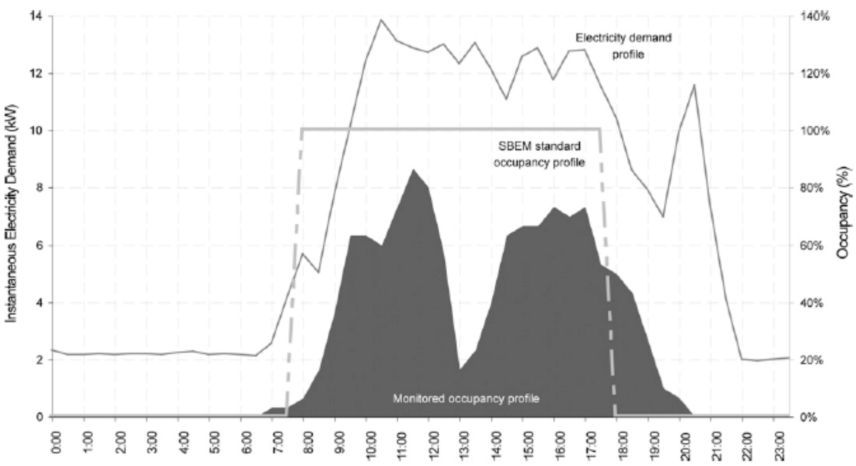

Figure 24 - Analysis of surveyed occupancy profile compared to the SBEM standard. (Menezes et al, Op Cit)

Menezes et al investigated the impact of occupancy presence assumptions. (2011). This work, which ascertained actual occupancy of offices and compared this to the Simplified Building Energy Model (SBEM) standard as illustrated above, clearly demonstrates the inaccuracy of standard guidance. Through half-hour metering analysis the study also demonstrates the actual electrical energy use compared to the occupancy profile. The hypothesis used by Azar and Menassa (Op Cit) that electrical demand could be modelled using analysis of occupancy behaviour is not completely validated by the work of Menezes et al, in that it can only account for part of the electrical loading.

Others have attempted to model the impact of the building occupant on cooling system design. The study by Kwok and Lee (2009) uses a probabilistic entropy-based neural (PENN) model, which deploys an algorithm to forecast the probability of occupancy based on specific input variables. In this work, the research team was less concerned with the accuracy of the occupancy profile and largely focused on the correlation between variability of occupancy and the consequential impact on the cooling load. As with the occupancy behaviour studies there was no attempt to consider the variability of occupancy in the building, because the research focus was a narrow set of objectives. Furthermore, because the research is attempting to understand the correlation between behaviour and energy demand per se, they argue that once a rational has been established it can be applied widely in the engineering design.

The conclusion that the author gleans from the research is that in order to obtain an holistic *and accurate* predictive forecast of the impact of the occupant on energy consumption, the accuracy in both the presence of occupants and as well as accuracy concerning how they would use the equipment and services in the building is an absolute necessity. This is a key issue should be considered in the briefing process.

KEY ISSUE

This is clearly explained in the use of ABM, (Liao et al., 2012). In setting out the context for their research the team clearly articulated the same need as has been defined by the author:

> *"The requirements of an occupancy dynamics model may differ depending on the intended application of the model. For use in building design, an occupancy model should be able to predict statistics of occupancy related variables, e.g. mean and variance of occupancy, distribution of the first arrival time of occupants in a zone or building, etc. Since the number of occupants directly impact the sensible heat gains and that from lighting and equipment, fluctuations in the building load can be predicted accurately only if fluctuations in occupancy can be modelled accurately."*

Their work noted numerous inaccuracies in the application of these methods, largely because of the number of assumptions being made. Furthermore, they were not able to quantify confidence in their results because they had not understood the impact of the different variables on them. In using ABM technique they also observed the significant complexity of the model. Perhaps this indicates that for the research context set out above the use of ABM is wholly inappropriate? The research team also observed the significant time required to specify the 'nominal presence probability profile for each agent.

Dong and Lam (2011), developed algorithms to support statistical analysis. The algorithms have been developed from extensive and detailed surveys (such as records of light switching, or occupancy sensors), which enable them to deduce patterns of use in order to do so. There is a clear attempt here to reduce the number of assumptions (and thus increase certainty) in the computational model. Of particular interest in this study is the tolerance that occupants have in regard to comfort conditions, where they studied how users interacted with the Heating Ventilation and Air Conditioning (HVAC) control system rather than automated sensors controlling the environment. From this knowledge new understanding of patterns of behaviour emerged more akin to 'Respondent behaviour' discussed earlier.

In contrast Roetzel et al. (2011), used a more pragmatic approach by utilising the EU Energy Star database and worked with an occupancy dataset appropriate for a heavily used office building. In this example there would be a substantial assumption that all office buildings would be used in the same way, which would most probably limit the application of the theory developed by the researchers into practice. Indeed, the authors appear to recognise this when they conclude that in early stage design process such models could be useful to engineering designers because they provide a quality of data to support the design process, much improved over the assumptions that would conventionally be made. Nevertheless, they also acknowledge the limitation of this approach in larger more complex situations, hence the focus on early stage design process. Virote and Neves-Silva (Op Cit) also emphasise the complexity of the algorithm increases as the buildings size increases and they also emphasise that the model can only work where people of the same cultural background are being modelled. Both of these factors: a) large building size and b) ethnic mix would be common features of an acute hospital, which would suggest that this would be an inappropriate method for this building type.

In this section the literature review has concentrated the research into understanding the causal factors (predicated in logic) of occupancy presence. It has also identified standard methods for defining occupancy presence, such that it can then be simulated using different input variables.

3.3.3 - Predictive analysis through simulation: Agent-based simulation and Discrete Event Simulation

Liao et al (Op Cit) set out to analyse occupancy presence through the use of an ABM. They argue the need for such a method because they wish to understand 'occupancy dynamics', where peaks, means and variances of occupancy driven heat gains can be computed. Firstly they assigned an occupant's actions to an agent. They modelled the agent behaviour as a function of surveyed movements in an office building. They introduced the notion of primary and secondary agents determined by the nature of the occupancy: full time (Primary agent) and part-time (secondary agent). The challenge was then to create behaviours and rules for each agent type, which was achieved through survey. Furthermore constraints were defined (which in the author's opinion may or may not reflect reality, but might be an approximation of it). The researchers also considered the use of Markov Chains but found that these became too complex to model. Consequently they found that they needed to create a simplified representation of reality. This approach typifies many attempts to create a rationale for occupancy dynamics.

A test of the accuracy of the prediction of the model would be through calibration and verification. This required the researchers to correlate the dynamic occupancy statistics computed from the simulation with an interpretation of the survey of the survey data largely gleaned from sensors. The results were varied and failed to demonstrate conclusively that this approach could be used successfully to predict occupancy flux for groups of agents. Only single agents occupancy could be predicted with 'high probability', but this was not quantified.

From the authors perspective this 'bottom up' approach in the use of ABM clearly demonstrates its limitations, mostly notably with regard to the difficulty of modelling the logic for agent behaviour with embedded stochastic features, and in terms of the substantial quantity of data that is required to, at best, approximate a 'real world' scenario. In the context of the complexity for an acute hospital the research teams model was based on a highly simplified office on a university campus.

Zimmermann (Op Cit) also used an ABM approach to modelling and rather than attempt to model a multi-agent system, the focus was on single agents. Again survey data from field studies was used to understand activities and roles. Algorithms were developed to model the parameters for the agent. The researchers acknowledged that the models of agent behaviour are tactical only, because they have insufficient knowledge of the strategic context from agent behaviour. In the author's opinion this acknowledgement also points to the limitations of agent based modelling. They attempted to provide a strategic context through the use of SDL (Specification and

Description Language), and used for modelling concurrent processes. However, the researchers found that the complexity of such models meant that they could not be used effectively. Despite this, the author's opinion is that without a strategic (higher-order) process meta-model, how could it be used to provide context for tactical agent behaviour anyway? A key learning point here is to design the method of analysis appropriate to the research question.

These two examples can be contrasted with a very different approach adopted by Augenbroe etc al (Op Cit). In their study: *HVAC design informed by organizational simulation,* the team used organisational simulation processed using DES software. The use of organisational simulation provides the process context for the organisation. This contrasts to the aforementioned approach by Zimmermann, for example, where there was no higher order process meta-model. In this example, the researchers constructed a patient process flow chart and it was this chart that effectively encapsulated the process context absent from the aforementioned studies. Indeed this approach is aligned to that advocated by Degelman (Op Cit) where he argues for *predictable and routine processes* if we are to achieve predictable modeling of energy consumption. A key outcome of this work was to demonstrate the opportunity to model occupant presence and to use this knowledge to inform the basis of design of the HVAC system. It also raises an interesting 'cross-domain' insight, and that is that there already exists a large evidence base for organisational simulation in the Health Care environment (McNulty and Ferlie, Op Cit) and (Gunal and Pidd, Op Cit). This points to the opportunity to leverage organisational simulation in the support of service redesign as a foundation for the analysis of occupant presence in hospitals. It is a subject area in which the author has much experience in a different context: that of airport design, and the simulation of organisational processes relative to passenger flux. There is an interesting corollary with mathematicians attempting to model randomness in financial markets without understanding how human behaviour (market trader expertise) influences decisions. Organisational simulation is one means where health care experts are able to design the organisational response to variables in patient demand in health care for example. Consequently, theoretical constructs using algorithms devoid of practitioner insights may also suffer from poor predictability, a subject that will be returned to later in this review.

3.3.4 - Building engineering physics: A review of *Modelling Methods for Energy in Buildings* (Underwood and Yik, Op Cit)

Up to this stage of the literature review the focus of it has been to understand the theory of In-use primarily concerned with occupancy presence and the diversity of occupancy within a facility. The literature review has identified the wide body of research in pursuit of the modelling of occupancy such that substantially greater predictability of forecasting of energy use could be achieved. The outputs from these simulations have then been shown to form the basis of predictive energy modelling.

The next step in the literature review is to understand the physics that is used to analyse these input values and so inform the engineering design. This is the objective of this section.

Building engineering physics is defined by The Royal Academy of Engineering (RAE, OP Cit) as:

> *"Building engineering physics comprises a unique mix of heat and mass transfer physics, materials science, meteorology, construction technology and human physiology necessary to solve problems in designing high performance buildings. Add to this the requirement for creative design and rigorous engineering analysis, and it can be seen that building engineering physics is quite distinct from any of the established applied science or construction engineering professions."*

It states that building engineering physics requires an understanding of the science governing energy flows in buildings and through this:

> *"…applied building engineering physics complements and supports the discipline of building services engineering. However, applied building engineering physics must also consider the engineering performance of parts of the building not traditionally considered to be systems, such as the architectural form and envelope."*

Returning to the analysis of Short et al (Op Cit) the need for a holistic understanding of the physics, not only that pertaining directly to engineering services design is required. Those aspects of building engineering physics that are concerned with heat and mass transfer, materials science – the thermodynamic principles that govern building performance are discussed in detail by Underwood and Yik (Op Cit, 2004). The book discusses the principles of thermodynamics in buildings. It explains how hear transfer takes place and then discusses the modelling implications based on how the science is applied.

At the outset of the author's explain how the science should be applied in practice. A key statement relevant to this thesis is:

> ***"Quantification of the annual energy use in buildings requires the predication of the space cooling loads of individual rooms in the building that would arise at different times in the operating periods throughout the year.*** *This involves determination of the heat and mass transfer through the buildings envelope that are significant parts of the heat and moisture gains or losses of an indoor space. The other sources of heat and moisture gains include occupants, equipment, and appliances present within the air-conditioned spaces and infiltration."*

This statement is significant because it serves to emphasise how the science should ideally be applied from an analysis of all spaces and not from an estimation based on formulaic principles.

The book is of particular relevance to this thesis because it studies in detail a major aspect of building engineering physics, which is concerned with the buildings energy performance. It discusses the impact that different assumptions (explicit or implicit) could have on the results.

Key aspects

- Thermal behaviour of buildings and building spaces: Lumped capacitance method (Ibid, p33). The author's explain that in certain special cases the thermal response must be done at 'high time resolution', such as in analysis of control system response and control system optimisation. It also explains how much simpler process can be adopted by treating the thermal response from building elements as 'lumps' by which a uniform thermal response is assumed.

  The author's explain the errors associated with the different methods and this poses the question as to what assumptions have the engineering designers made when considering the thermal performance of buildings elements. In doing so how sensitive would these assumptions be on the forecast energy consumption?

- Modelling heat transfer to spaces. The Heat Balance Method is one that converts heat gains to a space and converts these to room cooling loads. Due to the complexity of the analysis that is required, the authors describe the practical methods for modeling of these cooling loads for an air-conditioned space.

  The author's make significant reference to ASHRAE guidance. It appears that these methods have been developed by ASHRAE to provide the industry with guidance as to how to most effectively apply building science with the need to avoid overt complexity. An example of this is the Radiant Time Series Method. (Ibid, p81)
- Mass transfer, Air movement and Ventilation: Network ventilation models. The authors explain that the complexities of room space analysis can be mitigated by defining spaces as zones. They explain that by zoning a facility the bulk transfer of air between spaces and groups of spaces is of greater relevance than the study of individual spaces. An example of this approach is used in the study of ventilation rates.

  The author's explain the significance of air leakage paths (both uncontrolled ventilation and opening window ventilation). The analysis requires a study of ventilation based on methods for estimating UK wind velocities and pressure coefficients. It raises an important question as to whether heat losses and moisture gains are incorporated into the energy model by the means proposed, or whether generic assumptions are made here too.
- Steady State Plant Modelling. The author's explain how the modeling of the performance of an HVAC system involves setting up mathematical models for various systems components (Ibid, p129). They discuss the merits of using system models based on fundamental principles, but also explain the challenges of obtaining 'appropriate data' to use within these models. The challenge is made more complex when knowledge of the characteristics of key system components is not available. In this case the author's note that 'black box' thinking is required, such that system is considered a 'black box' where the output is solely dependent on the input

variables. This requires understanding of the set conditions from which the 'black-box' system was derived.

An example of the aforementioned considerations is explained in the design of chillers, which the author's explained: "*are the dominant electricity consumer in buildings with central air-conditioning*". Clearly the accurate forecasting of energy consumption will be largely determined by the ability to accurately model the energy demand of the chiller system. The author's explain key assumptions made in chiller analysis and the impact of variables on the forecast power demand; the most significant of which is the cooling load[31] on the chiller and the temperature of the cooling medium applied to its condenser (Ibid, pp134-136).

The author's also discuss the need to compute another part of the plant infrastructure, notably that relating to the fan and pump performance, which will vary according to the various operating speeds in for example a VAV system. This requires data concerning pump/ fan performance at different operating speeds, but if this is not available then they can be assumed from rated speed performance and fan/ pump laws. The implication here is that at an early stage of the engineering design process the latter maybe applied, but later on in the process the former should be applied once more data is available from the plant selection process.

The author's also explain need for in-depth studies for part load performance of the air-conditioning system. The analysis requires assumptions to be made concerning the determination of heat and mass transfer coefficients, subject to the configuration of cooling coils, such as corrugated and wavy fin configurations.

- Modelling of control systems. The author's explain that the foregoing methods make on substantial assumption: it is that the plant can be assumed to respond in a steady-state manner. However, for the analysis of control system design a full dynamic description of the plant is essential in

[31] …and thus stressing the importance of understanding the major cooling load of occupancy.

order to capture the time varying behaviour of state variables and in some cases model parameters (Ibid, p182).

The modeling will ultimately require the analysis of the control design as much as the components of the control system. This leads the author to reflect that it would imply that in the early stages of the engineering design process there is an assumption that plant is operating in a steady-state mode. Consequently, once the controls requirements are specified, then the control parameters can be modelled as well (Ibid, p210). This is likely to reduce the variance of forecast energy performance to a narrower band of forecast performance as more data becomes available in the design process.[32]

Essential arguments put forward

Having examined the modeling studies as outlined above, the author's then consider modeling in practice as the means by which the modeling studies are systematically investigate with the engineering design process (Ibid, p266). The author's explain the differences in approach between a 'black-box' analysis that 'by-pass the need for physical descriptions of systems in contrast to 'white-box' analysis requiring large amounts of data and highly parameterised. They discuss an alternative approach using 'grey-box' models where a hybrid approach is used, with a restricted set of parameters, but noting the reduced range of applicability. However, the need for large amounts of data in 'white-box' models is not universally shared. A detailed discussion on the differences of each type of analysis possible with each is discussed by Henze and Neumann (2011). They also argue that:

> *"A greater amount of effort is not necessarily needed for modeling of 'white-box' models as opposed to other model types."*

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[32] Subject Matter Expert, Bordass (VOLUME 2, p100) explained that one failing of energy modeling simulations is not to take into account how the building controls would impact energy performance. The models often assume steady state conditions that would never arise in reality. He also makes the point that engineers assume that the facility will actually be engineered in the way that they have modelled it.

They justify their assertion by explaining that it is the detail of the model not so much the amount of data required that determines the model complexity. For example, very simple ‘white-box’ models can be developed to accurately model the behaviour of the actual system. Nevertheless they emphasise that the underlying technical, practical and mathematical descriptions must be known.

A particularly useful explanation of the energy design analysis pathway that is described (Ibid, p223), and this would be of particular relevance to the process for the Energy Efficient Brief (Refer to Chapter 8.0)

Of particular relevance to this thesis is the discussion concerning the RTS method discussed earlier, which requires daily periodic peak loads to be established and suggest that the design can evolve through a series of iterations to enable the impacts of these periodic loads to be calculated. They note the similarity with the UK method, which is called ‘*frequency response-based admittance method*’. However they also note that it is a cumbersome method that ideally assumes fixed daily patterns of outdoor conditions. It is these periodic loads that should be made visible through an analysis of In-use and specifically occupancy analysis.

It is the variability’s in both the outdoor and indoor environment that challenges the accurate forecasting of energy performance. As with other research investigations the authors acknowledge the highly stochastic issues of building use and thus the challenges of forecasting accurate energy consumption without such data.

This raises the issue of validation and verification (Ibid, p272). The author’s explain the challenges of effective calibration and explain the large quantities of data required and in particular that required for measurement uncertainties. Clearly the purpose of the simulation and the extent to which it will be used to inform energy modeling decisions would significantly impact the type of validation required.

Relevance to thesis

There is much in this book that is relevant to this thesis. Specifically it describes in details aspects of building engineering physics that are challenged through lack of ‘appropriate data’. This suggests to the author that at key stages of the engineering design process, the engineering designers should make explicit the methods that they propose and the impacts that methods could have on the outcome of the energy forecasts. For each forecast there should be a schedule of uncertainties (based on the methods used) such that a risk analysis would identify where further studies maybe required should the risk assessment require it. The most significant learning points have been identified in the section:

a) It is clear to the author that from this critical review that many *implicit assumptions* are made in the engineering design process. It also follows that these assumptions are largely influenced by the method of analysis that is used. The method of analysis used by the engineers will be in large part determined by the accuracy of the results required, as much as the availability of appropriate data.

b) It suggests also that the client needs to be appraised of the risks to forecast targets of energy performance, which will be a trade-off between the effort (time and expense) of deep analysis, compared to the accuracy in the predictability of forecast energy consumption, which is a central concern of this thesis.

c) It suggests also that the aforementioned risk assessment could also be flawed should an insufficient level of validation / verification be carried out relative to the quality of the decisions that would be required.

KEY ISSUE

The last of the Key Issue points raised above returns the investigation to the management of uncertainty. In terms of practice, this was discussed in Section 3.2.7 - Managing uncertainty in practice. It is now appropriate to consider the literature from the theoretical perspective of uncertainty.

3.3.5 - Managing uncertainty: a theoretical perspective

The importance of the work of Wit and Augenbroe, (2002)is that it has the potential to minimise the number of input specification assumptions that need to be made in establishing the logic for the dynamic nature of occupancy in buildings. The need to make substantial assumptions in this area of the research endeavour is a common feature of many of the research projects studied in this literature review. Logically this should lead to the need for a confidence assessment of the research results because of the inherent uncertainty. In all the papers studied there was scant reference to confidence and in particular expression of confidence in the accuracy of the simulation compared to behaviour observed in the ‘real-world’. This poses the question as to how such uncertainty can be quantified? The author suggests that this is important because where the objective of simulation is ‘*predictive*’ then confidence in the forecast results will be an important consideration for a decision-making process. This would be particularly so when assessing the forecast energy performance of the facility, which in the context of this Thesis is the hospital. This is a question that was investigated by Wit and Augenbroe (Ibid), where they describe options for quantifying uncertainty, either emanating from specification uncertainty (input variables concerned with the values to be modelled) or model uncertainty (model variables arising from assumptions in the simulation software or the configuration of the simulation model). These aspects are also researched in some depth by E. Azar and Menassa (2012). Wit and Augenbroe (Op Cit) found insufficient data to inform their analysis, and instead they were obliged to resort to other techniques to identify the variables that would enable the uncertainty to be modelled:

1. Through consultation with the Subject Matter Experts, and from these consultations to derive parameters for quantifying variables from which the uncertainty could be measured.
2. Through analysis of published results, and from this analysis to derive semi-empirical values

Using this knowledge, these uncertainties were propagated through the model and the impact of these on the simulation results were then evaluated through random sampling. The authors argue that this knowledge can ultimately be used to enable managers to make informed decisions based on the utility contribution of each to the final decision. But this raises a question: What is the relationship between an estimated (uncertain) probability of failure and the level of confidence that the utility contribution of the proposed solution will be satisfactory? This implies a level of ‘probabilistic confidence’ (Reid, 2007). It is salient to note that the challenge posed by the researchers was to quantify the uncertainties inherent in the simulation, or the advice from the professional team, yet in analysing these uncertainties the researchers were also obliged to resort to expert judgement. This raises the question about what uncertainty factors can possibly be influenced through knowledge and what cannot.

Uncertainty is conventionally defined as either ‘epistemic’ or aleatory’. In the former the possibility exists to improve predictability (reduce uncertainty) by gathering more data or refining the model. In the latter there exists no possibility of amelioration of the uncertainty. To answer this question suggests the need to explore matter from the process context in which uncertainty is being considered. In the context of the design and forecasting of energy performance in an acute hospital there will be many instances through the planning and design process where uncertainty considering the impact of planning and design decisions on the eventual energy performance of the building needs to be understood. For example, in an early stage of a design process where strategic decisions need to be made that could impact the ultimate energy performance of the building, they may need to be informed by a level of information which does not or cannot exist.

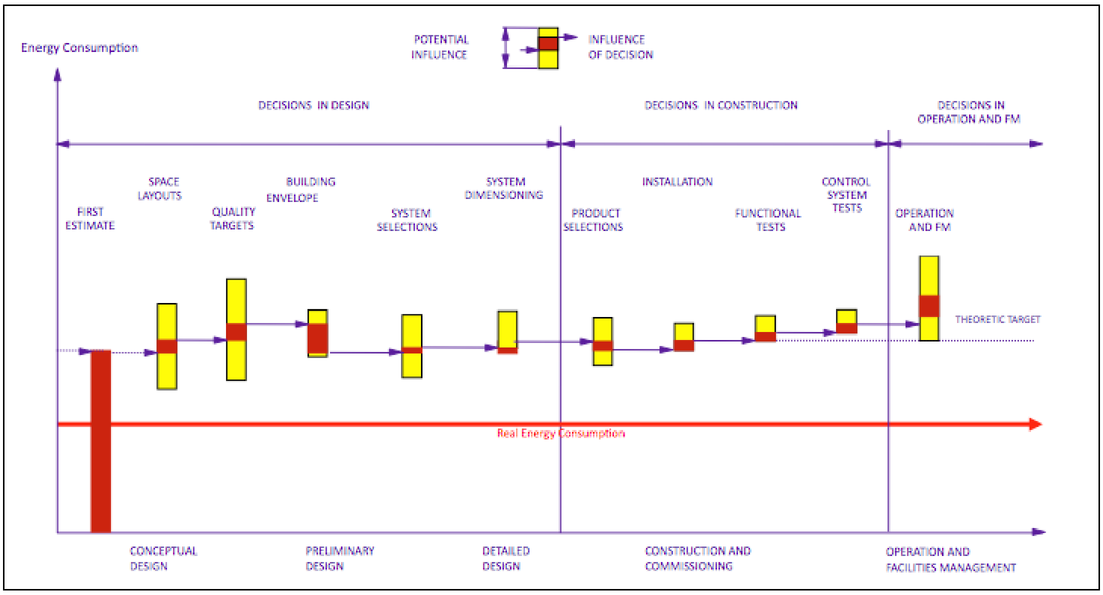

Figure 25 - Process context for decision making concerning the potential energy impacts of design decisions (Source: Granlund OY)

Figure 25 illustrates the issue. It is a conceptual diagram to illustrate how design decision can ultimately impact the energy performance of the building. It can be seen that in the early stages of the planning and design process a few decisions can have a significant impact on the eventual energy consumption. How can these impacts be quantified and if they were to be analysed, which would have the greatest relative impact? Which of these are likely to aleatory and which epistemic?

Earlier in the literature review it was found that In-Use energy consumption could be a factor of three to five greater than the asset energy consumption. The illustration does not account for this and it could be argued to represent an engineer's view of consumption based on his or her own epistemic perspective. However, at the early planning and design stage how can a decision – maker or analyst understand the potential impact of planning or design decisions on the users of the facility in terms of their ability to manage / control energy consumption? In a conventional linear design process, it could be argued that such questions fall into the aleatory category. In the Latin *alea,* means the rolling of the dice, in other words it has inherent randomness. It is the process that prevents the knowledge of In-Use being used to inform the decision-making process. However, if the process were to be reengineered and an In-Use perspective incorporated into it, there maybe the opportunity to take what knowledge or data is known of In-Use and attempt to model the In-use impacts of planning and design decisions. Thus from an epistemic perspective, any epistemic uncertainty at that stage is logically one that could be presumed as being caused by lack of knowledge, or data. It is here where it is imperative that variables define statistical dependencies (correlations) in a clear and transparent way. (Kiureghian and Ditlevsen, 2007)

Yet from the work of Wit and Augenbroe (Op Cit), it can still be seen that there would be a level of judgement (albeit expert) applied to the selection and prioritisation of variables. In fact the number of systemic variables in simulation can be substantial and this raises the question as to bias of such judgements and 'prior' assessments, which could simply be reinforced through the Bayesian updating suggested by the researchers, and so distort the results.

Whilst researchers attempting to quantify the impacts of uncertainty in terms of potential risk and to do so through complex mathematical analysis, an alternative approach would be to address the fundamental reasons why uncertainty exists in the first place. The author alluded to this earlier by suggesting that through process redesign uncertainty could be reduced. He also concluded that it is the lack of In-Use data, which has been a common theme through the literature review in both practice and theory.

Referencing work such as by (Kotek et al., 2007), (Lam et al., 2008) and later (Hopfe and Hensen, 2011) an understanding of those input parameters at each stage of the design process which lead to the most significant sensitivity analysis values would provide a valuable insight into those aspects of process redesign that should directly address those areas of uncertainty.

In terms of managing the uncertainty of the impact of early decisions on potential energy and carbon impacts, the lack of evidence from the literature review implies that an inadequate codification of process lies at the heart of both practice and research. The author has found no examples of process redesign attempting to reduce uncertainty in simulations in a systematic manner. A briefing process should attempt to address such uncertainties. This suggests another gap in our current knowledge.

KEY ISSUE

However, this is not to suggest that theory has not been developed in this area. Work that does attempt to inform this issue in office buildings has studied the whole building lifecycle and attempted to quantify the most significant impacts at each stage (Frankel et al., 2012). The most significant impact discovered in their research that poor architectural and design practices can lead to 90% increase in energy consumption compared to best practice, but poor HVAC design practices can lead to an increase in consumption of up to 210% over best practice. They found that poor user practices could lead to between 30-60% increase in consumption over best practice. Whilst the researchers listed all of the key variables that were analysed, there was no attempt to correlate these to the engineering design process and as such the author argues that this remains a gap in current knowledge.

Developing the argument from Frankel above, another perspective of understanding uncertainty, is to identify the key causal factors within HVAC design that have the greatest impact on outcome of energy performance. The author reasons that in identifying these factors, these should be the area of focus in early decision making concerning the energy performance impacts of those decisions. It follows also, that if these impacts could be managed through the design and engineering process, then the predictability of energy performance in the design phase might be improved: one of the two central themes of this thesis. The research by Corrado and Mechri

(2009) is particularly relevant because in studying uncertainty and sensitivity analysis in Energy Star ratings they identified five major variance factors, (from 129 factors studied) that have the most significant impact on that rating (in decreasing order of influence):

1. Indoor air temperature
2. Air change rates
3. Occupancy
4. Metabolism
5. Equipment.

This suggests that in process terms it should be these factors that need to be addressed at an early stage of the design and engineering process. Indeed a number of the factors that were identified as very important to the briefing process were also identified in the analysis of CIBSE KS8 discussed earlier. Using these findings from Corrado and Mechri it is immediately apparent that they all relate to In-use. This is further evidence of the need to focus on these factors for the engineering design briefing process. Yet the question remains how should the engineering design process be designed to reduce the uncertainty in each of these areas? This question has been partially addressed through a study of energy analysis activities in early stage forecasts of energy consumption (Picco. M et al., 2014), but does not discuss the design process implications. A much earlier report by Hayter et al. (2000) discusses engineering design process for sustainable buildings but fails to acknowledge the importance of In-use. It does stress the need to consider internal cooling loads as one of a number of factors, but does not acknowledge how In-use factors impact the estimation of cooling loads, and indeed how estimation errors in them can have a major impact on energy performance outcomes Carrodo and Mechri, (Op Cit). Furthermore, the authors fail to establish a critical basis for their recommendations other than that the activities were identified from case studies during the 1990's. All of this work suggests that there is a significant need to understand how an in depth understanding of In-use can be used to inform the early stage engineering design process for low energy – low carbon performance. It also suggests a need to establish a closer coupling between the high impact factors defined by Carrado and Mechri, uncertainty analysis as suggested by

Wit and Augenbroe (Op Cit) assimilated with an analysis of In-use.

3.4 Gaps in our knowledge

In this section the author analyses the literature review findings in the context of the discussion concerning the research questions (Section: 2.6 Initial Research questions). By this means it is hoped to ‘join the threads’ of the issues implicit in these questions, with those research findings and in so doing assimilate these into the current gaps in our knowledge.

In Section 2.6 the author stated that (identified by italics):

- *The research needs to understand the factors that cause the situations (as described by the research question) to arise. In particular it must consider the building engineering physics that informs the engineering design, as much as the working practices on which the physics is based.*

  Literature analysis: In this section the author examined these factors from the perspective of practice (application of building engineering physics) and academic research (development of theories in building engineering physics). It was found that whilst the science is mature and built on a legacy of tested theory it was found that there is a ‘Great Divide’ between what the application of the science requires of engineers and what is actually implemented. It was found that whilst the same divide exists in academia, the research community has attempted to ‘bridge’ that divide with sophisticated modeling analysis. A key finding was that in both practice and academia there is an immature understanding of In-Use.

Gap in our knowledge - 1: Lack of comprehensive In-Use data, means that engineering designers have poor empirical evidence on which to base engineering decisions. **Specifically a gap in our knowledge concerns the potentially critical importance that building occupancy datasets have on building engineering physics and in particular the impact of building occupancy on accurate energy performance and the forecast analysis of In-use**.

How does the author justify this assertion?

Firstly: It is apparent from the current research that occupancy presence and behaviour are potentially critical to understanding In-Use energy performance, but have yet to conclusively demonstrate this.

Secondly: Building engineering physics recognises that internal cooling loads emanate from occupancy, such as people presence, equipment use, lighting and other In-Use activities and processes. Yet the relative impact of occupancy loads has not been sufficiently studied, even though the research suggests that it is significant.

Thirdly: The Subject Matter Experts identified this as a gap in knowledge of engineering practice. None of them were aware of the theory of occupancy presence In-Use.

- *The author postulated that it could be the application of the science that maybe at fault. An example of theory testing was used to demonstrate how the application of building engineering physics might be tested. This was further examined by studying how simulation models are tested in order to validate them. The author suggested that the process factors that could lead to erroneous results warrant deep study.*
- Literature analysis. Earlier in this Section the author found that application of the science was imperfect, leading to many assumptions that are rarely tested In-use. A key finding was very poor In-Use data, leading to a difficulty in calibration of models and an immature basis on which to further develop the application of the physics. The Subject Matter Experts confirmed this in the Critical Review.

Gap in our knowledge - 2: Models of engineering analysis can be considered to be imperfect. Models are rarely tested with In-Use data (most often because it is not systematically collected), and consequently the application of the science fails to mature. The lack of testing against reality means that model errors are likely to be repeated from one project to the next. **Specifically a gap in our knowledge concerns the lack of knowledge concerning what data could be available from In-Use such that it could be used to inform engineering briefs and model design and to validate forecasts of energy use**.

How does the author justify this assertion?

Firstly: Building engineering physics recognises that In-Use data; understanding of In-use processes, and the associated working practices of users are important elements of the Energy Efficient Brief. Yet the evidence from the literature research identifies that the supply side is insufficiently equipped to develop an effective dialogue with users that might answer these questions. For example the CIBSE Energy Efficient Brief in CIBSE Guide F fails to mention anything about these requirements. This could partially explain the poor In-Use energy performance of hospitals because clinical users are insufficiently informed concerning the consequences of their working practices.

Secondly: The Subject Matter Experts all agreed that as structured In-use data is not systematically collected and analysed from building management systems within the construction industry, this results in a lack of accurate data available for validation testing. Current engineering methods imply forecasts of absolute energy performance, but such methods make extensive use of assumptions within the application of the physics. This partially explains the poor predictability of energy consumption.

Thirdly, there is no formalised (codified) process in the UK construction industry that links In-use (Post-occupancy) to strategic briefing and early stage design requirements. In particular, the RIBA Plan of Work 2013 (where this could be expected to be acknowledged) makes no mention of this.

- *The argument was developed to consider how by understanding these process factors a new contribution to building science might emerge. The author justified this potential by examining how energy modelling methods are applied in contemporary engineering design. This examination clearly demonstrated how assumptions are made, because 'appropriate values' are not available to engineers as they attempt to apply mathematical models based upon fundamental principles.*

  Literature analysis: Earlier in this Section the author found poor understanding of the analysis of In-use requirements. Post-occupancy studies from the 1990's found a ‘Great Divide’ between the supply side and the user side. Poor communications exist, where the user side insufficiently understands the language of the supply side and visa versa. This results in a critical lack of understanding so that design strategies fail to understand In-Use impacts, and conversely In-use practices fail to understand the potential impact(s) on the design.

Gap in our knowledge - 3: The CIBSE Energy Efficient Brief fails to communicate the importance of In-Use. Specifically it fails to translate In-Use requirements in to building engineering physics in terms of ‘*appropriate values’ for mathematical model based on fundamental principles*’. **Specifically a gap in our knowledge concerns lack of knowledge as to the content of an informed Energy Efficient Brief and specifically the means by which In-Use requirements need to be analysed to inform that brief.**

How does the author justify this assertion?

Firstly: The justification set out in Gap in our knowledge – 2. The research investigation could establish no evidence of a briefing process and an associated methodology designed to systematically elicit user requirements specifically to elicit ‘appropriate values’ to inform the mathematical models.

Secondly: The Subject Matter Experts all agreed that their training as engineers did not adequately prepare them for the briefing process.

3.4.1 - Informing the Point of Departure

In preparing for the research the author has analysed the gaps in our knowledge from both a practice and a research perspective. The author believes that it is important to understand the research interface between current knowledge and the need for new knowledge as identified in the forging summary. This is because it is clear from the body of literature that academic endeavour leads practice. For example while there is some evidence of the analysis of occupancy in practice (albeit through Room Data Sheets for example) by far the most significant evidence is to be found in academic literature concerning occupancy presence and occupancy behaviour. Consequently the precise Point of Departure will be determined through an extrapolation from the body of literature, and in understanding the current knowledge from this perspective, it will provide logical progression for sustained argument to inform the research objectives that follow this Section.

It is also important to emphasise that this analysis, which has the objective of informing the point of departure, has been carried out from a positivist perspective and not from the Constructivist perspective. This is because the research questions are predicated from a positivist perspective.

To summarise the author's findings thus far, the research need can be summarised as:

1. Insufficient knowledge of the critical datasets required to inform building engineering physics such that forecasts if In-Use energy can be considered to be reliable.
2. Insufficient knowledge of what data could potentially be available from In-use that would provide 'the appropriate values' required for the mathematical models on which building engineering physics is based.
3. Insufficient knowledge of what is required to inform the 'Energy Efficient Brief', such that the requirements arising from 2.0 above can be effectively communicated into 1.0 above.

Placing the above finding in the context of theory testing discussed on p55 when the author considered the work of Runeson and Skitmore (Op Cit) and speculated that any one of the process factors could have the potential to cause distortions of the predictions in theory fail, it becomes immediately obvious that there are two significant issues that correlate directly with the above listed findings:

1. Measurements

- Lack of In-use measurement datasets – meaning that the theory cannot be properly applied.

- Lack of appropriate values – meaning that are assumptions are made, leading to the use of ‘inappropriate samples’.

2. Transformation of theoretical concepts

   1. Insufficient knowledge of what is required to inform the ‘Energy Efficient Brief’ – the translation of the requirements of the theoretical concept of occupancy presence into data for the proper application of building engineering physics.

From the foregoing, the author reasons that there is a predilection to failure because the above issues are the likely causes of failure in the predication of energy forecasts.

3.4.2 - Examination of the precise point of departure

The tables below summarises the conclusions from the literature review in terms of engineering design practice and research, and from this the knowledge gaps have been identified.

Perspective	Industry practice	Key text	Knowledge Gap
Practice of modelling occupancy presence in buildings.	Estimates of occupancy based on understanding of activity. Engineering design based on assumptions.	(Olesen, 2007), (NBS, 2013)	Olesen discusses the European regulatory requirements. The requirement is set out in detail in Part L2A of the UK Building regulations in terms of understanding use of space and the impact on the control system design. The challenge concerns lack of 'appropriate values' to inform the engineering design.
		(GBC-UK, 2007)	Lack of comprehensive In-Use data, means that there is little empirical evidence on which to base engineering decisions.
		(Mahdavi, 2011)	Acknowledges that whilst there have been 'many recent' research efforts to accurately model occupancy the resolution of occupancy input data is still relatively low. (A point also made by Underwood and Yik, (2004, p229))
		(Wang et al., 2011a)	A commentary on the practical constraints of determination of the stochastic properties of occupancy and the difficulty of accurate determination.
		(F.Dominguez-Munoz et al., 2010)	The author's comment that a typical (and erroneous) assumption in practice is that peak occupancy occurs simultaneously in all building zones. Application of a diversity factor to assume variable nature of occupancy is required.
		(I.P. Knight and Dunn, 2003)	Whilst this could not be classified as key text, it does present the results of 30 Office buildings in the UK. It raises the question: How to predict occupancy presence other than by 'rules of thumb?
Practice of modelling occupancy presence in hospitals.	No evidence found. Indeed there is scant evidence in practice for any building type.		

Table 1 - Analysis of gaps in knowledge.

Perspective	Industry practice	Key text	Knowledge Gap
Practice as to how occupants consume energy through In-Use	Estimates of use based on design guides, and formulaic principles.	CIBSE Guide F, 2004 (Olesen, 2007) (I.P. Knight and Dunn, 2005) (Menezes et al., 2011)	This is where generalised (simplified methods) are suggested resulting in standardised occupancy density based on floor area of specific building types. In this study of 30 office buildings in the UK small power loads were calculated and a comparison with practice guidance was carried out. Menezes et al. carried out a similar study with detailed survey results.
Practice as to how occupants in hospitals consume energy through In-Use	No evidence found.	(Robinson and Haldi, 2012)	In this research overview the authors note that majority of effort in research has been in workplace environments.
Practice of how In-Use operational processes are accounted for in the early stage planning and design process of buildings.	The information requirements are documented in CIBSE KS8.	(Race-CIBSE, 2006) RIBA Plan of Work 2013	This provides headline statements, but other than this little information concerning the critical datasets required in each phase of the engineering design process. No recognition of sensitivity analysis. The Green overlay provides high level guidance in terms of the key objectives of each RIBA stage. There is no recognition of the connection between RIBA Stage 7 (In-use) and Stage 0 (Strategy)

Perspective	Research	Key text	Knowledge Gap
Theory of modelling occupancy presence in buildings.	Estimates of occupancy based on probability using analysis of survey data, such as presence detection or light switch use.	Dong and Lamb, 2007 Chan and Hong, 2013 (F.Dominguez-Munoz et al., 2010) (Bourgeois, 2005), (Page et al., 2007) (Robinson and Haldi, 2011)	Research teams lack In-Use data, meaning reliance on theoretical models of occupancy presence is required. Research teams carry out project specific surveys in order to gather 'real world' data to inform the research. Proposed method to manage uncertainty in input data (such as occupancy) using stochastic methods rather than 'worst-case'. Investigation into the possibility of using evidence of occupancy (light switching and sensors) to deduce patters of occupancy. Observation that modelling of occupancy predictably remains a challenge. The author's argue that it will be of increasing importance to accurately model occupants' presence and behaviour as we strive for fully passive buildings with no dedicated heating of cooling system.

Table 1 continued

Perspective	Research	Key text	Knowledge Gap
	Occupancy diversity based on understanding of an organisational process.	(Shen et al., 2013) (Augenbroe et al., 2009) (Tabak, 2009)	Lack of knowledge of In-use working practices leading to understanding of variance in occupancy diversity. A rare study into the analysis of occupancy in connection with space utilisation in offices. It concludes: *Human activity behaviour in office buildings is very complex and differs per employee. "A comparison of the predicted activity behaviour (USSU) with the observed activity behaviour (RFID/POPI+) per employee could result in considerable differences."* The analysis however was based on activity analysis with little reference to process context.
Theory to how occupants consume energy through In-Use	Probability analysis using various statistical methods based on survey or sensor data.	(Page et al., 2008) (P. Hoes et al., 2009) (H. Burak Gunay et al., 2013)	Complex buildings not studied. Impacts of larger groups of occupants not effectively studied. A review of methods used. The work does not advance understanding so much as derive improved knowledge from current strategies. It concludes: *"A major challenge of simulating occupant models is predicting the instants at which occupants decide whether or not to undertake an adaptive behaviour".* As with the other cited studies there is no attempt to study human behaviour such as that investigated in Applied Behavioural Analysis.
Theory of occupancy presence in hospitals.	Limited study in an A&E Department provided an insight into HVAC design implications.	(Augenbroe et al., 2009)	This work is unique in that it considers an A&E department processes to consider impact on occupancy. A wider understanding of hospital meta-processes is required to inform occupancy <u>and correlated to In-Use energy is required.</u> This is a Gap in Knowledge. Analysis of In-use organisational process design studies from the perspective of clinical users (Constructivists perspective) would assist this work.
	Studies of working practices in a university building. Key project objective to study impact on project briefing phase using VR tools.	(Shen et al., 2013)	This paper investigates how 'pre-occupancy' studies could be used to inform the design process. Yet it stops short of achieving this and focuses on engagement of the client in a design review process. Gaps in knowledge: Lack of systematic understanding of In-Use operations in the Briefing process. Lack of critical insight into uncertainty and sensitivity analysis because of lack of understanding in this area.

Table 1 continued

Perspective	Research	Key text	Knowledge Gap
Theory of how In-Use operational processes are accounted for in the early stage planning and design process of hospitals.		(S.J. Hayter et al., 2000)	A key report that analyses the engineering design process – but from a design and asset performance perspective (not In-use) in terms of the information requirements at each stage of the process. Very similar to the RIBA 'Green Overlay'. Very little (and then only oblique) reference to In-Use and poor recognition as to how In-use could inform the engineering design. The paper does not acknowledge uncertainty analysis. No specific reference to hospital design.
		(K. Tupper and Fluhrer, 2010)	Not a key paper, but a rare one that attempts to address some issues of the early stage design process. There is no reference to In-use and the focus is typically from an engineering perspective, not an In-use one. The paper does not acknowledge uncertainty analysis. No specific reference to hospital design. Gap in knowledge concerning early stage planning and design process for hospitals informed by In-Use operational processes to avoid assumptions concerning use having to be made.

Table 1 continued

3.5 Point of Departure: Proposition

Arriving at the Point of Departure from a positivist perspective, the author has chosen to develop a proposition – in other words a basis to investigate operational concepts in the design and operation of the acute hospital, all of which are consistent with a positivist paradigm (D. Amaratunga et al., 2002). Consequently, it is at this juncture that the initial research questions can be set aside in favour of a new proposition for low energy – low carbon performance:

As the effective implementation of building engineering physics is compromised by a lack of 'appropriate In-use data', it follows that making good this deficiency should ultimately enable improved forecast In-use energy and carbon performance. Yet as it is clinical users that fundamentally impact In-Use energy and carbon performance, they will require knowledge of the energy and carbon impacts of their working practices.

With this new knowledge, it follows that if they were to understand[33] these impacts they would then have the means to work towards further improvements in that performance though continuous improvement of their working practices. Through a process of negotiation, engineering design strategies and In-Use working practices could become closely aligned, where such alignment would be documented in the Energy Efficient Brief. The expected result would be improved forecasting and substantially improved In-Use energy performance and carbon emissions.

From this proposition the following research needs emerge and through this research it should be possible to develop a new understanding of low energy – low carbon acute hospital design and operation:

a) *How* an understanding of In-use can be used to inform building engineering physics.

b) *How* the working practices of clinical users can be organised (or even changed) to reduce energy consumption and thus improve performance.

c) *How* these requirements should be most efficaciously translated into a requirements specification for engineering designers.

Through an investigation into these ‘how’ questions, the need remains to translate the answers to them into an in depth understanding of In-use. The literature review identifies some of the aspects of In-use such as was identified in the review of CIBSE KS8, but until the knowledge of In-use can be fully understood then the ‘what’ of information and data that is required remains unknown. This is the underlying research challenge.

3.5.1 - Research challenges

A research challenge therefore, is one of achieving an in depth understanding of In-use knowledge. Whilst the need is clear, the means of addressing this need is not. The challenge still remains: From a positivist (engineering designers’) perspective,

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[33] The implication here is the clinical users are probably not aware of the full impact of their working practices on energy consumption and carbon emissions.

with little understanding of the constructivist (clinicians) perspective of In-use, how is the engineer to know what information or data is available? Both the engineer and the clinician have their own vocabulary, which does not readily translate into knowledge for the other. This is the challenge illustrated in Figure 26

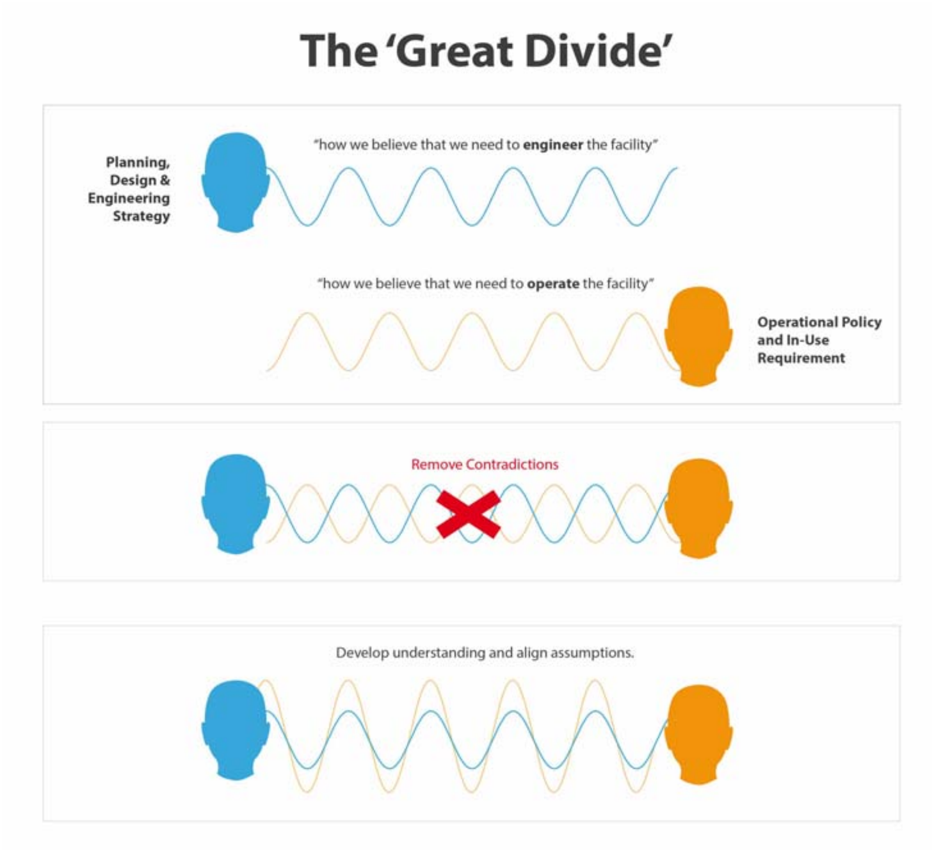

Figure 26 - Communicating across the 'great divide' between the engineer and the clinician

In the aforementioned diagram the author illustrates the challenges of effective communication. As was explained earlier in this thesis this has been characterised as the 'Great Divide'. It is across this divide that the 'how' and the 'what' of In-use must be communicated. These can be summarised as follows:

- How the facility will be operated to achieve most effective clinical outcomes.
- What the operational policies should be to achieve those operational outcomes.

- How the facility will be engineered to achieve optimised low energy – low carbon performance.
- What the engineering strategy should be to achieve the engineering outcomes.

With this understanding and referring back to the proposition, developing a deep understanding of the knowledge of In-use should enable the first part of the proposition to be addressed:

> *"As the effective implementation of building engineering physics is compromised by a lack of 'appropriate In-use data', it follows that making good this deficiency should enable improved prediction of In-Use energy performance."*

The author proposes to focus on this challenge as the first research objective.

The next part of the proposition states:

> *"Yet as it is clinical users that fundamentally impact In-Use energy and carbon performance, they will require knowledge of the energy and carbon impacts of their working practices. With this new knowledge, it follows that if they were to understand these impacts they would then have the means to work towards further improvements in that performance though continuous improvement of their working practices."*

The clear inference here is that to understand In-use is to understand how the clinical users would seek to optimise use of the facilities through service redesign and optimisation of their working practices. However, in the pursuit of low energy and low carbon performance, to do so there needs to be a clear understanding of the impact of the remodeled services and working practices on energy and carbon performance. Consequently 'if' they were to understand these impacts the clinicians may be disposed to address them in the service redesign. How could a coupling between the engineering and operational strategies be achieved? The author proposes to focus on this challenge as the second research objective.

Finally, the proposition concludes with:

> *"Through a process of negotiation, engineering design strategies and In-Use working practices could become closely aligned, where such alignment would be documented in the Energy Efficient Brief. The expected result would be improved*

forecasting and substantially improved In-Use energy performance and carbon emissions."

The coupling between the two strategies then needs to be formalised into a brief for the engineering team. The author proposes that the method to achieve this objective would be the Energy Efficient Brief. Whilst the need for such a brief has been clearly explained by CIBSE Guide F, the reader will recall that the author argued in the earlier part of this literature review that the content was insufficient to provide all of the 'appropriate values' demand by building engineering physics. It is this need that leads to the final research objective.

3.5.2 - Research objectives

Research Objective 1. The research objective is to make a new contribution to building engineering physics focused on accurately modelling occupancy presence in acute hospitals through an analysis of In-use.

How might this be achieved?

It would be achieved by investigating occupancy presence and the diversity of occupancy presence through an analysis of process and Operational Policies in acute hospitals. It would be expected to facilitate significant improvements in forecast energy performance. Data would be created which the author would translate into a format appropriate for engineering design. The concepts for this are illustrated in Figure 27 below.

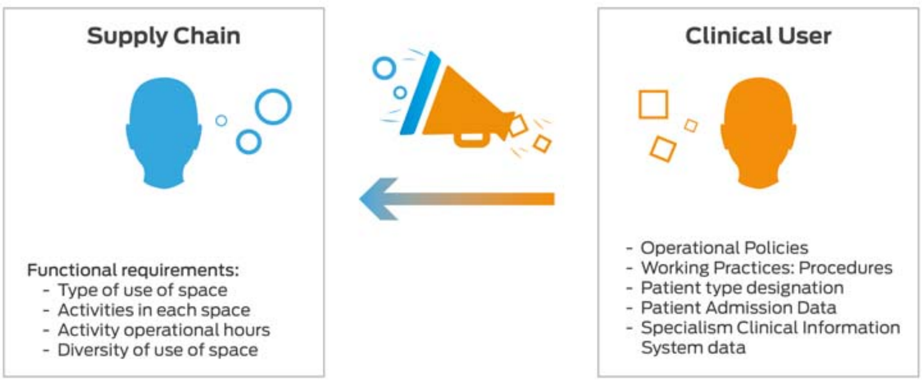

Figure 27 - Translation of In-use data into engineering requirements.

What value is this new knowledge expected to provide?

Occupancy presence and the diversity of occupancy presence has been demonstrated as being one of the most significant factors that impacts the engineering design of buildings. It would be expected to facilitate significant improvements in the accurate forecasting of energy performance. From the literature review it could also be expected to enable the right sizing of engineering systems in hospitals and directly address the issues of engineering system over sizing. It could be expected to deliver benefits in both capital expenditure and operational expenditure.

Research Objective 2. Through organisational and service redesign to investigate how to achieve low-energy – low carbon performance of an acute hospital.

Figure 28 - Objective 2: Using organisational and service redesign to improve performance, drive down demand for energy and reduce carbon emissions

How might this be achieved?

It would be achieved by enabling users to understand the impacts of their operational processes on energy consumption associated carbon emissions. This would require the energy and carbon impacts of operational processes to be modelled. The concepts for this are illustrated in Figure 28 above and Figure 29 on p147. Why would users wish to change? What confidence does the author have that they might be disposed to do so?

The recent study previously referred to, Barbu et al. (2013) for the European Environment Agency offers some tangible insights into the need for behaviour change:

> *"Policymakers seem focused more on the instrument itself than on the behaviour and consumption practice that needs to be changed…*
>
> *"Understanding the relationship between feedback measures, demand response programmes and energy efficiency programmes is crucially important in order to avoid potential conflicts, and ultimately to capture the full energy-saving potential available."(p21)*

These observations correlate well to those cited earlier in this thesis in the literature review – the need to help those being expected to change, to understand the need for change. The feedback measures will be investigated in Stage 2 of the case study.

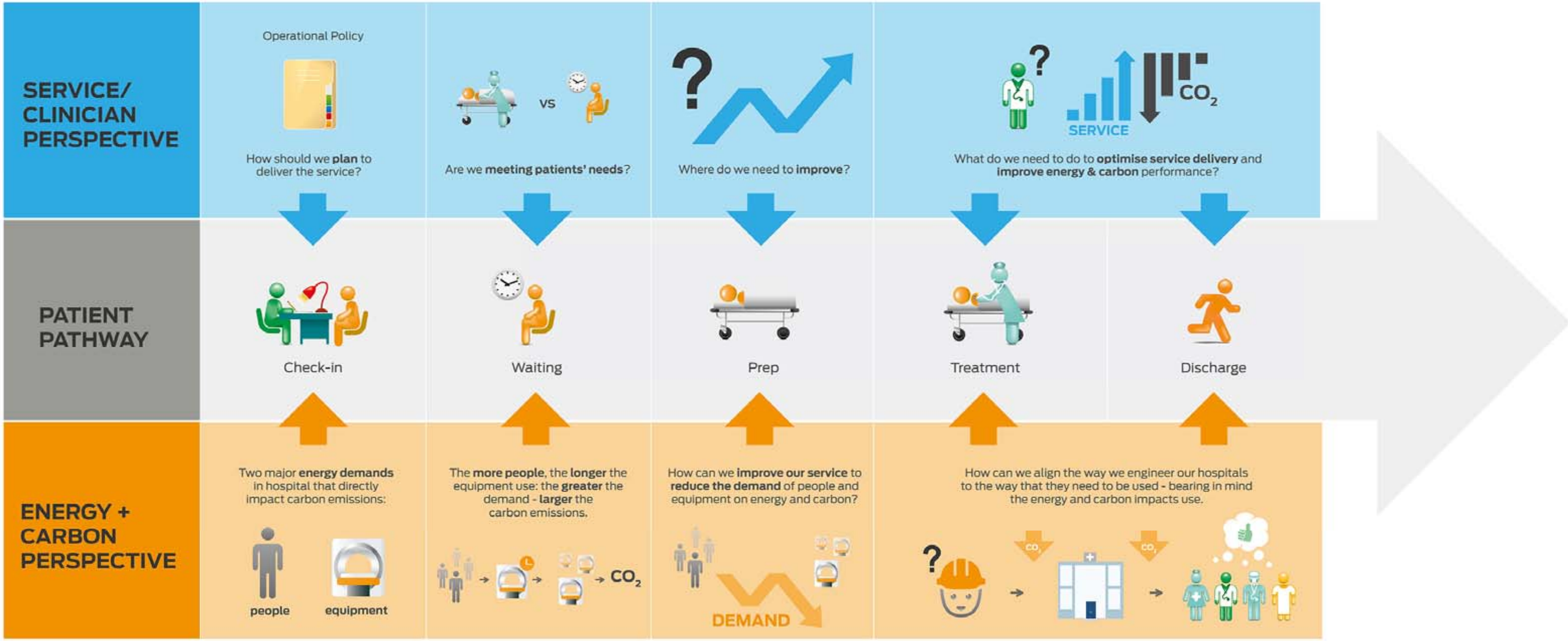

Figure 29 - Objective 2: Using service redesign to improve performance, drive down demand for energy and reduce carbon emissions

What value is this new knowledge expected to provide?

By making the link between organisational and service redesign and the associated energy and carbon impacts of use, users should be able to understand how to both achieve improved process outcomes and low energy- low carbon performance as well. The author speculates that it should also be possible to optimise organisational processes such that peak energy loads could also be optimised. This should enable further reductions in energy consumption and associated carbon emissions.

Research Objective 3. The research objective is to make a new contribution to the briefing process, called ‘The Energy Efficient Brief’, such that this brief would provide the data required for the engineering teams at an early stage of the project process.

The ‘Energy Efficient Brief’ is an enhancement to that documented in CIBSE Guide F, and would provide the essential data required to achieve Low energy – Low Carbon hospital performance. Conceptually illustrated in Figure 30 it would be the interface between the supply chain and the clinical user for the translation of requirements. As such it would need to embrace the language of both teams.

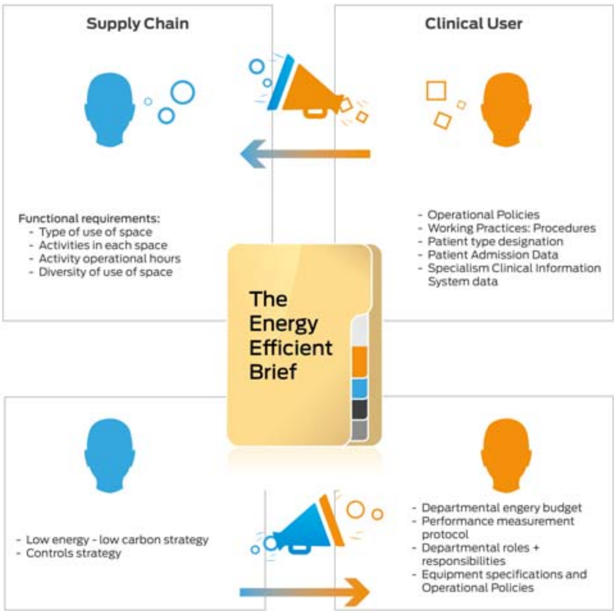

Figure 30 - Objective 3: Translating requirements for the Energy Efficient Brief.

How might this be achieved?

It would be achieved through assimilation of the knowledge gained from the Literature Review, the case study, and assimilating the learning from this work into a template for an In-Use overlay to the RIBA Plan of Work 2013.

What value is this new knowledge expected to provide?

It would provide new knowledge as to the datasets available from a study of In-use that could be used for the engineering design of low energy – low carbon acute hospitals in the UK. In providing comprehensive occupancy data it is expected that engineering design will become closely aligned to the In-Use operations of the facility being served, and so close the gap between forecast and actual energy use.

Chapter 4.0 - Research Philosophy, and Research Method

4.1 Chapter overview

The first research objective clearly establishes the need to ground the research in the epistemology of In-use. In Section 4.2 the author will therefore discuss the knowledge of In-use. The new understanding that arises from this discussion will then be used to investigate how organisational and service redesign could be leveraged in low energy – low carbon performance. From this investigation the author will seek to further the understanding of In-use. In Section 4.3 this discussion will then be developed to consider the author's philosophical position in relation to these objectives, because this will significantly influence the research method, and the rationale for the research design, which will be discussed. The author will then consider how the new understanding of In-use should be translated into the Energy Efficient Brief. This will be a translation based on the authors philosophical position based in 'Real World' research – and the reconciliation between a constructivist perspective of the clinical user with the positivist perspective of the engineering designer.

Section 4.4 will discuss the rationale for the research design. It will consider how the research objectives would be most effectively achieved through the research design. The author will explain how the research design considerations led to the use of a longitudinal case study. The case study will be designed to show how the many factors of In-use, yet to be investigated in the research of low energy – low carbon acute hospital performance, have a substantial impact on the achievement such performance.

The author will address the following features of the research design[34]:

a) The research activities and the grouping of them into logical work streams.

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[34] Whilst the overall design will be explained in Section 4.4 the research design for each case study will be explained within Chapter for each section of the case study.

b) The logical sequence and inter-relationships of the activities in the research

c) The resources required to support those activities.

d) The proposed method of data collection and quantitative analysis.

e) The development of new methods to develop a new understanding of In-use following deep analysis of In-use data.

f) The proposed method for validation of the data.

It will be from this work that the author set out to investigate his proposition, create new knowledge, and make a unique contribution to the application of building engineering physics to achieve low energy – low carbon hospital performance. The 3Ts redevelopment, which is the subject of the case study, provided the ideal opportunity for the author to influence the outcomes of the research through active influence in the outcomes; in other words through action research.

4.1.1 Action Research

The author's research method required the development of a detailed understanding of low energy – low carbon acute hospital design. The author reasoned he could do so by seeking to change the outcomes of conventional engineering practice through experimentation with the input values that are fundamental to building engineering physics. The author reasoned that to influence those values would require him to engage with the clinical users and through such an engagement to demonstrate how a new understanding of In-use could lead to the required input values. Robson (2011) refers to the work of Kurt Lewin, who viewed action research as a way of learning about organisations through trying to change them. He argues that practitioners are more likely to make better decisions and engage in more effective practices if they are active participants in the research. As the research objectives require the development of new practices as much as understanding how organisational redesign could influence engineering design the use of action research as a central element of the research plan would be eminently logical. The author's proposed alignment of the research method with action research is neatly summarised by Robson:

1. *The improvement of practice of some kind.*
2. *The improvement of understanding of a practice by its practitioners.*
3. *The improvement of the situation in which the practice takes place.*

Referring to the last chapter setting out the research objectives, the reader should immediately recognise how the features of action research set out by Robson align well to those objectives.

Yet the risks inherent in action research are also well documented, and scholars, particularly in the human sciences, have documented these in some detail over many years. An early discourse titled: *Three Dilemmas in Action Research* (Rapoport, 1970) identifies the three issues of *ethics, goals* and *initiatives.* The overriding risk is that resolution of these issues leads away from scientific resolution. In other words the sort of action that is not theoretically informed. Resolution of the goals can lead to idealistic research, lacking in relevance to practical pursuit. Rapoport argues that balancing of these three dilemmas (he refers to 'good action') is a means for addressing theses risks.

In terms of addressing the ethical dimension, the concern is how the researcher balances the duality role of the consultant with that of the researcher, particularly in regard to the relationship with the client. The ethical dimension arises where the commercial goals of the work being researched may conflict with the values of the researcher. The need to reconcile these within a value framework is one such means of addressing this potential risk. Issues of confidentiality and protection are also of concern in that what maybe appropriate to share in research may not be appropriate in a commercial context. Obtaining ethical approval for published work is clearly one means of resolving this potential dilemma. However, even this may not be sufficient. Rapoport also suggests that a degree of detachment is required in action research, such that the researcher remains objective and not compromised by commercial considerations that could compromise the research and the attainment of the research objectives.

It is the compromising of research objectives (goals) where Rapoport explains that the researcher has to be sensitive to gather information for purposes unrelated to the concerns of the organisation and so compromise the attainment of the holistic research objectives of both the organisation and the research. He suggests that the researcher and the client need to make mutual goals as explicit as possible.

The dilemma of initiatives is the third area of concern identified by Rapoport. Succinctly explained, the concern is that initiatives identified in the research, whilst perceived to be important to the researcher may not be so for the client. The need for reconciliation between competing objectives is the issue that is of concern. Could the clients demands effectively compromise the research? However, so too may the researchers own perceptions unwittingly compromise the potential learning experience of the organisation. Rapoport cites a phenomenon referred to as 'defensive reaction', where those involved in change reject the proposed change or should the researcher leave the decision as the problem definition and resolution to the client he may '*slight the practical and scientific goals of the study*'.

In recent years more contemporary action researchers such as Somekh (2006) who works in the field of educational research, and Mejia et al (2007) who investigated action research associated with collaborative systems in engineering, have discussed these challenges and have developed techniques to address them. The latter discuss 'cyclical practices' and 'reflective practices' that would address competing objectives such as outlined by Rapoport. They observe the value of bring in a team together in reflective practice such that joint understanding and potential conflicts of interest can be reconciled. Clearly the research design must ensure that these concerns are addressed.

Yet there are also philosophical considerations too concerning the use of action research. It is now appropriate to discuss these in the context of the author's philosophical position as much as how such a position might impact the action research design.

4.1.2 - Introduction to authors research philosophy

The foundation for the research design is the author's philosophical belief, which is summarised in Figure 31 over page. It is here where the conceptual divide between the built asset as an assembly of systems founded in applied science, as distinct from the built asset as a place for people to work, and founded in social science, is illustrated.

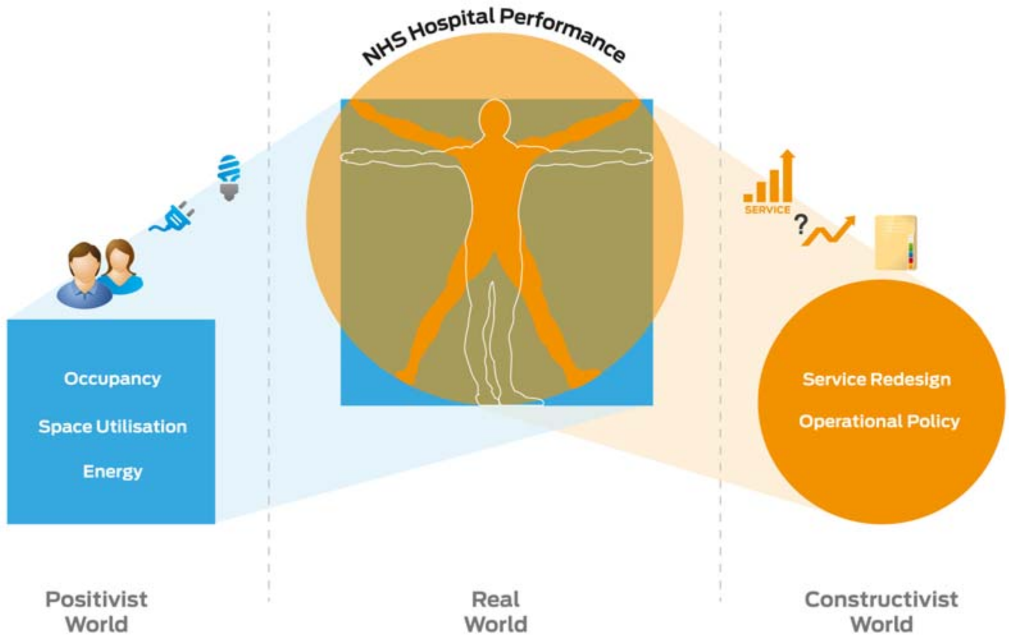

Figure 31 - The author's adaptation of Vitruvian Man

In borrowing from Leonardo da Vinci who conceptualised this divide in his famous rendering of Vitruvian Man, the author is attempting to place the research in the context that Vitruvius sought to reconcile – the relationship between man of the earth (physical) and man of the universe (spirit). It has been described in these terms[35]:

> *"Leonardo envisaged the great picture chart of the human body he had produced through his anatomical drawings and Vitruvian Man as a cosmografia del minor mondo ("cosmography of the microcosm"). He believed the workings of the human body to be an analogy, in microcosm, for the workings of the universe. Leonardo wrote: "Man has been called by the ancients a lesser world, and indeed the name is well applied; because, as man is composed of earth, water, air, and fire…this body of the earth is similar."*

In Vitruvian Man it can bee seen that Leonardo has articulated the oneness of man in both the 'spiritual' and the 'physical'. He has demonstrated this through the describing of man both within the circle (the cosmos) and the square (the earth). In this

[35] Please see http://www.britannica.com/EBchecked/topic/336408/Leonardo-da-Vinci/59785/Anatomical-studies-and-drawings for further information.

oneness the author also sees the potential for reconciliation between the constructivist (social and sciences) and the positivist (applied sciences). As indicated in the opening paragraph to this chapter, the author considers the reconciliation as expressed in Real World research. Vischer (2008) argues in a similar vein. Whilst Vischer's argument for these two perspectives is born out of the need to establish a user centred theory for the built environment, the issues that Vischer discusses are those that challenge the author; described to use Vischer's words: *as 'theoretical polarities'.*

> *"As a result, user-centred theories have tended to be located somewhere along a continuum ranging between a deterministic definition of the environment–behaviour relationship, and one that minimizes the impact of the built environment on users."*

The departure of the author's work from that of the analysis by Vischer is that the author's research is concerned with understanding the consequences of In-Use (right hand side of the diagram) on the design of the building asset (left hand side of the diagram), whereas Vischer is concerned with the behavioural impact of In-use. It follows that the research would be concerned with understanding how In-Use practices and methods (through organisational redesign for example) could be used to explicitly shape the engineering design inputs <u>to accurately forecast In-Use low energy and associated low carbon performance</u>. This is not to suggest that there is no precedent that organisational redesign has not been used to inform the engineering design inputs, but that the author has found no evidence that has been done to explicitly achieve the outcomes underlined above.

The approach outlined above also aligns well with the author's positivist ontological position in that he is concerned with 'conceptions of reality' (Dainty, 2008) and how to influence methods and indeed the science of the engineering design process. It for this reason that the author has chosen to investigate his proposition, focusing on facts and fundamental laws. In contrast, that aspect of In-Use that would drive the design in response to the constructivist epistemological perspectives learnt from the experience of In-Use and expressed in organisational redesign and policy is not within the conceptual scope of this Thesis.

The foregoing discussion succinctly outlines the author's position so far as the overall approach to the research is concerned. But in the action research design how would this be impacted by the author's philosophical position? In other words what is the author's research position in relation to the researched – notably that of clinical users? From an epistemological perspective, could not the reality of the users be so subjective that it would cause a conflict situation in the case study? The author will demonstrate that knowledge can be mediated with the users, and particularly that knowledge which needs to be actionable for the purposes of eliciting 'appropriate data' for the two methods forming two stages of the case study. It is now necessary to discuss the epistemology of In-use knowledge.

4.2 The epistemology of In-use knowledge.

> *"As a sub-discipline of modern philosophy, epistemology is principally concerned with the theories of knowledge. These theories attempt to answer questions surrounding the theories of knowledge, its limits and how we acquire it". (Knight and Turnbull, 2008).*

In the context of the research for this thesis the author seeks to understand the epistemology of In-Use as it relates to acute hospitals in the UK. Principally the question concerns the type of knowledge that is important to understand from In-Use and to transform that knowledge into 'appropriate data' for processing into mathematical models for building engineering physics as it is applied to this hospital type.

However, in order that building engineering physics can reliably utilise the knowledge of In-Use we must have confidence that the knowledge is actionable. To achieve this objective it will require a scientific method to verify that what is said, or documented about the knowledge of In-Use can be observed in the 'real world'. Systematic analysis of In-use knowledge is therefore necessary. It will be from this analysis that justifiable knowledge of In-Use can then be translated into 'appropriate data' for building engineering physics.

Put in pragmatic terms, would documentation created and used by clinician's concerning their working practices reliably communicate knowledge of In-Use? To answer this question we need to discover from the information created by the clinicians, what is relevant to In-Use knowledge, and we need to establish a means for verification, such that engineering designers could reliably act upon it. The verification (justified true belief) would need to demonstrate that the input data can be reliably processed, such that it represents a realistic representation of the clinician ‘real world’ experience. This is what the author argues is the epistemology of In-Use knowledge. The implication for the systematic analysis in the research is two-fold:

- To prove that In-use knowledge is actionable.
- To prove that In-use knowledge reflects ‘real world’ experience

4.2.1 - The domain of In-use knowledge

The subject area of In-Use has been established through the literature review as that knowledge concerned with the causes of occupancy presence in acute hospitals. This is certainly what CIBSE KS8 focuses on as was discussed earlier. However it was also discovered in the literature review that there are other factors of In-use, related to occupancy presence that will place demands on energy consumption (see p83). Donn et al (Op Cit) summarised these as:

- User expectations of performance
- User interaction with controls
- User preferences for space quality

Referring back to p130 and the investigation by Corrado and Mechri (Op Cit) the factors that impact energy performance can all be ascertained within the above three domain areas of In-use. These factors can be summarised into what is defined as ‘indoor thermal quality’. They are of key importance to the proposition because how they are addressed in the engineering design will impact cooling and heating demands (Treek, 2011). This could be considered particularly important in an acute hospital environment where the needs of patients can be extreme. It follows that any analysis of In-use occupancy must also address these needs. This was a matter discussed with Subject Matter Expert, Dr. Bill Bordass where the author outlined his proposed analysis of In-use, who agreed that these considerations should be a fundamental part of the briefing process (VOLUME 2, p103). In stating this, the author is not inferring that these matters are not addressed in current practice, but only that they are a fundamental consideration in the domain of In-use, and as such must also be included in the Energy Efficient Brief.

In an acute hospital environment all of the three above-mentioned factors will be substantially informed by the type of occupant using the space. Clearly a patient's needs would be very different from those of a clinician. But even the needs of different types of patient and clinician could also be very different. Consequently this means that if the design is to optimised the need will be to understand not just the diversity of use of occupancy, but diversity of use of occupant type.

Another potentially important consideration of In-use would the attitude of clinicians to conservation of energy and their willingness to adopt responsible working practices that would not waste it. The author has chosen not to include this aspect of occupancy in the scope of this thesis because it would unacceptably widen the scope of it. Not least the issues would then need to consider the constructivist epistemology that would necessitate a whole new area of investigation.

Returning to occupancy presence, we now know from the literature review that the factors determining occupancy presence are largely concerned with the processes that lead to it. Consequently, the research needs to understand what processes that cause occupants to be in different part of the hospital throughout the day. The literature review identified a need to establish a logical rationale for this, and devoid of process knowledge of the building types studied, researchers have been obliged to develop theoretical principles that become the foundation of this process logic in their models of occupancy. However the critical reader would rightly question: is it only processes that determine occupancy presence? The literature review identified the need to consider the inherent variability (stochastic nature) of occupancy presence. The reason for this is because clearly not all processes are totally predictable and furthermore not all people are necessarily predictable in their behaviour. Consequently in a theoretical model of occupancy we must also consider the inherent un-predictability of occupancy as much as that component of occupancy that is predictable.

This discussion raises an important insight, because it also raises the specter that whilst processes maybe universally understood in the organisation, does it follow that they are universally followed in it as well? Perhaps predictability might vary according to the occupant that is part of the process? Yet if we are to comprehensively understand occupancy presence within the acute hospital environment then we will need to acquire knowledge as to all the types of occupants that work within these processes, as much as the process factors that cause occupants to occupy specific areas at each time of the day.

The question also requires understanding of space. In what spaces are these occupant types dwelling? How should space be identified? At what level of abstraction of space is appropriate for study: the whole hospital, the department, or the room? Furthermore, understanding the route that the occupant takes in moving from one space to another will be another important consideration, because our own experience informs us that moving through a complex facility such as a hospital is not predictable either.

Time also becomes an important consideration. Expanding this reasoning, we can understand also that besides process and space we need to be concerned with the temporal nature of use. How long occupants spend in a space – what are the causal factors that cause them to dwell in a particular space at a particular time of the day? How long does it take the occupant to move from one space to another? Is the route logic an important consideration here?

In-use concept	Required knowledge	Examples
Process factor (J. Reijula and Tommelein, 2012)	How do the clinical processes impact occupancy presence?	Analysis of the patient pathway will identify the key process steps for clinicians and patients.
	How predictable is the process? Are the variances in the process able to be determined? (A. Xie and Chauvin, 2010)	Outpatient check-in process. Patient arrivals are either scheduled or batched according to operational policy. Policies that cause crowding our relevant here.
	How is patient flow managed? (M.M. Gunal and Pidd, 2010)	The patient journey is managed by a dedicated team member. Policies concerning Inpatient management and return to home.
	Management of length of stay (LOS) (J.Farrington-Douglas and Brooks, 2007)	Policies concerning management of patient, diagnostics and medical intervention – how, when and where.
Planning (A. Xie and Chauvin, 2010)	Physical patient pathway management.	Patient pathway and the relative physical locations of each specialism on that pathway will impact length of stay.

Table 2 - Examples of In-use strategies from a clinical perspective.

In Table 2 above there are listed just a few examples of how the issues discussed above have been considered in operational research, service design and health care planning. It is studies such as these that could provide the operational insights that would need to be considered in any study of In-use. Such studies establish the process factors that are likely to impact occupancy presence. From an epistemological perspective it is now necessary to understand how this knowledge can be made ‘actionable’. To do so, requires a deeper understanding of how this knowledge can be used in building engineering physics. This is explained by Underwood and Yik (Op Cit, pp129-130):

> *“Modelling the performance of an HVAC system involves setting up mathematical models for various system components and linking the component models together to form a system model. Input to the HVAC system model includes the loads on*

> *the system…and the boundary conditions under which the system operates. The output of the system model will be the predictions of the system parameters of interest such as…the energy input to the system.*
>
> *There are merits and limitations of using system models derived on fundamental principles. Since the predictions of such models bear physical meanings, it is easier to detect modelling errors, or input errors by examining if the values of the model outputs are reasonable or physically possible…*
>
> *…Incomplete knowledge about the characteristics of system components is a barrier to the development and use of mathematical models that are based on fundamental principles….”*

The author quotes extensively from the authors above, because this passage addresses the fundamental challenge for the application of building engineering physics. It is important to raise this issue at this stage, because it could be argued that there would be little value in analysing occupancy presence if it were not actionable within building engineering physics. Should engineering design, focused on prediction of system parameters be modeled from fundamental principles, or should formulaic models be developed that approximate the science?

It is apparent from the Underwood and Yik that without appropriate input parameters, models based on fundamental principles are not usable. We can also now appreciate how a formulaic approach maybe unreliable when the model is applied to situations outside the set of conditions on which it was derived. That is not to suggest that formulaic models are not appropriate, but only so, when a mathematical model would deliver more accurate results where such accuracy is required. It is this tension that the author argues lies at the heart of poor predictability of energy forecasts.

The justification for not utilising models based on fundamental principles can be one of complexity and unreliable data. Whilst the issue of complexity will remain, the question of unreliable data is a matter that is of principle concern in the section of the thesis. The reader will have understood from the literature review that the occupancy data with respect to building engineering physics is a key component of this data. It is now appropriate to consider the data requirements for the mathematical models. It is from this understanding that the epistemology of occupancy presence can be developed. In other words is the knowledge of occupancy presence actionable knowledge in relation to the science of energy modeling of hospitals? Is knowledge of occupancy presence sufficient to lead to low energy – low carbon performance of UK hospitals? This is the epistemological concern that is central to building engineering physics.

4.2.2 - Actionable knowledge: Data requirements for occupancy presence

The epistemology of In-use knowledge requiring it to be actionable means that it must therefore be translated into a form appropriate for engineering designers to use. This is what the author interprets as 'actionable knowledge'.

That part of building engineering physics that is concerned with the impact of occupancy presence on building energy modelling is concerned with modeling of heat transfer in building envelopes. This was broadly explained in the literature review. Building engineering physics utilises different methods for the calculation of heat transfer. All of the methods aim to calculate the internal (sensible) heat gains, which will eventually become the cooling loads of the room, or indeed to offset any heating loads to it. However, whilst there are different methods used for the calculation of heat transfer, they all use similar methods for the determination of sensible heat gains from occupants, lighting and equipment (Underwood and Yik, Op Cit, p84).

Occupancy presence also directly impacts the total heat transfer to a room through latent heat gains. These are categorised as latent loads and room moisture content balance. These will instantaneously become a cooling load component (Underwood and Yik, Op Cit, p89). The rate of heat gain will become a critical component, and will be determined by the activity of the occupant as much as the type of equipment being used in the space being analysed. CIBSE Guide A (Op Cit) provides the type of information required to calculate the values for different occupant types for each space. But the Guide does not define what type of occupant activity needs to be specified, for generalised approximation this maybe sufficient, but for an acute hospital with a large cohort of sedentary patients and highly active clinical staff the use of multiplying factors advocated by the Guide are inappropriate. What expectations of performance are acceptable for different occupant types? Will some users have higher or lower expectations of system or equipment performance than others? Will some occupant types have a greater or lesser tolerance to indoor thermal quality than others? These questions also lead to the need for occupancy data schedules based on different occupant types for each type of space.

Referring back to p75, the author argues therefore that it is the correlation between different occupant types, (and the associated impact on the requirements for indoor thermal quality), occupancy demand of each patient type with each space type, which will provide the answers to the foregoing questions.

In-use requirement	**Underwood & Yik**	**CIBSE Guide A**	**CIBSE KS8**
Occupancy presence: 1. How many occupants? 2. What type of occupants (patient type for example) 3. Occupant activity (patient type would inform this: renal dialysis patient needs will be very different to a non-invasive cardiology patent needs.) Consequently the renal patient activity is sedentary whereas the latter s likely to be much more active where therapy sessions are undertaken. (M.A. Melhado et al., 2005) establish the principles of different patient activities with regard to indoor thermal quality.	Radiant Time Series (RTS) Method (p81) for cooling load estimation. Requirement: Hour-by Hour cooling energy simulation. This method requires periodic zone response factors to be calculated. These calculate the split between radiant (sensible) and convective Latent) components.[36] However the Transfer Function Method (TFM) uses weighting factors (p84). Presumably they require assumptions to be made in pre-determining the split between radiant and convective components Sensible heat gain sources to be calculated (p89): Heat gains (converted to cooling loads): Lighting, Equipment, Occupants. Latent loads and room moisture content balance (p89): processes, equipment/ appliances that may emit moisture, and occupants.	Referring to Figure 19, it can be seen that the guide categorises different building types and activities of occupants in those building types. There is no hospital building type and the occupant activities do not directly relate to a hospital environment. It maybe of benefit to create a specific categories of hospital type and activities based on patient type. The guide also assumes occupant density within typical space types. Again there is no direct correlation to hospital space types.	Referring to Figure 21, and the following text restated here: 1. Gather design information, such as occupancy hours, activity and density of occupancy (p11). 2. Document a design brief: "which can include occupancy" (p15) 3. Analyse the impacts of occupancy and activity in order to assess internal heat gains (p32) 4. Analyse internal design conditions for the assessment of intermittent operation, internal loads comprising small power and lighting (p19) 5. Perform a load diversity analysis to establish peak demand (p30) 6. Understand the impacts of oversizing heating systems (p36)

Table 3 - Analysis of data requirements (Actionable knowledge)

[36] The author accepts that there is a process constraint here, in that clearly at an early stage of the process it would not be appropriate to carry out engineering analysis at this level of detail, until the major aspects of the building form and function had been fixed.

From the analysis in Table 3 it can be seen how one aspect of In-use (Occupancy presence) derived from an analysis of operational policy will largely determine where occupants will be in time and space. This needs to be converted to data to inform the engineering design.

In this analysis it can also be seen where both implicit and explicit assumptions can be made by the engineering designer:

- Should the engineering designer elect to calculate the internal loads to a space using fundamental principles, they may assume occupancy density and occupancy activity (explicit assumptions).
- Should the engineering designer elect to use (implicit assumption) the Transfer Function Method rather than the Radiant Time Series Method they may assume (implicit assumption) a weighted factor for calculation of sensible and latent heat gains.
- Should the engineering designer elect to calculate the internal loads to a space using a formulaic approach, they may choose to calculate the loads based on the area of the spaces to be conditioned, without any regard to the diversity of use, or diversity of occupant type (maybe either explicit or implicit assumptions).

Whether an assumption is either implicit or explicit maybe regarded as a somewhat arbitrary distinction. In choosing to undertake calculations based on fundamental principles the engineer may seek to request the client for direction in this, and maybe requested to explain the value of this to them (VOLUME 2, pp10-13)). This would be an example of an explicit assumption being presented to the client, and in which case it is no longer an assumption but an instruction. However, the engineer may then make an implicit assumption as to which method they will use to calculate the internal loads. The author argues that this is where the engineer should be agreeing with the client as to the level of certainty that they wish to achieve with regards to the outcome energy and associated performance. This is important because as was discovered in the literature review it is in the potential over or under-estimation of these loads that the greatest variance in final outcome can be found (p120)

It can now be appreciated how there is a direct correlation between the knowledge of In-Use and how it relates to building engineering physics. **Equally as important is that through an analysis of occupant presence there exists not only the possibility to provide the data required to effectively implement the fundamentals of building engineering physics, but the possibility also to correlate an understanding of In-Use (the input to the system model) with the energy and carbon impacts of use (the output of the system model)** because to quote part of Underwood and Yik again:

…The output of the system model will be the predictions of the system parameters of interest such as…the energy input to the system….

KEY ISSUE

4.3 Research objectives in a philosophical context

In the discussion in Section 4.1.2 where the author discussed the research questions (pp141-146), the reader will have understood that the author's philosophical position is based on positivist epistemology and an objectivist ontological predisposition. It is this philosophy that established the context for the research objectives and the research methodology. In considering these matters further it is now appropriate to develop the authors philosophical position in greater detail.

The author's belief is that there exist certain immutable scientific principles concerning building engineering physics that will always determine building energy performance. These scientific principles were advanced by Lord Kelvin nearly two hundred years ago, and are known as thermodynamics. Building engineering physics applies these principles to energy performance of buildings.

The author's position with regards to the research objectives are deliberately 'singular' in their focus, which is concerned with empirical data needs (quantitative analysis) and the vehicle for communication of that data: The Energy Efficient Brief. The 'singular', perhaps somewhat myopic perspective is deliberate, because as mentioned previously, the author does not wish to widen the scope of this Thesis into the less tangible issues of interpretive epistemology and the associated issues of user behaviour or perception.

So what does positivism and objectivism mean in terms of the author's research objectives? From the author's perspective, it means that In-use data regardless of what it means to the users, is at the time of creation a factual representation of events, be they conscious, or un-conscious – deliberate or chaotic. It is created out of whatever the clinical users regard as an appropriate definition of their working practices and use as the basis for carrying out their functions. This would the equivalent of their 'belief' at that point in time. It will also be the agreed representation of the knowledge of In-use at that point in time. This is the objective reality to be used in the quantitative analysis. This analysis is then translated into 'appropriate values' (as analysed in Table 3 on p164) such that are used to inform the mathematical models that embody the fundamental principles of thermodynamics as they are applied to building engineering physics.

The following discussion references each of the research objectives from pages 141-146 of this thesis and considers each in terms of the author's research philosophy:

Research Objective 1. In terms of the critical datasets required to inform the energy modeling process and which would enable the proper application of building engineering physics, it means that the data does not require interpretive (qualitative) effort by the users, but is the result of quantitative analysis. The objective is not to understand 'why' (interpretive epistemology) clinical users have adopted the practices, that will provide the data, but to synthesise the data analysed from these practices for modelling purposes.

Is such a position sustainable? In adopting this philosophical position how could the author embrace alternative operational scenarios founded in change brought about through alternative constructivist ontology? For example, how could the author be certain that the data that would be analysed would be reflective of the organisational objectives of the users? The question arises because such data maybe predicated on clinical users desires to balance the empirical (objectivist) requirements with subjective organisational (interpretive) knowledge of the clinical users?

The author argues that it would be through the users arriving at an appropriate balance of these two philosophical positions that data would then be gathered to provide the input to the Energy Efficient Brief as illustrated in Figure 30. Furthermore, the author contends that once user groups understand the impact of their decisions in the briefing process they may be prepared to redress this balance to achieve a balanced outcome for their working practices. This argument leads to Research Objective 2. The author argues that this is not dissimilar to a conventional briefing process where a dialogue between users and the supply chain can take place with respect to functional requirements.

The need for engagement of the users in this process will be critical. If they are to invest time in the process, it is likely that they will need to be assured that the effort will deliver benefits to them, not least in terms of low energy-low carbon outcomes. It will also be important the new data that would be the outcome of this process has been validated. Referring again to Figure 30 there is an obvious risk that the 'translation' process fails in some way. Clearly both the supply chain as much as the users will need confidence in the results.

Whilst the foregoing discussion points to the need for triangulation in the research design, it also raises a philosophical perspective at the 'translation' interface, i.e. that which is required to 'bridge the divide' between the potentially 'constructivist' perspectives of the clinical users with the positivist needs of the supply chain. The translation suggests the need for a 'Real World' perspective where clinical users may debate the efficacy of their organisational processes as identified by Operational Policy, and yet be required to translate approved processes into an empirical basis for processing by the supply chain. If we were to consider the 'upstream' activities of the clinical users in terms of their internal negotiations centered on Operational Policy, as distinct from the 'downstream' activities required to translate the policy information into data, then the boundary of this Research Objective would the point at which the users had agreed their operational policies and the briefing team translate those policies into empirical data. This is the 'Real World interface referred to above. The focus is thus one of causation – the causal factors of In-use on energy consumption and carbon emissions.

A triangulation process would aim to validate (through critical realism) the perspective of the supply chain and that of the clinical user. On completion of the validation process the In-Use data could then be used for the activities in Research Objective 2.

Research Objective 2. The foregoing discussion points to a potential for user intervention in the briefing process for the Energy Efficient Brief (Refer to Research Objective 3) in that once users understand the energy and carbon impacts of use they maybe inclined to modify their requirements and in doing so to seek to change proposed working practices through organisational redesign. The objective of the redesign would be to: a) achieve appropriate clinical outcomes and b) achieve desired low energy and low carbon performance objectives.

The need for engagement with the clinical users. Should the users not be willing to engage in such a process – would this invalidate the research objective? The author argues that it would not because the research objective is to investigate how In-Use practices could be modified based on new knowledge arising from the organisational redesign. It points to the need to directly correlate In-Use energy performance data directly with both organisational and service redesign.

The energy and carbon impacts of use would need to be quantified in terms that users could recognise. The language needs to be aligned to the language of the user, and thus 'translated' from the language of the engineering team. It is in this 'translation' that the mechanisms for it need to be understood through quantitative analysis in the research investigation. The translation needs to be essentially empirically based, in that to provide the appropriate data for Research Objective 1, data from the analysis in this Research Objective 2 needs to be in a form appropriate the needs of the supply chain that will be processing this data. The supply chain requires data that can be processed into mathematical models as was explained earlier in Section 4.2.2. This is essentially the 'Real World' interface as described in Research Objective 1.

The need to understand process factors. From the literature review the author discovered the need to consider the stochastic variability of use, and the impact of this on user presence. The literature review suggests that the factors that impact variability are not always transparent. That this is complex to understand may also emanate from the fact that the literature review also identified a poor understanding of organisational processes on occupancy presence. Without such a framework from which to understand variability, this maybe the reason for the lack of apparent transparency referred to above. This suggests that within this research objective the process factors that drive occupancy need to be investigated. Such a direct correlation between input (process) and result (occupancy presence) would suggest the need for quantitative analysis founded in positivist epistemology.

In the context of the 'translation' process there would then be the need to ensure that ontological relationships have been mapped between those entities processed within an In-Use schema and those required for the mathematical model used for the modeling and forecasting of energy consumption. The basis for this translation is outlined in Table 3 (p164). The research would need to address this challenge. By this means there should be an effective means for processing data across the 'Great Divide'. This is the purpose of Research Objective 3.

Research Objective 3. Having identified the data to be processed (Research Objective 1) and then processed the data (Research Objective 2) the final research objective is to communicate the empirical requirements by the means of the Energy Efficient Brief, which is the purpose of Research Objective 3.

It is here where the data needs of the supply chain (principally the engineering designer) are to be documented. What form does it need to be in? What level of detail is required? Should the processing be through some form of machine processing, or would tabular data be appropriate?

From a philosophical perspective the research objective here is concerned with the communication interface between the supply chain (engineer designers specifically) and the clinical users; the question is not concerned with understanding the perspectives of the actors in this process, but the information or data exchange process that needs to take place. No interpretivism is to be considered, only the positivist epistemological one, where opinion is to be set aside from objective reality of the consequences of use.

Nevertheless for understanding to emerge across the 'Great Divide' the process context for the data needs to be established. This will be essential not just for aiding understanding of the data, but as a basis for further analysis should users wish to change any part of their processes.

The documented Operational Policies would provide some of this context, as does the meta-information relating to process definitions. It is inevitable in the author's opinion that there will still need to be some interpretation of the data arising from Research Objective 2. This further suggests the need for a degree of pragmatism and thus a 'Real World' perspective. A critical reader may challenge this position and suggest that such a compromise could obscure the veracity of data. Furthermore they may argue that for the data to be justifiable surely validation of users opinion is required? The author would agree that in doing so there does need to be validation of the data. The author also accepts that to some extent interpretation of data will be required (expert judgement). Through the research design this will need to be made explicit in the investigation.

4.3.1 - 3Ts context for the research.

Coincident with the writing of this thesis was the contract awarded to the author to develop the low energy – low carbon strategy for the new hospital redevelopment project. This project was briefly described in the Introduction to this thesis. It was through this commission that the need emerged in discussion with Professor Passman that the project should become an exemplar of a new approach to low energy – low carbon acute hospital design. In essence this would become a case study that would publish results for the benefit of the wider healthcare design and construction community.

The project is known within the larger 3Ts project as the 'In-Use energy' project. It comprises seven work streams:

1. Benchmarking and Target setting
2. Basis of Design
3. Whole Facility Energy Modelling
4. Occupancy Analytics
5. Controls and Monitoring
6. Equipment
7. Research

Those work-streams appropriate to this thesis are Whole Facility Energy Modelling, Occupancy Analytics, Basis of Design and Research.

Whole Facility Energy Modelling stream

Development of a Whole Facility Energy Model: one that considers all aspects of consumption based on asset specifications and planned In-Use policies. This is contrast to the production of energy forecasts based on building asset specifications alone that mislead the hospital management team into believing that they will be provide with a high performing facility.

Occupancy Analytics stream

Development of a better understanding of user requirements through a new method of analysis called Occupancy Analytics. The method generates occupancy data that is the foundation for mechanical engineering design and environmental controls and monitoring requirements. This is contrast to an existing process founded in substantial assumptions concerning building occupancy.

4.3.2 Research stream

From the earlier discussion in section 4.1.1 it will be understood that a potential dilemma faced by action researchers would be the potential conflict between the business and the research objectives of the project. A key part of the research design for the 3Ts case study was to establish a 'Research stream'. It would be through this work that a collaborative environment between the researcher/ consultant and the client would seek to identify experiments that would be means to address potentially competing objectives and needs for different initiatives. Through the research stream the research objectives and the project business objectives should be reconciled. In doing so the research context would be under regular review.

4.4 The case study

The 'Real World' view founded in critical realism has been established by the author as the uniting methodology between the 'positivist' and 'constructivist' perspectives of In-Use. The author suggests that the case study could ultimately reveal how these two views could lead to an analytic generalisation of In-Use (Yin, 2014), possibly reconciled through critical realism. However, the argument for the use of a case study is more complex than just the need to ultimately reconcile these perspectives of In-use. This is because the *how* and *why* questions that arise from the proposition are likely to involve the need for a flexible design in the research strategy. Furthermore as data is collected from multiple sources this too may lead to the need to modify the design. These requirements logically lead to a case study methodology.

Yin (Ibid) amplifies the rationale for the case study in these terms:

> *"A case study is an empirical inquiry that: investigates a contemporary phenomenon (the "case") in depth and within its 'real world' context, especially when...the boundaries between the phenomenon and context may not be clearly evident."*

The author argues that Yin's criteria are a very close match to the challenges posed by the research objectives, not least of which is when the boundaries between energy consumption (the phenomenon) and the context (users) may not be clearly evident.

The purpose of a case study has also been to focus on the dynamics present within a single setting (Eisenhardt, 1989). The dynamics in this instance would be those between the clinicians as they seek to improve service delivery and the engineering designers as they seek to optimise low energy – low carbon performance.

Both perspectives cited above focus exactly on the research challenges perceived by the author. (Please refer to section 3.4.1, p134).

However, whilst the case study research method would appear to be ideally suited to the investigations implicit in the proposition, the critical reader could argue that the author's positivist stance (quantitative paradigm) means that the method could be regarded as too inflexible (D. Amaratunga et al., 2002). The author's argue that neither would such a stance be very effective in understanding processes. To counter this challenge, the author contends that a research objective is to model the results of quantitative analysis in the context of the processes in which the data has been derived (p147).

Alternatives to the case study would be a survey, historical analysis or experiment – all different methods of data collection and analysing empirical evidence. Yin (Op Cit, p9) suggests that the criteria for deciding on the most appropriate method, is firstly the form of the research question (such as how or why?). Secondly, does the investigation require control of behavioural events? Thirdly, does it need to focus on contemporary events? Given that the need in answering the proposition is to answer 'how and 'why' questions; No control of behavioural events is anticipated; The focus is on contemporary events, then author argues that there is established a clear rationale for the case study.

4.4.1 - Required type of case study in the context of the research objectives

It is now important to consider the type of case study that would be appropriate to investigate the proposition. Proverbs and Gameson (2006) quote Yin (2003a) in defining case study types. The following types are identified by the author's:

1. The critical case for use in testing a key theory or concept.
2. The extreme, unique of highly unusual case
3. The representative or typical case to capture everyday occurrences.
4. The revelatory case providing the opportunity to observe a previously unseen phenomenon.
5. The longitudinal case involving the study of the same case at two or more different points in time.

Of those listed above, the 'revelatory case' and the 'longitudinal case' would appear to be the most appropriate types of study for the research objectives. Yin (Op Cit) suggests that such a revelatory study would observe and analyse a problem not just unseen but previously inaccessible. The context for Yin's observation is in social science, but applied to the natural and environmental sciences it would be the revealing of the datasets that provide the 'appropriate values' for the building engineering physics; the revealing of the correlation between In-use working practices and the consequential impact on low energy – low carbon performance; the revealing of the transformation of In-use data into the Energy Efficient Brief would all qualify for the revelatory case study type. Yin (Op Cit) discusses the longitudinal case: studying the same singe case from two or more different points in time, or even address trends over a period of time, perhaps addressing critical events in terms of 'before' and 'after' logic. The same case could also be described as consecutive studies taking pace in different time periods. Certainly the nature of a sequential development process such as takes place in the engineering design process for an acute hospital would fit well with a longitudinal case study method.

Returning to revelatory needs of the project and specifically the need to reveal 'appropriate values', these could be described as 'inaccessible' as described by Yin, because they require a new form of dialogue between clinical users and the supply chain where traditional 'what' type accommodation and functional requirements are not appropriate. Neither are superficial 'sign-off's of drawings; rather a 'how' type dialogue is required, focusing on 'how' working practices impact functional requirements or 'how' Operational Policy could impact design strategies and visa versa. This requires knowledge of clinical practice where the observer is able to translate this knowledge (as has been previously explained) to the information required by the supply chain and visa versa. The case study must reveal these differences and so provide a new insight into improved communication across the 'Great Divide'.

To illustrate this, the following simple example is used: A departmental operational policy will consider how patients are brought into the process, and patient flux is managed through that process. A 'schedule driven' patient management policy (where patients are processed according to a schedule) will result in quite different operational impacts when compared to a 'batch driven' process (where patients are called into the process at the same time and then wait to be processed). Each will impact the physical planning of the department quite differently, because occupancy presence at the same time of the day will be quite different for each policy.

4.4.2 - Single or multiple case studies?

Having considered the type of case study that would be required, i.e. both a revelatory one, as well as a longitudinal one, the question now arises as to how many would be required. For example two linked longitudinal case studies or one case study with two stages to it? The author proposes that a single longitudinal case study design should be used for each work streams defined from the 3Ts project and comprising two stages:

- Stage 1: Occupancy Analytics: Case Study: Research Objective 1
- Stage 2: Whole Facility Energy Modelling: Research Objective 2

By this means the output of Stage 1 (the Occupancy Analytics study) would then become the input to Stage 2 (the Whole Facility Energy Modelling study). Figure 2 on p22 illustrates the relationship between these two stages in the context of the case study. The output of that study would then become the input to the Chapter 8, where the concept of the Energy Efficient Brief is dicussed. In designing the case study as a sequence of stages it provides the author with flexibility for the case study design such that as new knowledge gained through reflective practice is created it can be used to revise (if necessary) the subsequent stage.

The alternative option would be to run a longitudinal case study comprising multiple case studies for each of the two work streams. Yet this would introduce complexity and time that would be prohibitive. As hospital projects can take many years to realise and the nature of the study is also very resource intensive, then it would be impracticable to carry out multiple case studies, despite the fact that from multiple case studies it may be possible to generalise the findings, such that they could be applied to all hospital engineering design.

But is it always the case that a singular case study prevents generalisation of findings? (George and Bennett, 2005), argue that this is so:

> *"The epistemic perspective in general can be described as phenomenological. It can be argued that the local understanding of phenomena is useful especially in the case of*

> *applied research where the audiences is in the first place are practitioners concerned with the questions in relation with the case under question. However, this approach marginalises itself by denying the possibility to generate or contribute to broader applicable theories of social phenomena."*

Yin (Op Cit) however takes a different view:

> *"An analytic generalisation consists of a carefully composed theoretical statement, theory, or theoretical proposition. The generalisation can take the form of a lesson learned, working hypothesis, or other principal that is believed to be applicable to other situations (not just like "other cases"). Thus, the preferred analytic generalisation is posed at a conceptual level higher than that of the specific case."*

A support for this argument is (Burawoy, 1991) where he refers to the 'extended case method' – his way of describing how a generalisation "extends" a narrow case to some broader significance – in other words to extend the general from the unique. He argues that this is achieved when cases are selected specifically for their theoretical relevance, and by using a case to challenge existing theory generalisation from a single case study becomes possible.

How relevant would analytic generalisation be to the author's research objectives? How could the author justify generalisation from the specific in the case study that is proposed? Whist these are questions that will be returned to in the case study conclusions, the case study design should seek to identify higher level generalisations that could be used to inform future work in low energy – low carbon acute hospitals of other even other complex building type (Yin, Op Cit, p41)

Without appearing to dismiss the case for analytic generalisation (and referring back to the earlier citation from Yin), the author believes that the value of the single case study research will be that it will provide a strong indication of the causal relationship (the boundaries) between In-use working practices and the energy and carbon impacts of use. This perspective now shifts the debate from the disbenefits to the benefits of a single case study.

Yin (Ibid) defends the use of a single case study in these terms:

> *"…the single case study is eminently justifiable under certain conditions a) a critical test of existing theory, b) and extreme or unusual circumstance, c) a common case or where the case serves a revelatory one, d) longitudinal purpose."*

The argument for the single case study is justified through pragmatism but also though the justification of Yin cited above, where the case study is a revelatory one. Pragmatism is a compelling argument – its better to do one case study properly than skimming over five or six (Grix, 2010). But the revelatory justification is even more compelling: Discovering important features, developing an understanding of them, and conceptualising then for further study, is often achieved through the single case study strategy (Punch, 2000). These are features of the research objectives and further emphasis the relevance of the single case study.

4.4.3 - Features of the case study in the context of the research objectives

Remenyi at al. (2002) describe the key characteristics of a case study:

1. It draws on multiple sources of evidence.
2. Its evidence needs to be based in triangulation of these sources of evidence.
3. It seeks to provide meaning in context.
4. It has a clear-cut focus either on an organisation, situation or a context.

Addressing each of these in turn in the context of the research objectives:

Multiple sources of evidence. Figure 27 illustrates examples of multiple sources of evidence such as that from clinical information systems, and operational policies. Clinicians are also likely to have their own sources of data.

Triangulation. This need has already been discussed within the research objectives Proverbs and Gameson (Op Cit) state that case study research often adopts the use of triangulation in using three sources of evidence methods, with the advantage that such a method is likely to yield more robust results. Clearly triangulation needs to form a key element of the case study design.

It seeks to provide meaning in context. Again this was discussed within the research objectives. The operational policies are likely to provide the required context. Likewise the clinicians will also explain the context for any operational data that is collected.

It has a clear-cut focus. The identification and the analysis of data, the processing of that data and the communication of the results to the supply chain will provide the clear0cut focus. There is likely to be a strong organisational component.

Yin (Op Cit) further amplifies the scope of the case study with what he defines as the key features of the case study:

> *"Copes with the technically distinctive situation in which there will be many more variables of interest than data points and as one result…*
>
> *…Benefits from the prior development of theoretical propositions to guide data collection and analysis."*

There is clearly a close alignment between these features and that of the case study proposed by the author. The technically distinctive nature of occupancy and the numerous variables that have been identified in both the theory and the science are obvious features. A proposition with clear research objectives aligns well with Yin's second feature of a case study.

Prior to establishing the plan, an element of pre-planning is required to ensure that the pre-conditions for a case study can be satisfied. Clearly if they could not be, then and alternative research method would be required.

4.4.4 - Pre-conditions for a case study

There are three important pre-conditions for the case study suggested by Proverbs and Gameson (Ibid), they identify then as:

1. Time available
2. Availability of documentary information
3. Access to persons involved (e.g. for interviewing purposes).

So far as the potential case study project was concerned the time availability was not of concern because the strategic decision had been made by the project leadership team to carry out the project according to the seven work streams identified in the introduction to this section. More critical however was the availability of documentary information and access to persons who could provide the information and as importantly assist in the interpretation of it. A meeting was held with the BSUH Trust analyst to scope the project and identify the key datasets that would be required. The results of the meeting are set out in Figure 32 on p183. It was concluded from this assessment that documentation/ data would be available within the timescale required. The planning of the work stream could then commence.

Access to persons involved: Specialist experts

However, the nature of the analysis anticipated by the author was for a bespoke use of Discreet Event Simulation software in order to deploy what the author has invented as ‘Occupancy Analytics’. It also requires the bespoke use of sophisticated Thermal Analysis software, in order to deploy what the author has invented as a ‘Whole Facility Energy Model’, unique because it is conceived to receive data from the Occupancy Analysis. In both of these examples, the author needed to employ experts in the use of these highly sophisticated technologies. The resource challenge would be how to source them.

The Whole Facility Energy Model (WFEM)

In the year 2000-2001, the author had been appointed to be the International Evaluator of Finland’s’ national technology programme called VERA. During the appointment process he was introduced Reijo Hanninen, chairman of Olof Granlund. This relationship was to last some years, and it was in 2010 that the author discussed his vision for low-energy – low carbon hospitals with Reijo Hanninen and it was agreed that his company would support the author in the new work, based on the author’s specification for the Whole Facility Energy Model.

The Occupancy Analytics Model (OAM)

In seeking to understand the current knowledge concerning the relationship between occupancy presence and low energy – low carbon hospital performance, the author identified a paper by Professor Augenbroe (Op Cit) discussing the potential for analysis of occupancy to inform engineering design. Professor Augenbroe and the author had previously worked together, (but not in the field of applied simulation) and consequently it was an obvious synergy to collaborate on the work to develop the Occupancy Analytics work stream.

Both models would require extensive data, and consequentially the analysis of available data would be a key part of the 3Ts project plan as much as it would for the case study. The author's knowledge of enterprise information systems (founding director of ARK e-management Ltd and partner in health care informatics company: Eleven Informatics LLP) provided him with a specialist insight into these data requirements and the potential repositories of the data. Ironically in 1996, the author also led the Client Briefing Group in the International Alliance for Interoperability (the forerunner of Building SMART). The prescient mission of this group was to identify all of the key datasets that could exist in client organisations that could be used to create a properly informed facility brief (Bacon, 1998). Some fifteen years later this is the challenge for occupancy analytics.

Access to persons involved: Clinicians

A fundamental requirement for the 3Ts project and also for the case study is that the author should have access to the clinical users. Without such access the whole basis of the project could not be sustained, because the clinical users are essential to the dialogue for low energy – low carbon performance. This is a theme that dominates the proposition as well.

The complexities of engagement of clinical users cannot be underestimated. It was in *Complexities in Organisational Transformation* (T. McNulty and Ferlie, 2002) that the complexities of process reengineering, using a singular case study at Leicester Royal Infirmary, were investigated. The hospital management team attempted to make serious and sustained change. The process of change was highly contested and the results were variable across the organisation. The authors pointed to the doctors that controlled the working practices and the reengineering team found it difficult to reshape their working practices. The authors found that:

> *"…local behaviours reflected the sectoral context of UK health care, with its distinctive assumptions, strategic recipies, and regulating institutions. The pattern of professional dominance (Friedson, 1970, 1994) was still observable at the clinical level and was not effectively challenged…"*

This raises the question as to how to engage the clinical leadership team in the required dialogue? What should be the most appropriate mechanism to address the 'professional dominance'? Yet as McNulty also observes:

> *"Process reengineering is more appropriately seen as a social process, inseparable from the power and politics of the*

organisational setting."

Addressing the 'power and politics' of the organisation is clearly where the engagement of the users needs to commence. But how should this be most effectively orchestrated? McNulty (Ibid) quoting Hammer and Champy, who lead the process reengineering movement in the 1990's:

> *"Process redesign requires…imagination, inductive thinking, abandoning familiar ways of working, and suspending beliefs in time-honoured rules, values and procedures…**people need be educated in the need for change…the keys to getting people to accept the need for change…lie in the process of education, about the need for change, communicating change, and selling change to employees…***

Taking this lead, the author discussed the strategy with the 3Ts Project Director and from this discussion four candidate departments were identified for the initial consultation process. The leadership team in each of these was known to be receptive to many of the new concepts being developed for 3Ts and consequently it was reasoned that they would be open minded to the challenges posed by the In-use energy project being led by the author.

The initial consultation process was implemented by the author with the support of the Trust's Change Management team, which will be explained later in the explanation of the case study design. The contact commenced with a Briefing paper (illustrated in Figure 32) this being the initial step in educating the leadership team of the key issues that were to be investigated in the analysis. The contact with each department was very positive and each of the consultant leads expressed a strong willingness to engage in the process.

3T Programme

Health Activity Model

Following our meeting, my assessment of the information that we could use to populate the health activity model would be:

Patients in Each Area:

1) Ward Areas

Admission and discharge data to generate daily variation in number of patients likely to be admitted to each ward per day, and using length of stay to estimate the number of patients leaving the wards per day.

- Trauma ward
- Medical wards
- Haematology / Oncology Wards
- Clinical Infection Service wards
- Neurology and Neurosurgery wards
- Therapies Area (no data for this – need to go through briefs)

Timeframe for data collection: PAS data available now

2) Day Case & Other Treatment Areas

Daily patient flows for:

- Neurology Planned Investigation Unit
- Cardiac Investigation Unit
- Treatment Rooms
- CIRU
- Discharge Lounge

Timeframe for data collection and source: Discussions with Change Consultants re assumptions in briefs – 2 weeks

3) Imaging Department

Daily patient flows for:

- Main Imaging – Level 4
- Nuclear Medicine

Timeframe for data collection and source: Imaging capacity plan – 3 weeks

4) Out-patient Departments

Daily patient flows for:

- ENT / Max Fax
- Fracture Clinic
- Oncology
- Rheumatology
- Clinical Infection Service

Timeframe for data collection and source: OP model data – 2 weeks

Hazel Belfield-Smith
Senior Analyst, 3T Programme

5) Other Departments and Offices

Daily staff and patient flows:

- BSMS
- Private patients
- Trust HQ
- Teaching & Meeting Suite
- Simulation Suite
- Chaplaincy
- Facilities and Estates Management

Timeframe for data collection and source: Discussions with Change Consultants re operational briefs – 2 weeks

Staff Numbers in each area:

Referencing the workforce plans and operational briefs for each area.

Timeframe for data collection and source: Total staff numbers available now.

However, also will need to refer to Operational Briefs to understand staff patterns between each zone in the out-patient department

Visitors

Daily number of visitors accompanying and visiting patients

Timeframe for data collection and source: Check assumptions made in OBC re car parking etc.

Equipment Schedules

I have not had a chance to scope this with John in any detail. Will update you on this when I know more.

Hazel Belfield-Smith
Senior Analyst, 3T Programme

Figure 32 - BSUH analysis of availability of In-use data

4.4.5 - Purpose and scope of the case study

The purpose of the case study will be to achieve the three research objectives and in doing so to investigate the validity of the proposition set out in Section 3.5 Point of Departure: Proposition The case study will be scoped within the Occupancy Analytics, and Whole Facility Energy Modelling work streams of the 3Ts project described earlier. This is because it is within these two work streams that all of the component inputs required to achieve the first two research objectives are contained. The critical reader might challenge this research strategy by posing the obvious question: How can the author be certain that the research objectives will not be compromised by scoping the case study within these established work streams? The answer to this challenge is that the work streams were informed with these research objectives in mind, because it is these objectives that defined the project. The evidence for this is contained in the following extract from the In-Use energy strategy for the 3Ts project:

- *Major new facilities involve substantial requirements information. Management of the interdependency of requirements and ensuring proper compliance with them requires careful management. Invariably key requirements are 'lost' in decision-making processes because the interdependency of requirements is not fully understood by the project team.*
- *Design options presented to the client maybe sub-optimal a) because they do not recognise the interdependency of requirements, b) because the design team have made assumptions that have not been made explicit (and maybe incorrect) and c) because they have incomplete or inaccurate data.*
- *The risk is that decisions are made on incomplete and incorrect information. This leads to the key project objectives being put at risk.*
- *There is also strong evidence from European research that buildings are also not operated as assumed that they would be during the design phase. In other words, facility briefs are not coordinated with operational plans, or even to do not consider how the facility will be operated.*
- *There is a desperate lack of facility life cycle data. Without such data, the requirement to set realistic performance measures as required by the National Audit Office and the Office of Government*

Commerce will continue to present substantial challenges for construction clients and their briefing teams.

- *In-use occupancy data is essential for effective system performance and yet systems to collect data are rarely used. Research in the US has identified substantial energy savings for optimised facility operations.*

By referencing the three research objectives it is clear from the statements above of the close alignment between the objectives for the 3Ts project and the objectives arising from the sustained arguments presented in this thesis. For this reason the author argues that there is no conflict between the two sets of objectives. Furthermore it is this alignment that addresses one of the key 'dilemmas' expressed by Rapoport (Op Cit), i.e. that of conflicting goals. To further emphasis this alignment the following definitions were set out in the Project Execution Plan for the 3Ts project:

- ***Enhanced Brief[37].*** *This will be a document to complement the existing Facility Brief. It will identify the approved variations to the Brief for the FBC scheme.*

- ***Whole Facility Energy Model (WFEM)***. *This is a simulation model for Phases 1 - 3 of the redevelopment. It will model:*

    - *The thermal performance of the whole facility translated into normalised energy consumption metrics.*

    - *The forecast energy consumption for each of the primary departmental functions of the facility*

    - *It will record design assumptions used in the Basis of Design made by the MEP team.*

- ***Occupancy Analytics Model (OAM).*** *This is a simulation model for Phase 1 – 3 of the redevelopment. It will model:*

    - *The people flow (including patient pathways) through the whole facility to provide a reasonable understanding of the density of occupancy during specified periods.*

    - *The types of people based on their use of the facility, whether they are medical staff, desk-based staff, patients, or visitors. (The exact classification will be agreed during the project).*

[37] The author refers to this as the 'Energy Efficient Brief' in this thesis

- *The people flow through specific departments of the hospital based on the Health Activity Model. Only the most important processes (from the perspective of understanding density of occupation) will be modeled during specified periods.*

- *The usage of major items of equipment in specified departments that consume energy in specified departments.*

It is also important that the characteristics of the case study are not compromised. To remind the reader, these are:

1. It draws on multiple sources of evidence.
2. Its evidence needs to be based in triangulation of these sources of evidence.
3. It seeks to provide meaning in context.
4. It has a clear-cut focus either on an organisation, situation or a context.

4.4.6 - Interpreting the case study: New knowledge

Having established the purpose and scope of the case study the question must be posed: How does the author expect to analyse the results in order to verify the proposition? It seems logical to ask the question at this stage because it forces a focus on the case study outcomes to ensure that they will enable this question to be answered. With this understanding the case study plan must also consider how the analysis will be carried out and in doing so to consider the methodology required to achieve this. Yin, (Op Cit) suggests that:

> *"…every researcher should give at least a few preliminary thoughts, prior to the conduct of the case study to the design of the final case study report."*

The author suggests that as important, if not more important, the method of analysis of the results to verify the proposition needs careful consideration because understanding what the objective of the output needs to be will enable the input data and analysis to be managed.

4.4.7 - Planning the case study

The planning of the case study by the author does not need to embrace all of the planning activities normally associated with such work (Yin, Op Cit, p71) because the case study formed part of the planning for the work streams outline earlier in this chapter. Obviously the work streams had to be planned and the author needed to ensure that the appropriately skilled resources were available to deliver the work stream objectives. This was described in Section 4.4.4 Preconditions for the case study.

It was because the planning, data collection, analysis and conclusions were integrated into the work streams that the author was able to ensure that data and documentation required for the case study was collected and assimilated as the activities in the work streams progressed. Nevertheless the commencement of the case study required a reflective period (Somekh), which for the case study would be with the 3Ts project team. The author reasoned that it was important at the outset of the work to set out to achieve consensus with the client, engineering team and contractor. The process commenced with a series of workshops the objective of which was to achieve convergent thinking within the team. Key focus areas would provide the scope of the work for the action research. Eventually these focus areas were to become the work streams explained previously.

The case study is planned to provide the inputs (the results of reflective practice in action research) to the chapter setting out the requirements for the Energy Efficient Brief. These three areas of study will then lead to the Conclusion chapter where the implications for practice and theory will be discussed.

Action research: impact on planning the case study

McKay and Marshall (2001) describe the action research process as not just 'cyclical' and a single cycle as many action researchers describe, but in reality as a dual cycle, of planning, executing and fact finding on the one hand, and action planning, action taking, evaluating, specifying learning and diagnosing on the other. Where the former is more aligned to consulting, the latter has greater alignment with the research endeavour. In the latter cycle, they identify the need for reflection based on findings from the consultancy and then consideration of research themes, leading to research knowledge. By this means they argue that the 'consultancy' role and the 'research' role of the action researcher can be effectively carried out. It will be these characteristics that will be found in the author's research design in chapters 6 and 7. It is the in the experimental phases of each of the two stages of the action research that the 'research' cycle will be evidenced. It is here where the experiments are referenced to a theoretical context.

4.4.8 The case study protocol

The early stage work, described above as a 'reflective period' was not simply intended to ensure that all key stakeholders in the process were aligned to the objective of the proposed work streams, but beyond this to establish a clear protocol for the proposed method of working. It was through this protocol that the following requirements were identified:

1. Objectives ('Goals' as defined by Rapoport, (Op Cit)) of each work stream and the interfaces with the consultants, Principal Supply Chain Partner[38] and client. A clear understanding of the outputs of each work stream and how these would be used within the project.
2. Organisational design. Activity management and reporting protocol. The forum to discuss business and research objectives as proposed by the 'In-use Energy team' (in other words the author's own business) with the client and Principal Supply Chain Partner. Through this forum it was intended that the exploratory work and the project objectives would remain properly aligned ('Ethics' as defined by Rapoport (Op Cit)), and thus addressing a key risk in action research projects.
3. Data collection and management. As explained previously the Trusts data analyst was to be nominated as the principal contact with the In-use Energy team. The development of a 'Health Activity Model' was defined as the means to assimilate this data.
4. Methods for conducting experiments ('Initiatives' as defined by Rapoport (Op Cit)) and reporting of results as part of the Research works stream.

The protocol was then integrated into the plan of work for the project.

[38] The Principal Supply Chain Partner is the role of the main contractor within a Procure 21+ Framework operated by the Department of Health, see: http://www.procure21plus.nhs.uk

Chapter 5.0 The Case Study: Reflection on current practice and the conceptual design considerations for the modelling of occupancy presence, and holistic energy modelling in acute hospitals

5.1 Introduction

In this chapter the author establishes the theoretical framework for the case study. The theoretical issues that need to be investigated are defined by two methods: *Occupancy Analytics* and *Whole Facility Energy Modelling.* Each method is set out as a sequential stage of the case study.

It is in this chapter also that the conceptual design considerations for action research are discussed in detail. The two parts of the case study will report on each method introduced in the paragraph above. Each will be grounded in the context of current knowledge pertinent to the author's proposition. The discussion will provide justification for the model design based on the analysis of the precise point of departure. In this chapter the author will explain how the two work streams from 3Ts were developed into these two distinct methods with the objective of providing the 'appropriate data' for the application of building engineering physics using fundamental principles (and not formulaic methods).

In the previous chapter the author explained the proposed case study stages in relation to the 3Ts work streams.

In Section 5.2 the author will explain the key design considerations in the specification of the first method: *Occupancy Analytics*. In this Section the author will discuss the requirements of the 3Ts project and then correlate them to current knowledge gleaned from the literature review. The author will discuss the requirements of the building engineering science and how the proposed method described as Occupancy Analytics was developed. The structure of Section 5.3 will be similar to that of Section 5.2, where the second method: *Whole Facility Energy Modelling* will be discussed.

Finally in Section 5.3 the author will draw out key conclusions, supported by the observations from the design work, and explain the implications for addressing the proposition.

5.1.1 - Why Occupancy Analytics and Whole Facility Energy Modelling?

It has been made clear in the analysis of the examination of the precise point of departure (p137) that understanding the causal factors of occupancy presence is a significant issue to be addressed. Furthermore, the literature review found (and this was confirmed with the project team in the workshops reflecting on current practice) that because it has traditionally not been possible to reliably forecast model occupancy presence in acute hospitals neither has it been possible to directly correlate the energy and carbon impact of In-use with the occupant types that are present at a particular point in space and time. This is of fundamental importance, because unless users understand the impact of In-use, why would they actively seek to reduce energy consumption through their working practices? The importance of this need has been underlined by the European Commission (Op Cit, 2013). These are the key arguments explaining why the author believes that these two methods are unique contributions to the application of building engineering science.

How are these two methods relevant to the investigations into the proposition? To answer this question, the relevant parts of the proposition need to be restated (see p140):

> *As the effective implementation of building engineering physics is compromised by a lack of* ***'appropriate In-use data'****, it follows that making good this deficiency should enable* ***improved prediction of In-Use energy performance****. Yet as it is clinical users that fundamentally impact In-Use energy and carbon performance, they* ***will require knowledge of the energy and carbon impacts of their working practices****.*

To summarise: the objective of these two methods is to:

a) Provide 'appropriate data, and

b) Enable clinical users to acquire knowledge as to the energy and carbon impacts of their working practices.

In terms of the research objectives (see p144 et seq.) the development of the method referred to as *Occupancy Analytics* would be expected to satisfy Research Objective 1. The combination of both methods, *Occupancy Analytics* and *Whole Facility Energy Modelling*, applied in a process would be expected to satisfy Research

Objective 2. The two areas of focus within the case study (which will be two stages of investigation in the case study) are expected to demonstrate whether or not this has been achieved.

5.2 Key theoretical issues: Occupancy Analytics

The 3Ts Occupancy Analytics work stream commenced with a conceptual analysis of occupancy presence. The following questions were considered. It was from the analysis that the input/ output requirements of the occupancy analytics study was then developed.

1.1 What is occupancy presence?

1.2 How to forecast the probability of occupancy presence within defined areas of the hospital at hourly intervals throughout a 24 hour period?

1.3 What are the factors that determine occupancy presence in hospitals?

1.4 When determining occupancy presence what are the temporal issues in relation to the occupant demand on space?

1.5 How to forecast service demand from patients on imaging equipment, clinicians and other resources?

The answers to these questions provided the information to enable the author to develop a conceptual model of occupancy presence. The literature review provides the theoretical context for this work (notably Section 3.3.2 - Application of the theory of In-use in research). The author proposed that using the understanding gained from the investigation into these questions that he would develop a table of occupancy ontology classes and associated object properties. From this development he would then create a Health Activity Model (HAM). It would be this model that the author conceived would provide the basis for *Occupancy Analytics*.

A key issue arising out of the literature review (see p115) was the poor understanding that the research community has of the process drivers that cause occupancy presence. From the workshops with the 3Ts project team the same issues were observed. The author found researchers investigating indicators of occupancy (such as presence detection, light switching and plug loads), but not the logical causes of occupancy, such as occupancy caused by a process. With the 3Ts project the author sought to understand the predictable factors that cause occupant flux (and therefore presence) in hospitals. It was in discussion with the BSUH Trust analyst that the author became aware of Operational Policy documents. In reading through some of these, the author reasoned that Operational Policies could provide a basis for understanding both flux and presence. The content of these policies clearly demonstrated process centricity in them, and the author recognised the potential for these documents to provide the process logic that would lead to an understanding of both. Examples are illustrated in Figure 33. The first concerns intra-departmental flux and the latter inter-departmental flux.

Patient flow

The majority of the patients attending will be ambulant although some will be attending in wheelchairs. There should be no high gradient slopes in the building. Occasionally a patient may arrive on a trolley for treatment. In these cases the patient will be taken straight to the treatment area.

Patients will be received at the reception desk and will wait prior to treatment in the main unit waiting area. Individual patients will be called into the treatment area where they will have their treatment either on a bed or in a chair. Patients attending for blood tests will be taken to a treatment or phlebotomy room.

Imaging

- If a patient requires Imaging and has not already had their scan, the Patient Access Team will arrange this appointment prior to their outpatient attendance so that Imaging results are available for their outpatient appointment.
- The majority of Neuro outpatients do not require imaging prior to their appointment. If they are subsequently found to need imaging they are directed to go to Imaging to make an appointment, or if it urgent the Consultant will ring to arrange for an immediate appointment if possible.
- The introduction of the Spinal Triage service may mean that all patients have a scan before coming to Outpatients.

Figure 33 - Example of a process statement within an Operational Policy document.

In discussion with the project leadership team, notably the Project Director and the Project Board members, they too confirmed that the Operational Policies were conceived to provide a management framework that establishes how the new facilities were envisaged to operate.

What is occupancy presence? Occupancy presence is the probability of the quantum of occupants in a space measured at a predetermined time frequency through a 24-hour period. It is not the same as measuring occupant flow, where the measurement is concerned with the rate of flux of occupants through space. The evidence from the literature review identifies that because occupancy is stochastic, then the probability of occupancy should be measured.

How to forecast the probability of occupancy presence within defined areas of the hospital at hourly intervals throughout a 24-hour period? Through an interview with the Trusts' data analyst it was found that the variability of patient arrivals and departures to and from a specific department could be quantified. Some occupancy was found to be 'predictable' (i.e. logic driven, such as by a schedule) and other occupancy would be highly stochastic (i.e. probably not schedule driven, but subject to substantial variance). It was also found that the Trust could advise the proportions of patient arrivals to a department from other departments, as a consequence of inter-departmental flux. It would be this variability that could be calculated as a Standard Deviation (SD)[39].

What are the factors that determine occupancy presence in a hospital? The author interviewed the Trusts' data analyst and found that:

1. Outpatient schedules are a key determinant for outpatient arrivals.
2. Staff shift patterns and staff schedules are a key determinant for staff arrivals and departures into the hospital. Staff movement across the site can also be predicted at key times of the day.
3. Staff breaks and meal times determine key staff movements between departments and other spaces.

[39] It will be explained later how this data is used within what the author refers to as a '*Health Activity Model*'.

4. A significant proportion of the movement of Porters can be scheduled, such as Meal times, inter-departmental patient transportation, and linen deliveries and collections.
5. It was apparent that many staff movements are random and followed no logic – in other words they are highly stochastic.

These same issues were identified by Robinson (2006) who is highly critical of '*robotic deterministic models of occupancy presence based (if at all) on predefined schedules'*. He discusses the inherently stochastic nature of occupancy presence. Robinson's comments maybe correct for many building types, but in a hospital that is highly process centric, and for some occupant types that are schedule driven (Jun et al., 1999), there will be both predictable and stochastic occupancy diversity.

For those components of occupancy where significant stochastic movements of occupants were identified (an thus not possible to predict within a reasonable level of certainty), the author decided to specify that the Occupancy Analytics Model should randomly distribute them in those areas that each occupant type was likely to occupy. The random distribution was however based on known average values.

An alternative method suggested by Page et al (Op Cit, 2007) used an analysis of plug loads to estimate this randomness, but this fails to take into account those occupant movements that do no cause such loads. This is the argument of Azar and Menassa (Op Cit 2012), albeit that the focus of their research concerned the sensitivity of input parameters to energy models. As examined by Robinson as cited above, the author would argue that there could be no logical rationale, apart from where there are some known values. Typical examples of such randomness are:

1. Facility management maintenance staff – responding to either random or scheduled events.
2. Clinicians called to different departments as a consequence of random events.
3. Teaching staff and students attending lectures, seminars or exams (BSUH is a teaching hospital).
4. Visitors to Inpatients.

Inherent with both the largely 'predictable' (but still with stochastic attributes) occupancy and the largely 'unpredictable' (significantly stochastic attributes) occupancy would be the need to model the probability of occupancy presence. By this means the author argues that variance in occupancy, and by implication some of the potential inaccuracy (of the highly stochastic occupancy), could be expected to be absorbed within the parameters established for the range of probability of occupancy presence.

When determining occupancy presence what are the temporal issues in relation to the occupant demand on space? This issue relates to space utilisation at specified times each day. It is clear from the literature review (e.g. Section 3.2.6 - Critical analysis of KS8: CIBSE Design Framework) that engineering designer's need to understand the variability (diversity) of occupancy presence within each facility space. This is in direct contrast to the conventional method used by engineering designers where occupancy presence is determined through the use of Room Data Sheets associated with the Department of Health: Health Building Notes[40]. In this case, the engineering designers assume that all spaces (rooms) will be either fully occupied for the purposes of calculation or there will be a diversity factor applied to the space depending on a subjective judgement of the engineer. At least this was the evidence from the 3Ts project, and mirrors the author's own experience.

The concept of facility space was considered by the author to be a key consideration with respect to temporal occupancy. The author established a space organisation framework based on zones (departments) and sub-zones (like functions within a department). The requirement to model zones (defined as similar areas of use,) is required by the UK Building Regulations Part L2A (Op Cit). The value of this approach to energy modelling is also discussed by Raftery et al. (2009), where he discusses the benefits of what he refers to as 'zone typing'.

For 3Ts each zone was uniquely identified by a zone code. The author reasoned that this framework could be applied to all perspectives of the occupancy/ energy analysis. In discussion with the Granlund OY (WFEM lead) and Professor Godfried Augenbroe (OA Lead) these units of space were agreed as the basis of analysis. This concept was considered by the author as one of the key challenges to be

[40] See: https://www.gov.uk/government/collections/health-building-notes-core-elements

addressed in the forecasting of occupancy presence in relation to energy consumption within each zone. Referring back to the literature review (p109):

> *….but this task is complicated by the difficulty in reliably detecting the number of occupants within a building zone throughout the period of interest or, better yet, tracking occupants' movement throughout a building whilst present.*"
>
> (Robinson and Haldi 2011, Op Cit)

It is this challenge that Robinson pointed to in his earlier paper in 2006, quoted earlier in this Section. In developing the conceptual design for occupancy analytics the author reasoned that an understanding of the probability of occupancy presence in each zone/ sub-zone would be required because this would reflect both the stochastic component and the more 'predictable' component of occupancy presence.

The author also reasoned that there would be the possibility of modelling individual patient pathways through the zone/ sub-zones of the hospital. This reasoning emanated from the preliminary research for this thesis (see p36). He reasoned that because energy consumption and carbon emissions would also be modelled at this level through the Whole Facility Energy Model, it would be possible to determine the energy consumption profile for each patient type. This would provide a better indication of performance than measures normalised to floor area, which failed to acknowledge intensity of use. No precedent could be found for this approach in the author's research.

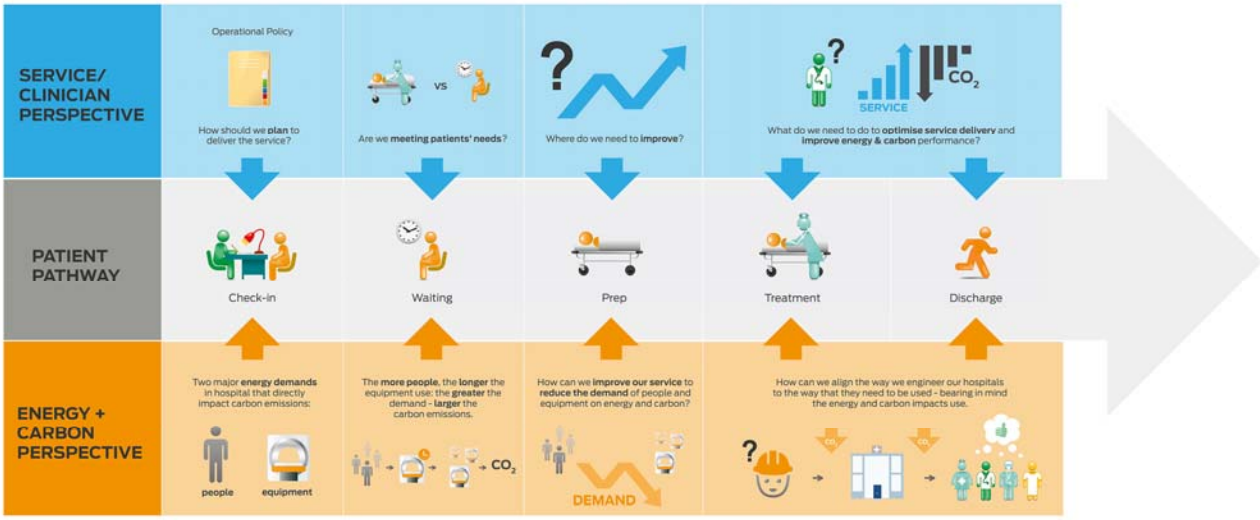

Figure 34 – Please refer to page 98 for the detail of this diagram

By adopting a patient centric analysis such as that illustrated in Figure 34 the author reasoned that the potential exists to directly correlate working practices to the energy and carbon impacts of use. It could provide the opportunity for users to optimise working practices not just to improve clinical outcomes, but also to reduce energy consumption and carbon emissions. As explained earlier a zone/ subzone strategy could provide a sound basis for this analysis.

How to forecast service demand from patients on imaging equipment, clinicians and other resources? Whilst there is much research in the forecasting of resources and optimisation of use, (the work of Reijula and Tommelein (2012) is one obvious example), the modelling of occupancy presence in relation to energy demand on hospital equipment resources is less well developed. The closest correlation is that of Page et al. (2007) where they use a Markov Chain method to model occupancy presence and then study the probability of office equipment use. Certainly their work substantiates the need, but the authors acknowledged that theirs was a simplistic model, recognising the limitations of the available data.

The significance of assumption errors in small power (equipment related) by engineering designers was investigated by Knight and Dunn (2005). They found the current practice over estimates small power loads by as much as 24%-650%, depending on the guidance used. The guidance is either based on formulaic – worst case guidance or 'rules of thumb'. They concluded that: *The average UK office small power load design estimate would therefore fall from around 40 W/m2 to between 12 and 25 W/m2, a reduction of 35–70%*. How did they arrive at these results? It was through a survey of 30 office buildings in the UK. They used actual data and from this data they were able to arrive at the new recommendations. This work demonstrates the value of a data-driven analysis, (such as *Occupancy Analytics*) rather than guidance emanating from the late 1990's. The author's also assert that this data will have a knock on effect leading to reduced thermal comfort, and increased capital and running cost of air-conditioning systems.

What could be the implications of this situation? The engineer will have therefore over-estimated the heat gains to the space and thus over-sized the cooling plant accordingly[41]. Haymaker and Clevenger (2006) suggests that over-estimation of small equipment loads could result in an increase in energy use of up to 24% and peak demand loads increase to about 2% in a cold climate. This raises the question, why has engineering guidance such as CIBSE Guide A, not been updated inline with this knowledge?[42] This also has implication for the briefing process in terms of how relevant standards are specified. The reader may recall that this was discussed earlier (p71).

KEY ISSUE

As it is clinical users that use the major equipment in response to the scheduled and un-scheduled demand of patients, then the occupancy analysis should enable the demand profile of all patient types on the imaging machines required for their diagnostics/ treatment to be modelled and thus avoid over-estimation of heat gains to the space in which the equipment is located. The reader will now appreciate the value of modelling of equipment demand because (as will be demonstrated in the case study) major equipment such as imaging equipment is a significant consumer of electricity.

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[41] Please refer back to Figure 23 for an illustration of these impacts.

[42] Even the 2015 update of the Guide fails to address this issue, despite referencing an update to occupancy related internal heat gains.

Specific to 3Ts, during the work stream concept design period the author held meetings with major equipment manufacturers to understand the impact of equipment specifications on energy consumption. The manufacturers provided the author with detailed data concerning imaging equipment performance. Just as with the equipment energy loads on offices as cited by Dunn and Knight (Ibid), during its operation the electricity consumption required to support the functioning of the machine is converted into heat. This heat is liberated from the machine into the surrounding space and this heat adds to the cooling load or offsets part of the heating load of that space.

5.2.1 - Key ontological issues

In developing the conceptual design for Occupancy Analytics the author worked with his team to develop a schema for the Health Activity Model (HAM) database, because he could not find any precedent from the literature review. In developing the HAM specification the author developed classes for occupancy ontology with associated object properties. The author could find no precedent for an occupancy ontology, but in the later research for this thesis of established semantic resources the approach taken by Dibley et al. (2012) was identified. The author found the closest approximation was that from the Building SMART IFC[43] definitions for occupancy (*IfcOccupantTypeEnum)*, but these definitions appertain to the leasing of buildings, as illustrated in Figure 35, which the author would consider to be an 'occupant type', and does not satisfy the requirements of the analysis of occupancy presence.

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[43] http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/ifcsharedfacilitieselements/lexical/ifcoccupanttypeenum.htm

Value	*Definition*
ASSIGNEE	Actor receiving the assignment of a property agreement from an assignor
ASSIGNOR	Actor assigning a property agreement to an assignor
LESSEE	Actor receiving the lease of a property from a lessor
LESSOR	Actor leasing a property to a lessee
LETTINGAGENT	Actor participating in a property agreement on behalf of an owner, lessor or assignor
OWNER	Actor that owns a property
TENANT	Actor renting the use of a property for a period of time
USERDEFINED	
NOTDEFINED	

Figure 35 - IFC classification of occupancy

The need of the ontology specification for 3Ts was to create occupancy ontology classes and to use these definitions as a basis for defining property sets for the simulation modelling. In their work on intelligent sensor-based building monitoring Dibley et al (Ibid) created at table of building ontology classes and from this they then developed the object properties Figure 36. It is this approach that was also adopted by the author. The literature review identifies the clear need to establish a full ontology of occupancy in future research.

Table 3.
Selected building ontology classes.

Class	**Description**
SpaceOpening	The super class for doorways and virtual boundary. A void through which people can pass for normal building use<comma> excluding windows etc. and excluding for the purposes of emergency evacuation
MonitoredOpening	Sub class of SpaceOpening<comma> an opening that can be monitored in terms of detection the directions of persons passing through
CheckableOpening	Similar to MonitoredOpening but can only detect passage and not direction of persons moving through
Zone	Definition of zone in terms of a minimum of 3 walls cf. wall assemblies is adequate. A zone is consider a closed area with typically openings such as doors and windows and virtual boundaries
Space	An internal region of a building
SpaceBoundary	Demarks a space. In the IFCs a given wall can span several spaces. In the ontology SpaceBoundary instances map to the wall connection geometry in the IFCs<comma> participate in the space topology and can participate in a further wall assembly
WallWithOpenings<comma> SolidWall	Subclass of SpaceBoundary. Opening may or may not be ",filled", with door/s using the topology
VirtualBoundary	Subclass of SpaceBoundary. Revit doesn't set IfcVirtualElement as a boundary although it does set some related connection geometry and the virtual flag is set in the objectified relating object. The ontology considers virtual boundaries as openings (passable through by people)
Door	Physical barrier. Door is not part of opening<comma> as it would no longer be an opening (when the door is closed)<comma> although it is topologically related to the opening

Figure 36 - Building Ontology Classes (from Dibley et al. 2012)

The development of the ontology of occupancy could be achieved through further research. At this stage, the author's work on 3Ts was pragmatic: to document the semantics of occupancy presence in sufficient detail to enable the formation of the Health Activity Model.

5.2.2 - Summarising the key conceptual issues for Occupancy Analytics

The key conceptual issues for Occupancy Analytics were identified as needs:

1. To define ‘occupancy presence’.
2. To define the modelling requirements of occupancy.
3. To develop occupancy ontology classes and associated object properties for the development of the HAM.

It was in understanding these needs that the author formalised the specification of requirements for the Occupancy Analytics model. As will be explained in the case study, the simulation application was then configured to conform to this specification and data collection templates were designed to enable the data from the BSUH Trust to be collated within it.

5.3 Key conceptual issues: Whole Facility Energy Modelling

In a parallel study to the 3Ts Occupancy Analytics work stream, the conceptual analysis of what the author conceived as ‘*Whole Facility Energy Modelling*’ also commenced. It was important for both work streams to be developed concurrently because of the strong interface between both work streams. The following questions were considered. It was from the analysis that the input/ output requirements of the In-use energy modelling study were then developed.

1.6 What key concepts were identified that needed to be addressed in a Whole Facility Energy Model?

1.7 What factors were identified that determine energy consumption in hospitals that the user could have control over?

1.8 How should the energy impacts of occupancy be modelled, such that it would provide actionable knowledge for the users?

The answers to these questions provided the information to enable the author and the In-use energy team to develop a conceptual model of forecast energy use and associated carbon emissions.

5.3.1 - What key concepts were identified that would be required in a Whole Facility Energy Model?

The key concept developed by the author is that as it is users that directly impact energy consumption in buildings, then all energy use impacted by those users must be modelled. However, it will be appreciated from the literature review that large assumptions are made by engineering designers concerning energy consumption impacts of use. The Whole Facility Energy Model was conceived to address those assumptions and to provide a level of detail that would provide much improved predictability of forecast energy use. Since commencing the writing of this thesis Leach et al. (2012) have published their work on establishing "*Whole-Building Absolute Energy Targets*". Of note is that they advocate the setting of absolute targets. For reasons that will be discussed later (please see Chapter 8) the setting of absolute targets makes no sense to the author, when there are so many unknown factors that could impact such a target. The author will argue for a target range. Nevertheless an important validation of the author's approach is the assertion that to arrive at a target a detailed understanding of In-us is required.

It was also learned from the literature review that In-use energy consumption is categorised from two perspectives:

1. The building asset consumption. It is the energy required to heat, and cool the asset to provide acceptable comfort conditions for the users. It is that which is to provide sufficient fresh air for the needs of the users. The energy consumed is that which is defined as 'Regulated Energy'. The energy consumption performance is measured through the Energy Performance Indicator (EPI).

2. The operational energy consumption. It is the energy consumed in the operation of the building in order to carry out the functions of that building. The energy consumption is that which is defined as 'Unregulated Energy'. The total energy consumption performance

(comprising both ‘Regulated and Un-regulated’ consumption) is stated through the Display Energy Certificate (DEC).

Only the ‘Regulated’ operational energy consumption is modelled in the Energy Performance Indicator is and because of this, it is the ‘Unregulated’ (hence the designation) component of consumption does not form part of the energy performance forecast of the professional team. The author’s concept for the Whole Facility Energy Model is to address this issue. However, this is not to say that others have not attempted to do this, but because they have insufficient temporal and spatial availability of occupancy related data, they are obliged to make assumptions. However, for the forecast to be meaningful and not based on many assumptions, the author conceived that the model must reflect forecast In-use energy consumption. It is here where the integration of the data from the Occupancy Analytics model would provide the values for the energy simulation.

5.3.2 - What were the factors that were identified that would determine energy consumption in hospitals that the user could have control over?

The question was discussed with between the author and user representatives from the Imaging, Fracture and Radiology departments. The discussions identified that understanding the impact of Operational Policies on occupant presence could be a key factor. This was explained in the earlier section of this case study in Figure 33. The reader will recall from the literature review that this is because occupant presence (and in particular) the peaks of occupant presence directly impact the sizing of the engineering plant: The larger the plant then the larger the potential energy consumption. A second consideration concerned the impact of operational policies governing the scheduling of departmental operations relative to each. The author reasoned that concurrent loads could also directly impact concurrent demand for energy, as investigated by Abushakra et al. (2004) in their literature review of diversity factors and schedules for energy and cooling load calculation. Reason suggests that this would be the case, because concurrent peaks of occupancy in interconnected departments would lead to larger aggregated peaks of occupancy. It follows that if these peaks could be managed through diversity then energy consumption could also be managed. The evidence for this should be revealed within the Whole Facility Energy Model. An analysis of the benefits of this approach was identified by Weng et al. (2011)

Conceptually therefore the occupancy profiles from the Occupancy Analytics studies would need to be replicated within the Whole Facility Energy Model usage profiles.

Another example of the potential for user control of energy impacts would be concerned with major imaging equipment utilisation. Concurrent demand profiles for equipment use would also be expected to impact overall consumption such that peaks of consumption would arise. This was a matter highlighted during the project planning phase in discussions between the author and the Imaging department.

These examples suggest that by understanding impact of In-Use working practices and operational policies on energy consumption then further opportunities for reducing energy consumption could emerge. The conclusion of these considerations was that the Whole Facility Energy Model would need to provide sufficient flexibility to enable alternative scenarios to be modelled.

5.3.3 - How should the energy impacts of occupancy be modelled, such that it would provide actionable knowledge for the users?

In discussions with clinical users and the Director of Facilities at the Trust it became apparent that users have little understanding of the impacts of their working practices on energy consumption. Furthermore, a common-held view was that as energy consumption was only reported in highly aggregated terms at whole hospital level, there was no understanding of the impacts of In-use energy at departmental level. Awareness of energy consumption was simply communicated through encouragement to turn off lights and computers. The author reasoned that if users are to be engaged in change to reduce consumption (and the examples from the literature review highlight this need) then users need information appropriate to them and their needs. It should be sufficient to inform them of the energy and carbon performance in their workplace, i.e. the department level of abstraction.

This discussion highlighted the need to establish a concept of departmental energy budgets that would be created out of an understanding of In-Use. Yet the conceptual challenge would be how to establish a basis for departmental energy forecasting? What would be an acceptable protocol? To answer this question the author commissioned a study into departmental energy profiles in Finnish hospitals from Granlund OY. The purpose of this study was to establish what leading practices in Finland could be applied to the UK. The study concluded (Figure 37 refers) with an assessment of energy budgets based on either interpolated data or direct departmental data for all the key functions of the 3Ts. This study was to provide a basis for benchmarking the best of acute hospital performance in Finland, with the potential performance possibilities that might be achieved through an In-Use low energy – low carbon strategy.

Zone/ Sub-zone	Area (m^2)	Zone Type	Energy Consumption (kWh)			
			Heating		Electricity	
			Min	Max	Min	Max
Ear, Nose & Throat						
Shared Space	162.5	General Hospital Space	14625	21125	16250	26000
ENT & MF	240	Treatment	14400	21600	40800	48000
Audiology	127	Treatment	7620	11430	21590	25400
Offices	164	Office	14760	21320	16400	26240
Shared Support	92	General Hospital Space	8280	11960	9200	14720
Rheumatology OPD						
Reception and Waiting	51	General Hospital Space	4590	6630	5100	8160
Offices	96	Office	8640	12480	9600	15360
Consultation	140	Treatment	8400	12600	23800	28000
Staff Support	22.5	General Hospital Space	2025	2925	2250	3600
Discharge Lounge						
Reception	21	Office	1890	2730	2100	3360
Patient Area	142	Ward	11360	14200	14200	15620
Support	82.5	General Hospital Space	7425	10725	8250	13200
Other						
Main Entrance	493.4	General Hospital Space	44406	64142	49340	78944
Retail & Changing	568.5	General Hospital Space	51165	73905	56850	90960
Neurosciences						
Entrance	11	General Hospital Space	990	1430	1100	1760
Outpatients	491	Treatment	29460	44190	83470	98200
Neurophysiology	285	Treatment	17100	25650	48450	57000
Staff Support	568.5	General Hospital Space	51165	73905	56850	90960
Nuclear Medicine						
Reception and Waiting	163	General Hospital Space	14670	21190	16300	26080
Staff Support	33.5	General Hospital Space	3015	4355	3350	5360
Office Accommodation	182.5	Office	16425	23725	18250	29200
Clinical Area	482	Treatment	28920	43380	81940	96400
Radiopharmacy	162	Treatment	9720	14580	27540	32400

Figure 37 - Finnish energy benchmarking data for departmental analysis

Figure 37 illustrates the two components of energy consumption as described earlier in this section, which in the UK correlate to the EPC referred to as 'heating' consumption and the DEC rating which comprises both In-use energy and heating energy consumption.

At this stage of the project the author had a clear understanding that energy consumption needed to be correlated to space (through zones and sub-zones) as illustrated in Figure 37. Yet the question remains how would consumption need to be modelled within the Whole Facility Energy Model such that it would provide meaningful knowledge, which would then be actionable by the users and thus deliver improved performance? In discussing this question with the In-Use energy team the need to modify room space performance values was identified, such as: lighting, heating, cooling and ventilation. This lead to the need to construct a Building Information Model where all parameter sets could be altered such that different operational scenarios could be considered, and in doing so the energy and carbon impacts could be quantified.

5.3.4 - Summarising the key conceptual issues for Whole Facility Energy Modelling

The key conceptual issues for Whole Facility Energy Modelling were identified as needs:

- To model all energy consumption in a facility and to directly correlate that consumption to working practices and operational policies, so that it is given proper context for the users.
- To provide a means for modelling of alternative In-use scenarios, such that the impact of alternative working practices and operational policies can be investigated. Usage scenarios must be capable of being modelled at sub-zone level.
- To provide a means for the forecasting of departmental energy targets and for reporting of energy consumption using new norms such as those related to sub-zone type (e.g. kWh/ treatment room) or by patient type (e.g. kWh/ oncology outpatient). These norms should be relevant to the needs of the users.

5.4 Reflection on Current Practice

The case study reflection on current practice set out to understand if it would be possible to determine occupancy presence in an acute hospital, and to investigate if it would be possible to model the associated energy consumption. The author's conceptual design for the 3Ts work streams comprising Occupancy Analytics and Whole Facility Energy Modelling identified:

- A zoning strategy that would enable both occupancy presence data and energy consumption data to be modelled in the same zone. This would also provide the opportunity to establish departmental (zonal) energy budgets based on forecast patient demand.
- Occupancy data could be mined from clinical information systems, and it was further identified that this data was sufficiently detailed to identify the variance in patient processing such that would be required for the simulation. An occupancy ontology would be required such that a Health Activity Model could be created.
- A Whole Facility Energy Model could be developed. Early discussions with the author's energy modeling team identified that his proposal to use a Building information Model as a basis for the energy modeling would be possible to achieve. Furthermore, it was also agreed that the energy modeling at sub-zone level would enable an appropriate level of analysis to engage with the clinical users.
- Operational Policies were sufficiently comprehensive to provide the process logic for the simulation of occupancy presence. The investigation also identified how to mange highly stochastic occupancy flux in the simulation model.
- Imaging equipment use could be simulated and energy data from manufacturers could provide sufficient detail to enable consumption at different phases of equipment operation could also be simulated. Demand on this equipment could be modelled from the occupancy flux.
- Clinicians were sufficiently supportive of the work to engage in development of improved operational policies that could impact energy consumption. Imaging equipment use, collaborative inter-departmental operational policies and peak load smoothing (load shedding) were just a few initial ideas that were agreed could be investigated.

In terms of the research objectives, the author identified that there would be much potential to fulfill Objectives 1 and 2. In evaluating the potential at this early stage of the project, the author presented his finding to:

- The Director of 3Ts and the Project Leader.
- The 3Ts Programme Board

So far as the proposition is concerned this initial study provided the team with much confidence that a study of In-use would reveal the 'appropriate values' that would be required for engineering using fundamental principles, and so avoid the need for substantial assumptions to be made. Secondly, the initial study also provided much confidence that clinical leaderships would engage in the process and work with the author and his team to consider how to work towards low energy – low carbon performance through organisational and service redesign.

5.4.1 – Implications for the two stages of the Case Study

There was much enthusiasm for the work, and with clear objectives agreed, as described in this thesis, the work was agreed to proceed to the next stage, which comprised the development of the Occupancy Analytics Simulation and the Whole Facility Energy Model.

One key concern that was raised by the Programme Board: How to develop a close involvement with the users and to convince them that work is worthwhile. As was explained earlier in the previous Chapter, in his consultation process the author had been guided by the Director of 3Ts as to those departments that would probably be most receptive to this investigation. It was agreed that the author would work with the leadership team in each department in order to develop the work. It would be hoped that once other department leadership teams learned of the work that they too maybe inspired to collaborate. This approach was very much in line with that advocated by McNulty and Ferlie (Op Cit), please see p181.

Chapter 6.0 – Case Study Stage 1: Analysis of In-use through Occupancy Analytics

6.1 Introduction

In this stage the author will report on the results of the investigation into the analysis of occupancy presence for an acute hospital context in the UK. This part of the case study is a key part of the research to prove the author's proposition. Section 6.2 reminds the reader of the research objectives and the relevant parts of the proposition that require investigation at this stage.

Section 6.3 will then report on the detailed planning for this stage of the Case Study. Particular emphasis has been applied to the planning of data verification and on the validation of the results. The literature review consistently identified 'simple models' of occupancy and even with such 'simple' models, achieving predictability of results has been challenging. The author's analysis on the other hand is a relatively complex model, and is predicated on achieving a close dialogue with the clinical users. Detailed planning was essential to ensure engagement with the users was timely from both perspectives.

Section 6.4 reports on the data collection process. It reports on the development of an ontology of occupancy. This warrants further research, but the authors pragmatic positions was to develop sufficient detail to enable the HAM database to be developed, and to ensure the semantic definition of key entities. Another important data element is that of the clinical process logic. This is reported in Section 6.5. It is here where the author reports on his discovery in the use of Operational Policies as the source of such logic. This approach contrasts with established theoretical methods that attempt to model occupancy presence based on evidence from surveys of buildings use.

In Section 6.6 the hospital zoning strategy for the analysis is reported. The rationale for establishing integration with the Whole facility Energy Modelling work is explained.

In Section 6.7 the author reports on the development of the Occupancy Analytics specification. It is here where the author builds from the established body of knowledge and explains where the departure to the new method arises. The application of these methods is explained in Section 6.8 where the development of the occupancy model is reported. The author reports on his vision of a 'library of re-usable process components, conceived in clinical functions. Finally Section 6.9 reports on the findings of the analysis, and reports on the dialogue with clinicians to both validate the results and to experiment to seek ways in which clinical process could be improved whilst managing the factors that impact occupancy presence. The author discovered that established improvement initiatives such as those in 'Lean Healthcare', organisational and service redesign, could be leveraged to optimise occupancy presence. It will be demonstrated in Stage 2 of the case study, how such initiatives can lead to improved energy and carbon performance.

6.2 Case study objectives

In the foregoing Chapter the conceptual design issues for Occupancy Analytics were explained in the case study. In this section a case study of the implementation and results of Occupancy Analytics is now presented.

To remind the reader of the research objective relevant to the case study, this was previously stated as:

> **Research Objective 1**. To make a new contribution to building engineering physics focused on understanding occupancy presence in buildings.
>
> *It would be achieved by investigating occupancy presence and the diversity of occupancy presence through an analysis of process and Operational Policies in acute hospitals. It would be expected to facilitate significant improvements in forecast energy performance. Data would be created which the author would translate into a format appropriate for engineering design.*
>
> **Research Objective 2**. Through organisational and service redesign to investigate how to achieve low-energy – low carbon performance of an acute hospital.

It would be achieved by enabling users to understand the impacts of their operational processes on energy consumption associated carbon emissions. This would require the energy and carbon impacts of operational processes to be modelled.

As Research Objective 1, is expected to is make good the deficiencies of In-use data and to identify ‘appropriate data and Research Objective 2 is expected to enable clinical users to understand how to achieve low energy – low carbon performance, this work should lead to proving of this part of the proposition:

As the effective implementation of building engineering physics is compromised by a lack of ‘appropriate In-use data’, it follows that making good this deficiency should ultimately enable improved forecast In-use energy consumption.

The proving of this, as explained on p155 will be through the application of ‘appropriate data’ within the Whole Facility Energy Model, demonstrating how improved energy performance could be achieved. Hence the primary objective at this stage is to identify the appropriate data verified with the clinicians as discussed on p156.

6.3 Detailed Stage 1 Planning

From the Project Implementation Plan for the 3Ts project the following two key objectives had been established:

a) To understand the current Basis of Design in terms of the occupancy profile and equipment usage in the facility and to understand the impact of these factors on the predicted energy performance of the facility.

b) To assist the design team in the validation of design decisions in relation to the specification of public circulation systems and spaces in terms of capacity and speed of service.

The work was planned as part of the seven work streams, where each was modelled as was the information flow requirements between them. The work was planned as a series of three stages, and the strategy was to ensure that all seven work streams progressed such that the information flow between them could take place to maintain the momentum of the project.

An example of the planning of the work streams is illustrated in Figure 38 and Figure 38. These figures do represent the whole of the planning, but are provided to give an insight into the level of planning that took place for each work stream. Supporting each activity was a specification document and this detailed all of the task that would be required as well as the resources required to complete them.

The planning was developed in conjunction with the 3Ts director, the Project Leader and the Trust Change Management Team. The latter liaised with the clinical leadership teams in each department.

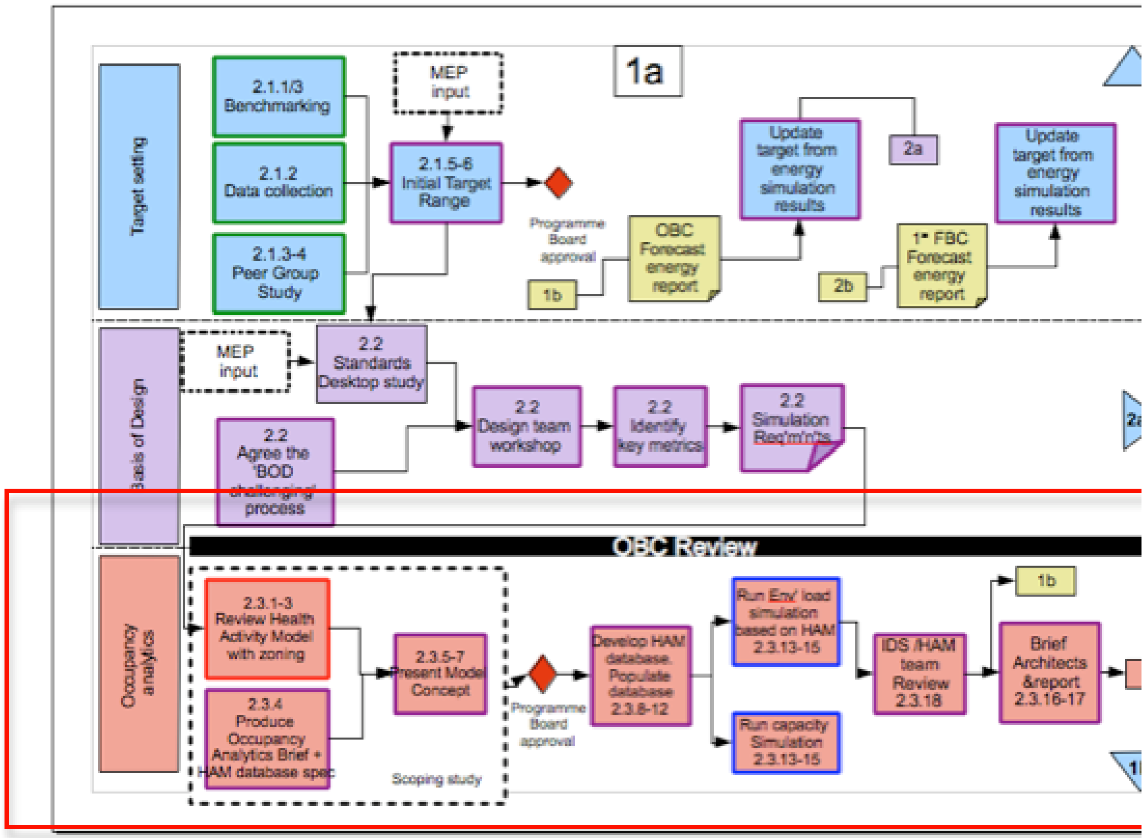

Figure 38 - Extract from the Project Implementation Plan to illustrate the Occupancy Analytics work stream planning

Key features of the plan:

Referring to the need for validation and proving that the results accord with what can be observed in the 'real world', p104 (please refer to p153). The plan introduces the clinicians to an initial briefing process where the model concepts are explained (see activity 2.3.5-7).

The model output is then reviewed with key project stakeholders (2.3.18), including the relevant clinical leadership team representatives from a User Reference Group.

The model output is then referred up to the Programme Board for approval should the 3Ts director consider this be required.

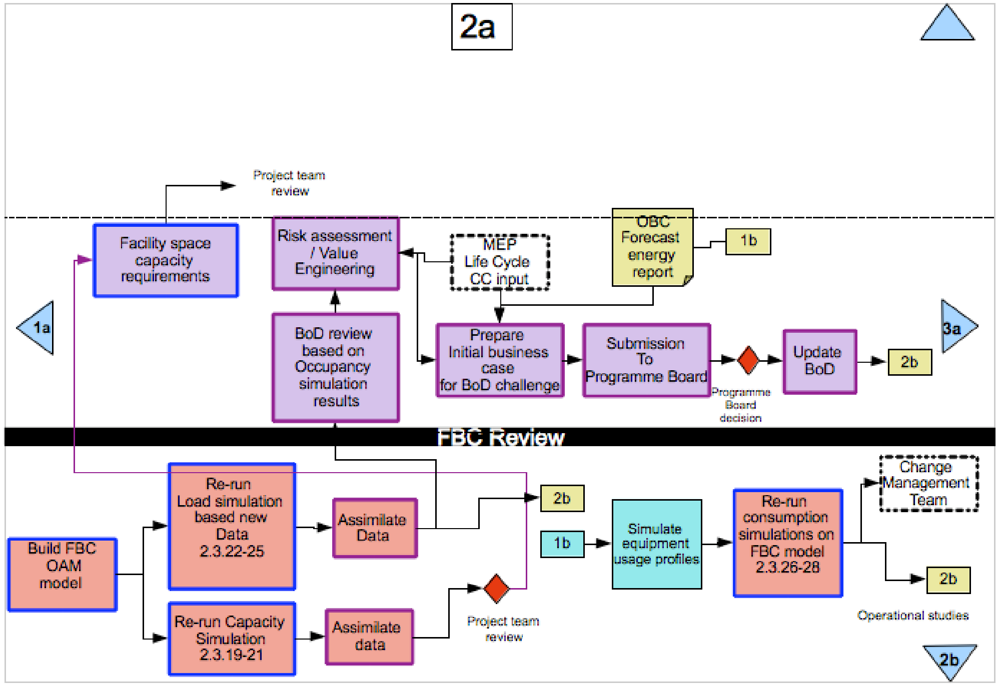

Figure 39 - Extract from the Project Implementation Plan to illustrate the Occupancy Analytics work stream planning

Key features of the plan:

Following the initial review and approval (subject to any simulation re-runs to respond to comments/ concerns), the occupancy model would be further enhanced (Build OA Model) to include latest patient forecast data, and planning data from the design team (such as occupant route logic based on the architects Wayfinding strategy).

The simulations would be re-run and the occupancy presence data would be produced as agreed with the engineering designers and architects (2.3.22-25).

Using the architects Room Data Sheets as appoint of reference the output data is to be assimilated with these to assess the difference between the between the two data sets. The results would then be reviewed with the clinical users and the project leadership team.

The two charts illustrate the planning of the work stream in relation to the Basis of Design, Target Setting and Occupancy Analytics work streams. With respect to the latter, the two charts illustrate the key work stream components:

1. Development of a Health Activity Model database
2. Develop Occupancy Analytics Specification
3. Develop Occupancy Analytics Brief
4. Populate HAM database
5. Verify the data
6. Validate the results

Concerning the verification and validation process the following issues were discussed with the clinicians through the User Reference Group (URG):

1. Data validity. Do the clinical users agree with the data values that have been used for processing into the simulation?
2. Model validity. Do the clinical users agree with the model logic, and modeling assumptions?
3. Operational validity. Do the clinical users recognise the model output in relation to their comprehension of 'The Real World'?

Sargent (2007) describes a simplified model for the validation of the simulation model, and it this model that provided the basis for the validation process proposed by the author. This is illustrated in Figure 40 over page.

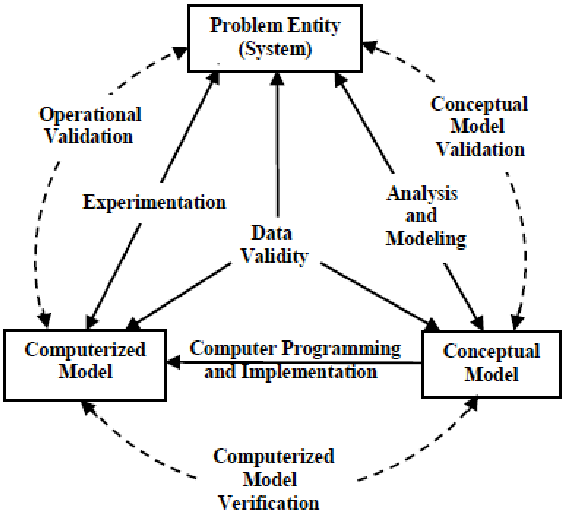

Figure 40 - Simplified validation process (Source: Sargent, 2007)

The process that was agreed with the User Reference Group was that there would be a two-stage process. In the first stage the data to be used for the simulation would be verified to confirm what CIS the correct data should be provided from. This was important because not all departments used the same system, and indeed some had their own systems in addition to the Patient Administration System (PAS) for example. In the second stage, through an in-depth review of the results, the validation process would be carried out. Data validation was considered of great importance to ensure that misleading results were not produced. The validation process will be described later.

The verification and validation work was considered a key part of the plan by the author because many critical decisions would be dependent on the results. The challenge would be to develop a reasonable forecast of the 'real world' that would exist when the new hospital becomes operational.

From the earlier discussion (p151):

> " To achieve this objective it will require a scientific method to verify that what is said, or documented about the knowledge of In-Use can be observed in the 'real world'.

The author reasoned that whilst the assumptions are explicit in the modelling process, the sensitivity of them on the outcomes could be evaluated in the simulation. It was planned that work would be carried out through experimentation[44].

Sargent, (2007): Process elements	**Bacon: Implementation for BSUH**
Problem Entity	This is the need to understand occupancy presence.
Conceptual Model	This is the Health Activity Model (HAM), which specifies the data sets and the model logic for the entity relationships.
Computerised Model	This is the Discrete Event Simulation instantiation of the HAM.
Computer programming and verification.	This was the internal testing carried out by the Occupancy Analytics Team.
Data Validity	This was the testing of the data between the Trusts' data analyst and each department. Together they validated the data from different data sources.
Conceptual Model Validity	This was tested through the dialogue with the clinicians through the interpretation of operational policies and the HAM. Model logic and assumptions were validated.
Operational Validation.	This was tested through the dialogue with the clinicians through the interpretation of the results. Did the results accord with their own understanding of the 'Real World'?

Figure 41 - Correlation between Page's model of validation and the work on 3Ts

The activities required in preparation for the simulation were largely addressed in Case Study 1. Having established the key concepts and translated these into requirements, the work stream activities of importance to this Case Study were to gather:

- The data for the HAM
- The process logic from the Operational Policies
- Zone definitions.
- Route logic.
- Finalise the specification based on the accumulated data.

[44] Experiments are investigated in the second stage of this case study (see p239)

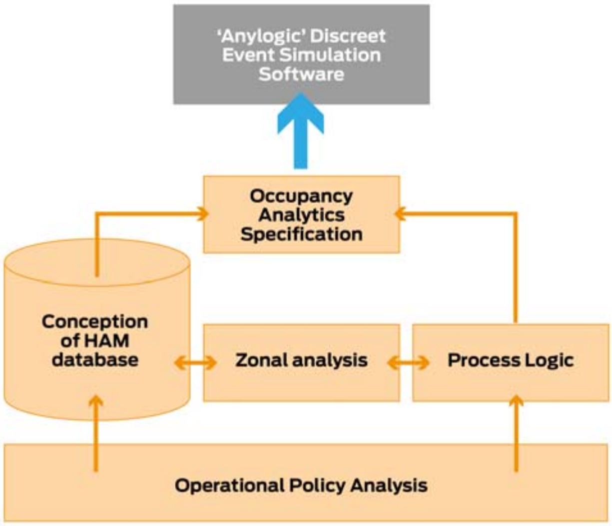

Figure 42 - Summary of activities for the preparation of the simulation

These five activities are illustrated in Figure 42. The need at this stage was to ensure that the HAM would contain sufficient data definitions and entity relationships sufficient to enable the flux of occupants through space to be modelled.

6.4 HAM data collection

The HAM data collection was planned using a data collection template designed in a spreadsheet. However, this decision was not made until the author had commissioned an experimental on-line form application that would enable users to enter the data directly into the database. In reviewing the design of the form as well as the potential technology related issues, it was decided that, unless the form had sophisticated validation embedded within it, then there would be too many risks in either incomplete or erroneous data entry. Furthermore the data interfaces to the simulation engine would have required extensive testing, which would have taken much time in the process with the potential risk of cost overruns and delays to the project.

SAME FOR ALL SCENARIOS

Interdepartmental Traffic			
From Department	To Department	Schedule	Ratio of patients
CIS OP	Imaging	8am - 2pm	4%
		2pm - 6pm	4%
Fracture	Imaging Cold	9am-11am	50%
		12am-1pm	50%
		2pm-5pm	50%
		6pm-8am	50%
Neuro OP	Imaging Cold	8am - 2pm	37%
		2pm - 6pm	37%
Neurophysiology	Imaging Cold	8am - 2pm	23%
		2pm - 6pm	23%
Oncology OPD	Imaging Cold	8am-2pm	21%
		2pm-6pm	13%
	Radiotherapy	8am-2pm	10%
		2pm-6pm	10%
Rheumatology	Imaging	8am - 2pm	33%
		2pm - 6pm	33%
	Phlebotomy	8am - 12pm	15%
		12pm - 6pm	15%
	Pharmacy	8am - 12pm	10%
		12pm - 6pm	10%
AMU	Imaging Cold	9am-11am	3%
		12am-1pm	3%
		2pm-5pm	3%
		6pm-8am	3%
	MEDICAL WARD	9am-11am	20%
		12am-1pm	20%
		2pm-5pm	20%
		6pm-8am	20%
	MW & MDU	9am-11am	5%
		12am-1pm	5%
		2pm-5pm	5%
		6pm-8am	5%
	STROKE WARD	9am-11am	5%
		12am-1pm	5%
		2pm-5pm	5%
		6pm-8am	5%

Figure 43 - Example of a table from the HAM to define the inter-departmental process flux

The example from the HAM in Figure 43 illustrates the inter-departmental relationships defined as data. Using the example of a Neuro Outpatient from the illustration, and then referring also to Figure 33, (the lower example of the two illustrated), it can be seen that the Operational Policy defines an inter-departmental relationship with the Imaging department. The data analyst then interviewed the clinicians to quantify the flux in terms of the proportion of patients that visit the Imaging department. It was this assessment by clinician and analyst that provided the data for the HAM. To avoid ambiguity within the team the author developed an ontology of occupancy classes and defined basic properties that could be configured within the HAM spreadsheet template. An extract of this is illustrated in Figure 44 and Figure 45.

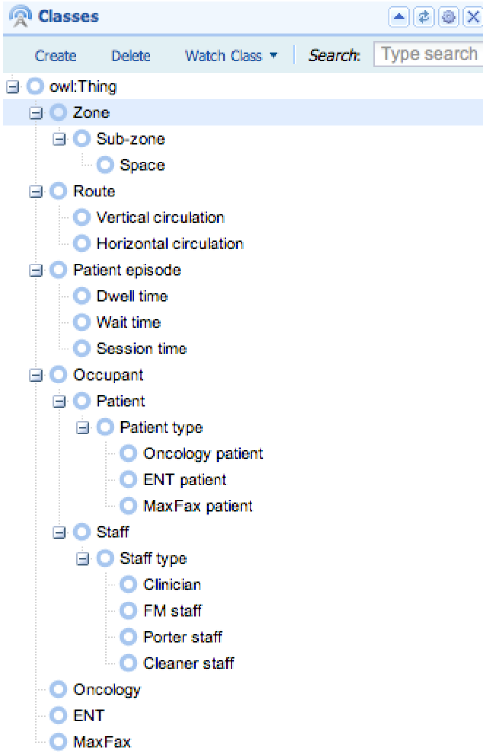

Figure 44 - Occupancy Ontology

Figure 45 – Example Domains within Zones

The ontology is a formalised representation of the agreed specification. From this representation it can be seen how Zones are connected by Route. Zones are occupied by Patient and Staff. There are clearly identifiable sub-classes that enable values to be attributed to each so that, for example, it would be possible to define the occupancy type present in each sub-zone at each hour of the day. The ontology provided a basis for communication with the Trust analysts so that they understood what data we would be seeking from the clinical information systems.

The tables for the HAM were then defined. Examples are illustrated in Table 4.

Table	Entities	Data type	Value	Description
Outpatient Dwell time				
	Zone [Department]	Zone Name	Text value	Standard names from Room data sheets.
		Zone Code	Integer value	Zone ID.
	Patient type	Category	Text value: New/ Follow-up/	Categories specified with clinicians.
	Dwell time	Duration	Minutes	Time patient in process. Only positive values rounded to whole minute.
	Standard Deviation	Duration	Minutes	Only positive values rounded to whole minute
Equipment: Length of Use				
	Zone [Department]	Name	Text value	Standard names from Room data sheets.
	Equipment	Type	Text value	Standard types from BSUH Trust Asset Register.
	Equipment	Number	Integer value	Number of assets of each type from BSUH Asset Register.
	Available minutes	Duration	Minutes	Minutes available within each hour.
	Electrical power	Power	kW	Power consumption per piece of equipment
	Patient ratio	Ratio	Integer value	Ratio of patients (%) using each equipment type.
	Mean Length of Use	Duration	Minutes	Only positive values rounded to whole minute.
	Standard Deviation for Length of Use.	Duration	Minutes	Only positive values rounded to whole minute.
Inpatient – Inter departmental flux.				
	Zone [Department]	Name	Text value	Standard names from Room data sheets.
	To Zone [Department]	Name	Text value	Standard names from Room data sheets.
	Schedule	Time	Hours: Minutes	Hour from / Hour to.
	Patients	Mean Number	Integer value	Number advised by Department Service Manager.

Table 4 - Examples of HAM database tables

The data for the HAM was assimilated from the Operational Policies. However the majority of data values were gathered from the data analyst interviewing departmental Service Managers. In some instances where this was not possible Service Managers carried out discreet surveys to (through observation or measurement) to provide the required values.

6.5 Process logic

The process logic was derived from (in the first instance) from the Operational Policies, which described the inter-departmental flux as described earlier. However, the author's specification required that physical pathways were also modelled. The specification also required that each circulation route be coded such that the routing logic could be defined.

Circulation Spaces								
Horizontal Spaces						Vertical Spaces*		
Name	Stage	Level	Length (m)	Time Spent by Type (sec.)		Name	Design Code	Time Spent (min.)
				Patient	Staffs & Other			
ME1	1	1	8	16.0	10.0	BL	Core 1-1-L1A/B/C/D	2
CA11	1	1	11.25	22.5	14.1	L11	Core 1-2-L1A/B	2
CC11	1	1	10	20.0	12.5	L21	Core 1-3-L2A/B	2
CD11	1	1	12	24.0	15.0	L31	Core 1-4-L3A/B	2
CA12	1	2	15	30.0	18.8	L41	Core 1-9-L1A/B	2
CA13	1	3	8	16.0	10.0	L1121	L11 or L21	2
CA14	1	4	7	14.0	8.8	L112131	L11, L21, or L31	2
CB14	1	4	13	26.0	16.3	L2131	L21 or L31	2
CA15	1	5	10	20.0	12.5	L12	Core 2-2-L1A/B	2
CB15	1	5	8	16.0	10.0	L12C	Core 2-2-L1C	2
CA16	1	6	11.25	22.5	14.1			
CB16	1	6	22	44.0	27.5	------- End of List -------		
CC16	1	6	10	20.0	12.5			
CG18	1	8	12	24.0	15.0			
CH19	1	9	7	14.0	8.8			
CA110	1	10	20	40.0	25.0			
CB110	1	10	18	36.0	22.5			
CG110	1	10	10	20.0	12.5			
CD111	1	11	7	14.0	8.8			
ME2	2	1	4	8.0	5.0			
CA21	2	1	5	10.0	6.3			
CE21	2	1	12	24.0	15.0			
CB22	2	2	11	22.0	13.8			
CC22	2	2	10	20.0	12.5			
CE23	2	3	15	30.0	18.8			
CI23	2	3	10	20.0	12.5			
CD24	2	4	9	18.0	11.3			

Table 5 - Table of HAM circulation space

For each coded route the time spent by two occupant types was modelled. The factors to be modelled, were concerned with:

- Ambulatory speed
- Corridor travel distance

Assumptions were made concerning the mean speed that each occupant type would traverse the circulation route, rather than attempt to model all possible permutations. This is because it was not possible to define the relative proportion of all occupant types in terms of ambulant, wheelchair and patients on trolleys or beds.

Having codified each route the next task was to define the route logic for the route between departments to identified. This was carried out in conjunction with the BSUH Trust data analyst and reference to the architects Wayfinding plans.

Circulation Spaces: From OUT to Departments																				
Department		Origins																		
		CP1								CP2										
ENT	Model Input	L41	CD11							CB16	CA16	L112131	CA11	CD11						MI
	Given Data	L41	CD11							CB16	CA16	L112131	CA11	CD11						MI
CIS OP	Model Input	L41	CA11	L112131	CA16					CB16	CA16									MI
	Given Data	L41	CA11	L112131	CA16					CB16	CA16									MI
Audiology	Model Input	L41	CD11							CB16	CA16	L112131	CA11	CD11						MI
	Given Data	L41	CD11							CB16	CA16	L112131	CA11	CD11						MI
Fracture Clinic	Model Input	L41	CA11	L1121	CA14					CB16	CA16	L1121	CA14							MI
	Given Data	L41	CA11	L1121	CA14					CB16	CA16	L1121	CA14							MI
Neuro OP	Model Input	L41	CA11	L1121	CA13					CB16	CA16	L1121	CA13							MI
	Given Data	L41	CA11	L1121	CA13					CB16	CA16	L1121	CA13							MI
Neurophysiology	Model Input	L41	CA11	L1121	CA13					CB16	CA16	L1121	CA13							MI
	Given Data	L41	CA11	L1121	CA13					CB16	CA16	L1121	CA13							MI
NIC	Model Input	L41	CA11	L1121	CA12					CB16	CA16	L112131	CA12							MI
	Given Data	L41	CA11	L1/2/1	CA12					CB16	CA16	L112131	CA12							MI
Nuclear Medicine	Model Input	L41	CA11	L1121	CA12					CB16	CA16	L112131	CA12							MI
	Given Data	L41	CA11	L1121	CA12					CB16	CA16	L112131	CA12							MI
Onc Day	Model Input	L41	CA11	CE21	ME2	CA21	L12	CC24		CB16	CA16	L112131	CA11	CE21	ME2	CA21	L12	CC24		MI
Treatment		L12C	L12	CC24																
	Given Data	L41	CA11	L12						CB16	CA15	L112131	CA11	L12	CC24					MI
		L1C2	CA11	L12																
Oncology OP	Model Input	L41	CA11	CE21	ME2	CA21	L12	CD24		CB16	CA16	L112131	CA11	CE21	ME2	CA21	L12	CD24		MI

Table 6 - Extract from circulation analysis table

It would be this routing logic (processed as part of the process logic) that would then be processed by the Occupancy Analytics simulation.

6.6 Zoning

The conceptual design issues pertinent to zoning were explained in the previous section (p195). To ensure that all analysis (occupancy, energy, and equipment modelling as typical examples) were carried out on a common basis the author defined a zoning strategy.

Benchmarking + Target Setting

- The zone/ sub-zone definitions provide a like for like basis for comparison with a peer group facilities.
- The zone definitions provide a basis for correlation of energy performance benchmarks that will be aggregated to the whole facility benchmark.

Occupancy analytics

- Zone / Sub zone functional analysis leading to a definition of sub-zone types (which maybe correlated to standard room types).
- Sub-zone types will enable standardised processes to identified leading to the streamlining of the Occupancy analytics work.

Energy modelling

- Zone/ sub-zone definitions will form the basis of the energy consumption analysis and will be referenced to the peer group analysis in the Benchmarking + Target setting work stream.

Monitoring + Controls

- Zone/ Sub zone definitions correlated to the Sub zone types will enable a standardised approach for monitoring and controls.

Equipment management

- Identification of all equipment types and performance will be correlated to the sub-zone in which each item of equipment functions. This data will be used to support the energy modelling analysis.

Figure 46 - Zone/ sub-zone definitions

Having agreed the zone/ Sub-zone definitions all of the floor plans for the hospital were then coded as illustrated in the example in Figure 47. As required by the ontology, each zone was designated a zone name and zone code.

Every zone was also colour coded as illustrated so that this made it easier to readily identify each zone. Circulation spaces were subsumed within each zone. This zonal configuration was defined as 'Level -1' by the author. Sub-zones were configured at 'Level-2'. By this means occupancy presence is modelled both at Zone level and at Sub-Zone level. From the Sub-zone level room analysis could also be carried out.

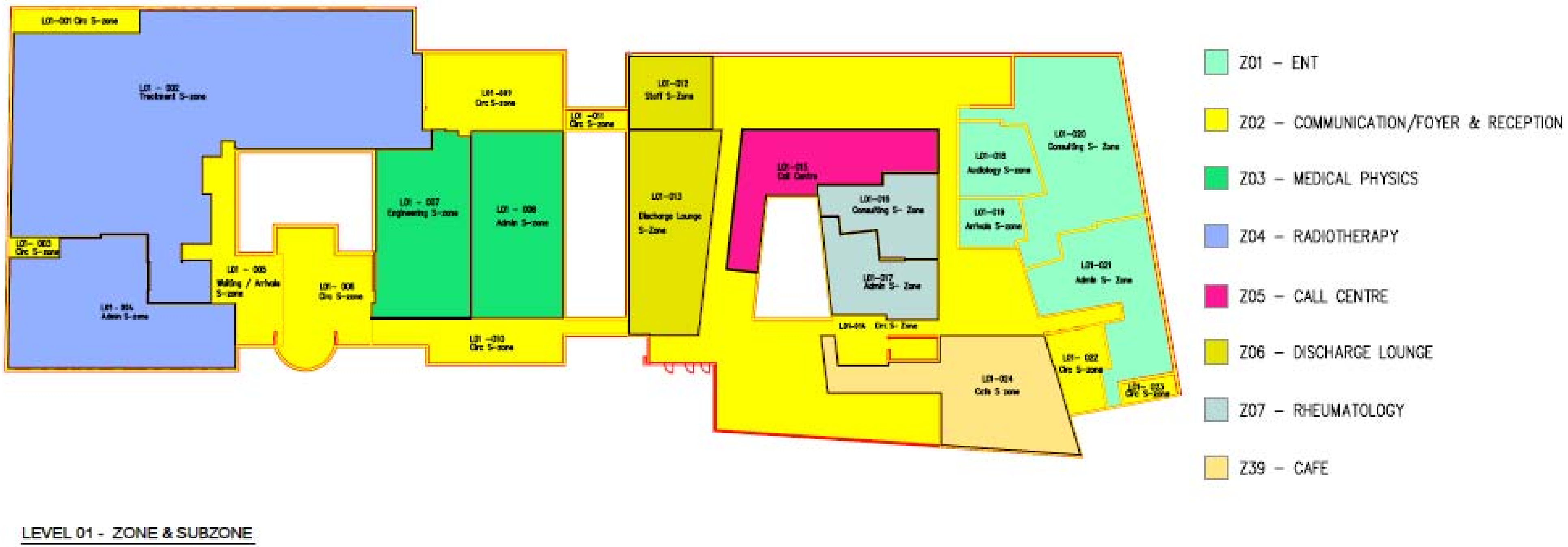

Figure 47 - Spatial analysis of zones/ sub zones

Referring to Figure 34 and Figure 47 the author envisioned how a patient pathway could be modelled through the hospital, where in each zone/ sub-zone, the patient impacts the energy demand on that space. In simulating that pathway there would be data collection points within each zone/ sub-zone such that energy impacts at each data collection point could be modelled. This will be discussed later in this Thesis.

6.7 Finalisation of the Occupancy Analytics specification

Having gathered the data as described in this section,[45] the next step was to complete the Occupancy Analytics Specification. It is not the intention of this case study to document the full specification because of compromising the author's Intellectual Property Right's. However, the key requirements for the simulation and an explanation of each are documented below (extracted from the project specification).

- Key requirements of the Occupancy Analytics Simulation.

1.1. Simulation requirements at Department level

- *Requirements for two levels of analysis Inter-zonal analysis (Level 1) and Intra-zonal analysis (Level2).*
- *Level 1 analysis required three scenarios:*
  - *Outpatient department to outpatient department*
  - *Outpatient department to ward*
  - *Ward to outpatient department*
- *Requirements for modeling occupant flux. Measurement of zone outflow such that process constraints within the department are reflected by the outflow. Simulation policy for modeling of patients leaving the hospital.*

[45] It must be unequivocally stated at this point that no personal patient data was required. Only meta-data was collected and thus no patient could be uniquely identified.

- *Requirements for modeling of staff flux. Shift pattern and No shift pattern.*

Patient Influx, Companion Ratio, and Model Input													
Department	Patient Influx												
	Data												
			Type 1		Type 2		Type 3		Type 4		Type 5		Companion Ratio
			Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	
Onc Day Treatment	8:00	14:00	30	10									70%
	14:00	19:00			31	10							
Oncology OP	8:00	14:00	9	1	38	4							100%
	14:00	19:00	9	1	38	4							
Radiotherapy	8:00	14:00	120										70%
	14:00	19:00	120										

Interdepartmental Traffic			
From Department	To Department	Schedule	Ratio of patients
Oncology OPD	Imaging Cold	8am-2pm	21%
		2pm-6pm	13%
	Radiotherapy	8am-2pm	10%
		2pm-6pm	10%

Figure 48 - Examples of patient flux table

Requirements for two generic zone types:

- *Static zones such as Wards and Offices (where the occupancy is largely static).*
    - o *Data to be used for the basis of analysis*
- *Dynamic zones such as Outpatient departments, Lecture halls, and Conference Room spaces (where the occupancy is largely dynamic).*
    - o *Data to be used for the basis of analysis*

1 *Level 2 analysis – sub-zone patient flux analysis. Also required:*

- *Categorisation of patient centric sub-zones for the purposes of space utilisation analysis.*

- *Post-processing of occupancy data for space utilisation analysis.*
    - *Calculation rules for patient centric spaces within sub-zone.*
    - *Algorithm for probability analysis of occupancy presence. Reporting of results: Mean/ 10 percentile and 90 percentile.*
- *Assumptions to be used in the model.*

- Key requirements for the simulation of Circulation Spaces.
    - Simulation requirements for horizontal and vertical circulation elements.

- *Requirements simulation and requirements for post-processing the raw output data.*
- *Circulation analysis from two perspectives:*
    - *Notation of horizontal circulation: Modelling of pathway route logic and pathway constraints. Pathway coding. Constraints.*
    - *Notation of vertical circulation: Modelling of pathway route logic and pathway constraints. Pathway coding. Constraints.*
- *Post-processing of data for circulation analysis*
    - *Algorithm for probability analysis of occupancy presence. Reporting of results: Mean/ 10 percentile and 90 percentile.*
    - Equipment modeling
        - Simulation requirements for imaging and radiotherapy equipment modeling.
- *Length of use for each equipment type. Post-processing requirements for equipment utilisation and probability analysis.*
- *Post-processing of lift analysis.*

6.7.1 - Comparison with engineering practice approach to the assessment of occupancy

The reader may recall that the conventional method for the assessment of occupancy that is usually adopted by engineering designers is carried out through an assessment of Room Data Sheets. In contrast the objective of the analysis proposed by the author was to use a Model-based method, driven from Clinical Information System (ClS) data. Table 7 explains the key differences.

Conventional method	Model-based method
Calculation of occupancy based on room capacity or statements concerning occupancy capacity in the Room Data Sheets.	Occupancy presence is determined by process logic and clinical information system data. Room utilisation is calculated from the simulation data.
Implication that the one person accounted for in a Room Data Sheet can be elsewhere at the same time resulting in over-estimation of occupancy.	Occupancy presence tracks occupant type at each hour of the day within each zone/ sub-zone of the hospital.
The engineering designer assumes the factor for the diversity of use.	Diversity of use is calculated through stochastic analysis.
Usually no recognition of the transient use of space by building users passing through it.	Transient occupancy is either randomly generated or where schedule is known, then it will be distributed according to that schedule/
Equipment usage profile assumes that equipment is in full use throughout the day.	Equipment usage profile based on analysis of demand for each item of equipment for each patient type.

Table 7 - Comparison between a conventional analysis of occupancy assessment and a model-based method.

The case study demonstrated that it is not always possible to obtain sufficient input data for the systematic analysis of occupancy and in this study the author found that assumptions were required where sufficient data was not available. Table 8 over page explains the assumptions required by the author in the occupancy analysis. The need for assumptions in the simulation raised the following questions in the validation process:

- Do these assumptions render the simulation output invalid (wrong)?
- To what extent is the model invalid? In other words, how close to the ‘Real World’ does the model perform?
- How close to the ‘Real World’ (extent of validity) is the model expected to perform?
- How might the extent of validity be tested? In other words, how uncertain are the results?
- Is it possible to quantify the uncertainty caused by the assumptions(s)?
- If uncertainty could be quantified, can the risks of inaccuracy of that uncertainty be quantified?

6.7.2- Comparison with theoretical approaches to the assessment of occupancy

The reader will have learned by now that the theoretical development for occupancy presence has been (as far as the author is able to establish) based on attempts to model the logic of occupancy flux using theoretical constructs such as Markov Chain analysis informed by surveys of use. Apart from the study of an Emergency Department, (Augenbroe, Op Cit) the author found no evidence of any significant attempt to model occupancy as a consequence of a process so that occupancy could be modelled in both time and space.

The approach adopted by the author has been to simulate clinical process at the level of inter-departmental flux. This was because the author's objective was to model occupancy presence at zonal level – the same level at which the engineering designers would be designing the engineering plant infrastructure. At this level of abstraction the author was able to access comprehensive data for the modelling. This meant that large assumptions were not required, as explained by Table 8 below.

Conventional assumptions	Proposed method
Assumption that each room has either full or partial occupancy.	Assumptions concerning: 1. Companion ratio for each Outpatient visit is assumed based on survey data. 2. Distribution of visitors and companions in public spaces is randomly generated. 3. Known aggregate numbers of FM staff and support staff (porters and cleaners for example) are randomly distributed. 4. Route logic for internal flux. 5. Imaging equipment use is based on an analysis of patient demand and not equipment availability. 6. Occupancy presence is analysed at zone/ sub-zone level and room levels.

Table 8 - Comparison of assumptions between a conventional analysis of occupancy and a model-based approach.

Consequently unlike conventional practice in occupancy research, the author has not needed to rely on theoretical constructs. Instead he has relied on statements of intent as expressed in Operational Policy. This is not to say that uncertainty still does not exist, because for the reason explained in the above Table, assumptions still need to be made, and with these assumptions comes a certain level of uncertainty.

The theoretical issues concerning the analysis of uncertainty were examined in detail in the literature review. Questions 5 and 6 above are in the author's opinion a reasonable summation of the challenge of attempting to quantify uncertainty. Those (such as Augenbroe, Op Cit) that have attempted to address this challenge, recognise that improved quantification can only be effectively achieved with current knowledge by using domain experts to provide opinion as to the correlation between 'Real World' and the simulation results. There remains a clear need for research in this area (Augenbroe, 2011). It is this rationale that should provide key terms of reference for consultation with the clinical users. Whilst these users could not be expected to provide certainty as to the veracity of the simulation, it would be reasonable to expect them to identify obvious deficiencies with it. Thus residual risks will always remain unless uncertainty can be quantified with confidence.

The reasoning concerning sensitivity could be expressed in the following terms: If the assumption (maybe expressed as constraints) were to be of value 'x', then the consequence would be value 'y'…or if the value were to be 'a', then the consequence would be 'b'…"

In discussion with the occupancy analytics team it was concluded that that the specification would require the results to be scrutinised in terms of probability analysis founded in stochastic variability. It would be this variability that would be expected to address variances caused through these assumptions. It was also agreed that should the URG have doubts in any part of the simulation, the factors that lead to these results could be subjected to further analysis through experimentation.

6.8 Constructing the simulation model

The author had no role in constructing the simulation model, because as was explained earlier, this work was contracted to Professor Godfried Augenbroe at Georgia Tech University. The author commissioned Professor Augenbroe to develop a library of Occupancy Analytics models for each clinical specialism (Figure 49). The author's vision is that for specific implementations of Occupancy Analytics re-usable libraries could be created, where specific departments (zones) would be joined through the process logic explicit in their Operational Policies.

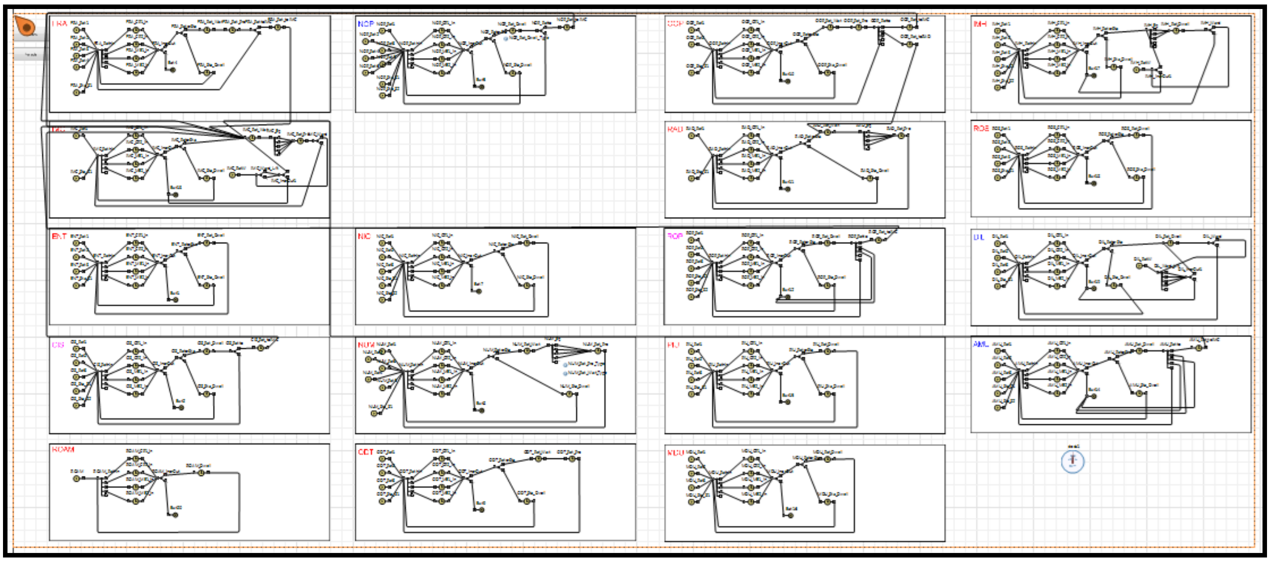

Figure 49 - The author's library of Occupancy Analytics models

As each model is joined to another, so a routing sequence is created (Figure 50). It is through this mechanism that the whole hospital was then modeled.

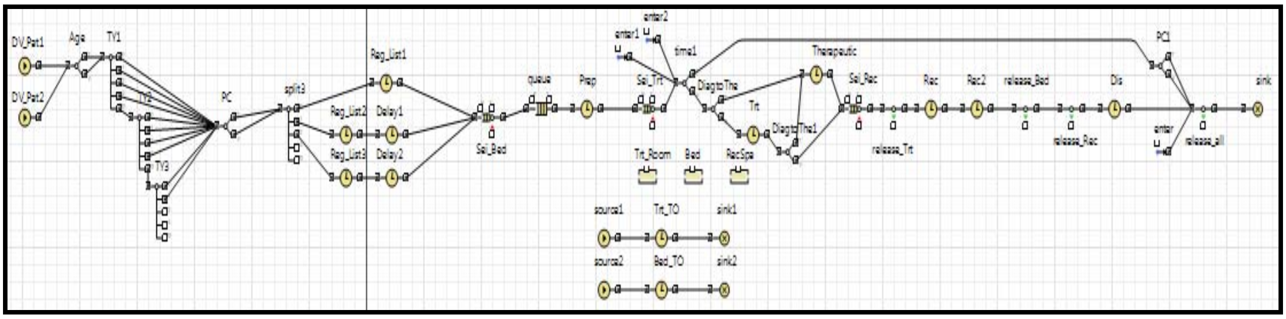

Figure 50 - Routing model of linked departmental models

At any stage of the process logic, ‘processing stations’ can be created that measure discrete events, (an example would be of ‘Dwell Time’) and it is from this that occupancy statistics are harvested. Data for this process is also derived from the entities within each departmental model (Figure 51). These were configured through a Java interface. Examples are: Patient arrival is defined using the parameters specified in each area of the library. Parameters control how patient flow will be organised and scheduled. Also, entities of patient/staff are differentiated by the type or identity property when the entity is generated.

```java
public class Person extends Entity {

    public Person( int identity, int type, int destination, int direction, double t ) {
        this.ID = identity;
        this.TY = type;
        this.DES = destination;
        this.DIR=direction;
        this.TS = t;
    }

    // Fields
    int ID; //0 stands for patient, 1 stands for staff
    int TY; //0 stands for New patient/Staff Shift 1, 1 stands for follow-up patient/Staff Shift 2, 2 stands for Staff Shift 3.
    int DES; //Number stands for the original destination of the person.
    int DIR; //0 stands for incoming, 1 stands for out;
    double TS;

}
```

Figure 51 - Property details of a specific entity

'Dwell Time' (DT) is an important component of the process logic, because it is the variance in the Dwell Time that causes the stochastic variance in occupancy (See also Table 4). DT is the time in which a patient is in process (not waiting) but receiving a service. The longer the DT for a given clinical resource, the longer the patient 'Waiting Time' (WT). Using the scenario described in the foregoing section, the author experimented with the impact of different DT's in the process. It was the analysis of the data from the processing 'processing stations' that provides the resulting impact of the different DT's. The longer the WT, the greater the occupancy in a given zone at a given hour of the day. This will be explained in greater detail later in this Case Study.

Having configured the model to provide the specified data, the next task was to run the simulation. The model was usually run for the equivalent of at least 100 days. It was found that running the simulation beyond this period showed no appreciable statistical difference in the distribution of the results.

6.9 Reporting

The output of the simulation was a raw data file, which then required post-processing. In his report to the author Professor Augenbroe described the results from the ‘Anylogic[46]’ simulation software in these terms:

> *“The raw output from ‘Anylogic’ is the annual raw occupancy for each department recorded every 5 minutes. Since we make a distinction between treatment and waiting, the data needed for room utilisation is the number of patients in treatment (not in waiting). For occupancy we use the total of “in treatment” and “in waiting”, multiplied by companion ration (1.7 was used for most patient types). An example of patient in treatment for ENT from 8am to 9am for the first day of the year is shown in Table 1.”*

	ENT
	Patient in treatment
8:00	0
8:05	0
8:10	0
8:15	0
8:20	2
8:25	3
8:30	3
8:35	3
8:40	3
8:45	2
8:50	5
8:55	4

Table 9 - Patient and Staff occupancy for ENT (Ear Nose and Throat) from 08:00hrs - 09:00hrs for the 1st day of the year

> *“In the post-processing, the above raw output is organised like this: according to the time stamp of each data point (for example in* Table 9, *patient number at 8:30 is 3), the maximum number of patients being processed in this hour (in this example 5) is recorded to represent the 9th hour of Day 1. This hourly maximum number is then put into a matrix (at the highlighted position in* Table 10*) where the corresponding column stands for the 9th hour of a given day. The organised matrix will look like* Table 10.*”*

Hour 1	…	Hour 9	…	Hour 24
Occ_H1_Day1	…	**Max_Occ_H8_Day1**	…	Max_Occ_H24_Day1
Max_Occ_H1_Day2	…	Max_Occ_H8_Day2	…	Max_Occ_H24_Day2
Max_Occ_H1_Day3	…	Max_Occ_H8_Day3	…	Max_Occ_H24_Day3
Max_Occ_H1_Day4	…	Max_Occ_H8_Day4	…	Max_Occ_H24_Day4
Max_Occ_H1_Day5	…	Max_Occ_H8_Day5	…	Max_Occ_H24_Day5

Table 10 - Organised matrix containing patient 'In-Treatment' data

[46] See: http://www.anylogic.com/

“Each day gives a new entry for the 9th hour. Typically we have run all simulations for as long as the distribution does no longer change. Typically this is in the range of 100+ days...

…Then for each column of the matrix, statistics are calculated for mean (M), 10 percentile (L) and 90 percentile (U) that corresponds to this particular hour. Finally, the post-processed occupancy data is presented in Table 11*…*

The M,L,U is done in ‘Matlab[47]’. It is a very simple code that operates on the tables (CSV files). The code uses the standard Matlab function PRCTILE”

Occupancy Analytics in Brighton Sussex University Hospital															
Department			Hour of Day												
			7	8	9	10	11	12	13	14	15	16	17	18	19
Simulation Results	Oncology Day Treatment	M	10	47	55	64	72	76	86	91	77	69	61	51	13
		L	0	38	45	50	53	57	58	63	60	55	48	39	0
		U	34	57	67	79	91	97	122	124	95	85	75	63	35
	Oncology Day Treatment Pat	M	0	4	13	21	29	33	34	36	34	26	18	8	1
		L	0	0	7	12	15	19	19	22	22	17	10	2	0
		U	0	9	19	31	43	49	49	49	46	36	26	15	3
	Oncology Day Treatment Sta	M	10	43	43	43	43	43	52	55	43	43	43	42	12
		L	0	38	38	38	38	38	39	41	38	38	38	37	0
		U	34	48	48	48	48	48	73	75	49	49	49	48	32
	Oncology OP	M	7	38	47	48	48	48	54	60	56	57	57	45	10
		L	0	26	40	40	40	40	42	45	47	49	49	32	0
		U	24	49	55	55	55	55	72	79	65	65	65	59	25
	Oncology OP Pat	M	0	7	17	17	17	17	17	21	25	26	26	15	1
		L	0	0	14	14	14	14	14	16	20	22	22	6	0
		U	0	14	20	20	20	20	20	26	30	30	30	24	2
	Oncology OP Sta	M	7	31	31	31	31	31	37	39	31	31	31	30	9
		L	0	26	26	26	26	26	28	29	27	27	27	26	0
		U	24	35	35	35	35	35	52	53	35	35	35	35	23
	Radiotherapy	M	13	62	71	71	71	71	71	99	81	80	80	69	13
		L	0	44	58	58	58	58	58	77	68	68	68	49	0
		U	41	75	82	82	82	82	82	123	94	93	93	89	36
	Radiotherapy Pat	M	0	14	23	23	23	23	23	28	32	32	32	22	1
		L	0	3	17	17	17	17	17	22	26	26	26	9	0
		U	0	22	29	29	29	29	29	36	39	39	39	36	3
	Radiotherapy Sta	M	13	48	48	48	48	48	48	71	49	48	48	47	12
		L	0	41	41	41	41	41	41	55	42	42	42	40	0
		U	41	53	53	53	53	53	53	87	55	54	54	53	33

Table 11 – Results of the post-processed occupancy simulation in the Oncology Department

Due to the variability in the parameters, the simulation generates an outcome in distribution. The results were presented in an 'MLU' format, in which 'M' is an abbreviation for Mean; 'L' is an abbreviation for lower (10) percentile, 'U' is an abbreviation for upper (90) percentile. Alternatively, some of the data are presented in 'MS' format, in which 'M' is an abbreviation for mean, and 'S' is an abbreviation for standard deviation.

These two formats can be converted to each other using a convenient formula:

[47] See: http://www.mathworks.co.uk/products/matlab/

L = M - 3S, U = M + 3S, and S = (U-L)/6

For both Haematology, Oncology & Radiotherapy departments (i.e., Oncology OPD and Oncology Day Treatment), occupancy analysis results are given. The data should be interpreted as the total occupancy number in a department during a specific period. For example, at 8 AM, Oncology OPD has occupancy with MLU respectively 38, 26, and 49. It means that in average from 8-9, there are on average 38 occupants in the department. There is a 90% probability that there are more than ‘x’ patients, and a 90% probability there are less than ‘y’ patients in Oncology Table 11. Or put differently, a 10% chance that there are less than ‘x’ and a 10% chance that there are more than ‘y’

To translate the 90 or 10 percentile into meaningful terms for the clinicians and example of a two-week period with 10 operating days was given. The 90 or 10 percentile typically indicates a situation that arises in 1 out of 10 occurrences, and thus in this example an occurrence that may arise 1 day in every two weeks. For instance, if it is found that there is a 10% probability that a department is short of 1 or more rooms at 10:00hrs, then it is fair to that once every two weeks there will be a shortage of rooms at 10:00hrs, whereas there will be no shortage the other 9 days.

The simulation engine processed the percentile calculations as well as the mean distribution. The 10 and 90 percentiles were chosen because they indicate a probability that would be readily appreciated by the clinical leadership team of each department. In another instance it maybe reasonable to use the 20 percentile, which would indicate that an occurrence arises on average one day per week. It is this occupancy diversity that the CIBSE Energy Efficient Brief describes as a matter of fundamental importance to the briefing process. To restate the requirements:

- ***Gather design information, such as occupancy hours, activity and density of occupancy (p10).***
- ***Document a design brief: “which can include occupancy” (p15)***
- *Analyse the impacts of occupancy and activity in order to assess internal heat gains (p32)*
- *Analyse internal design conditions for the assessment of intermittent operation, internal loads comprising small power and lighting (p19)*
- ***Perform a load diversity analysis to establish peak demand (p30)***
- *Understand the impacts of oversizing heating systems (p36)*

These aspects of the Brief will be discussed in Chapter 8: The Energy Efficient Brief. At this stage it was becoming clear that we could provide detailed diversity data for every zone in the hospital.

The analysis compares to the occupancy diversity approximation carried out by the engineering team on the project. As explained previously on p195 the team used their experience from past projects to estimate the diversity of occupancy in all areas, but there is no systematic analysis as described in this case study. The process adopted by the engineers was to use typical occupancy ratios (a function of floor area) for different space types, such as office, circulation space, clinical functions and so on. Using these ratios they calculated the occupancy for each space. This was the un-diversified occupancy, and equated to 7639 occupants. A diversification factor was then applied to the aforementioned calculation, using engineer's experience[48]. This resulted in a diversified occupancy of 6300 occupants.

In comparison, the aggregate of occupancy for the whole hospital as calculated by the author and his team was 2326 occupants (Well over a 60% reduction), a substantial difference when compared to the conventional method of assessment of occupancy as outlined above.

[48] The author has found no examples of any validation of these occupancy ratio's or diversity factors from post-occupancy (In-Use) studies.

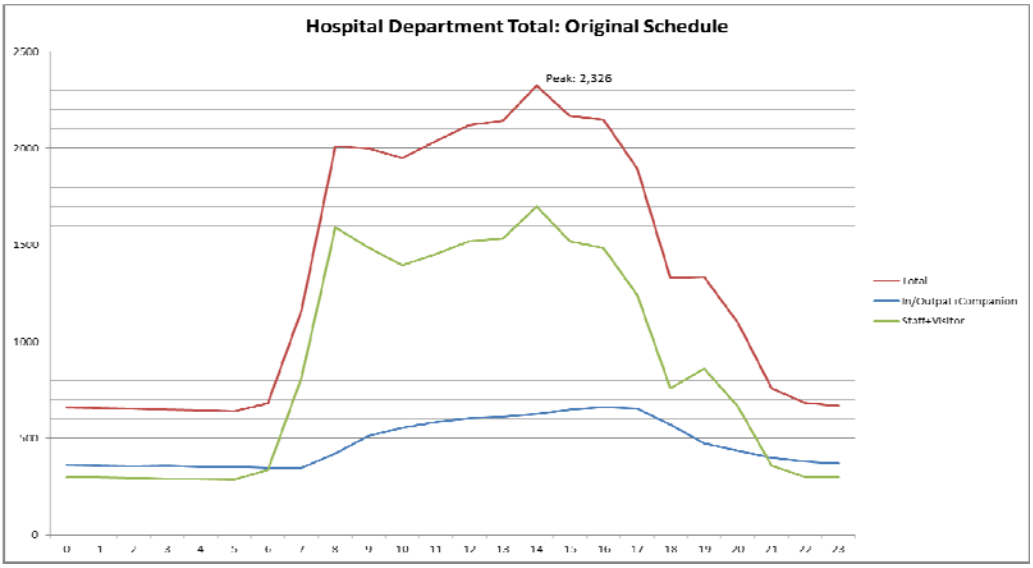

Figure 52 - Occupancy profile for the whole hospital (excluding circulation spaces)

There were two key questions at this stage: a) Validation of the results by the clinicians and b) Analysis of the potential impact of these results by the engineering team.

6.9.1 - Verification and validation of results by the clinicians

As was emphasised earlier in Section 6.3 - Case Study Planning (p211), engagement of the clinical leadership team within each outpatient departments was considered to be essential if the results of the analysis were to provide a new evidence base for the optimisation of the design of the proposed facilities. Outpatient departments were chosen for this process in preference to inpatient departments because the occupancy in the former is dynamic (stochastic variability), whereas in the latter it is (apart from staff movements and visitors) is largely static. Consequently, the Outpatient departments' occupancy has the greatest potential to impact on overall occupancy. Another factor in choosing outpatients was because it was evident from operational policies and discussions with the departments that their working practices would have significant impact on occupancy flux. For example, the Oncology Department had been experimenting with multi-disciplinary clinics and they had found that these caused a substantial impact on patient waiting time. These clinics were designed to reduce the number of outpatient patient visits, and whilst this may have been the result, the consequences of difficulties in having specialists available at the point in the process where the patient required their input, proved to be very difficult to manage in practice.

The significant waiting periods would thus add to the occupancy load of the department, with the consequential impact on the engineering systems to maintain acceptable indoor air quality, this demanding more energy and causing greater associated carbon emissions. The validation process would be expected to illuminate the factors that lead to variances in 'Dwell time' and 'Wait time' in situations such as this, and it would thus serve as an important element in educating the clinicians in the need for change, which could both impact low energy – low carbon performance as much as it could positively impact the patient experience.

The reader will recall that the literature review identified key issues in this regard concerning the management of change, and the work of McNulty and Ferlie (Op Cit) offers a clear insight into the issues that should be addressed, if change is to be effective. For example working with the leadership team to help them understand the need for change, as well as harnessing their influence in their department would be two of these key issues. To remind the reader of the quote from Champy (op Cit):

> *"…people need be educated in the need for change…the keys to getting people to accept the need for change…lie in the process of education, about the need for change, communicating change, and selling change to employees…"*

It was with these issues in mind that the author issued a briefing note through the Trusts' Change Management team (quoted original text in grey background):

Context.

- *Professor Duane Passman, Director of 3Ts Estates & Facilities, has sponsored a major initiative with the Trust's Principal Supply Chain Partner, Laing O'Rourke plc to work with a specialist low carbon team under the direction of Professor Matthew Bacon of Eleven Informatics LLP. The team has developed a highly innovative approach to the low carbon design of hospital facilities. Indeed the work is now being considered for short-listing in the Guardian newspaper 2012 Sustainability Awards under the Innovation category.*

- *Conventional practice in terms of Low Carbon design tends to focus on the specification of the buildings and systems that support the facilities. Professor Bacon is advocating that significant improvement in low carbon performance is critically determined by how we use our facilities. We know this from how we use our own* *homes. The NHS Sustainability Development Unit, which has taken a keen interest in the initiative, reports that whilst low carbon performance is improving in the NHS, major step changes are required in order to achieve the government's carbon reduction commitment targets. Large consumers of energy and other non-renewable resources (that lead to carbon emissions) are to be incentivised from next year to drive down their carbon emissions through the introduction of a Carbon Tax. For the Trust this will represent a significant additional cost, which has to be controlled. This underlines the commercial importance of this initiative.*

- *In focussing on how we use our facilities, Professor Bacon has been developing a new science called: Occupancy Analytics. This work takes the Operational Policies that have been developed with each clinical specialism and extracts key data, which is the processed in a unique database of process activities and resources. It has also processed forecast patient demand as well as the forecast inter-departmental flows. A simulation technology has then been used to model this data to produce a dynamic process model of the whole hospital. The model predicts where the major occupancy (staff and patients in particular) will be at all times of the day within each part of the new facilities. It also predicts space and major equipment utilisation.*

What is the significance of this work?

- *The design of complex facilities such as hospitals is founded on major assumptions concerning use. These assumptions are used as the foundation for the design of the engineering systems that control how energy is consumed. The assumptions are a major determining factor in the design of the systems that heat and cool our facilities. Research has clearly shown that these assumptions lead to the design of systems that are significantly larger than they need to be, based on how buildings are used.*

- *One of the major assumptions concerns the occupancy of buildings. Heat gains from occupancy are a the largest of all heat gains in a building. Fresh air requirements are also largely determined by occupancy. If these assumptions are wrong, then systems will also be incorrectly designed. Two important impacts arise:*

    - *The systems are far more expensive than they need to be, wasting valuable resources.*
    - *The systems do not function efficiently, meaning that they consume much more energy than is necessary.*
    - *Systems respond inadequately to how facilities are actually used, and so continue to serve spaces regardless of whether they are being used or not.*

- *The results of the work that has been carried out so far, are demonstrating that a significant impact on the systems design could be achieved. If implemented the impact could enable a radical improvement in the energy efficiency of 3Ts.*

1.0 Another benefit of this work is that it helps us to understand the factors that lead to the efficient utilisation of space and equipment. Occupancy Analytics enables us to achieve the best correlation between space and equipment utilisation and forecast demand by patients.

How can you help us?

- *We need departmental specialists to help us to validate the output data for the study. Each department has been analysed and we have established forecast occupancy and utilisation profiles for each. The question arises: How much confidence do we have in the results? What other work could/ should be carried out to help achieve a higher level of confidence?*

- *We plan to run a series of workshops with a selected number of departments and we are seeking the support of each to help us validate the work and verify key data sets used in the analysis. A workshop brief will be provided, along with a pack of information that explains the work and data analysis that was carried out. It is expected that one workshop will be required for a period of 2-3 hours. A follow up workshop maybe required subject to the outcome of the first.*

- *Workshop attendees will be asked to review the information provided which will be handed to them at a pre-meeting so that they have time to consider the information prior to the workshop.*

Thank you for your help in this valuable work!

The plan developed by the author in conjunction with the Trusts' Change Management Team was to orchestrate the validation process through two workshops. (Bacon, 2013) described the process:

> *"A series of workshops was planned with the leadership team in each department. The purpose of these workshops was to discuss the issues arising from the data analysis and obtain the manager's opinions of the results relative to their own experiences. In later workshops the variables in the process were specifically discussed and where assumptions had been made, these were then corrected or validated…*
>
> *…A pre-workshop meeting was carried out with representatives from each department being validated. The*

purpose of this workshop was to brief the attendees of the work outlined above and to ensure that they understood the basis of the simulation as well as the context in which their data was being used. It was important in the author's view that the veracity of departmental data could be verified.

Having concluded the Pre-workshop briefing, the representatives were asked to study the Briefing Pack and comment on the content. The BSUH Trust data analyst then met each department and discussed queries, or concerns arising from the study. In some instances new data was provided.

Where new data was provided, the simulation was re-run to demonstrate the impact of it on the results. These re-runs were carried out prior to the workshop. The updated results were then presented at the workshop and the results were discussed. In all instances workshop attendees expressed confidence in the results."

For each of the six departments that were studies there was at least:

- One Pre-workshop meeting to brief each department.
- An interim meeting following the workshop with the Trust data analyst to review the initial findings of the clinicians, then to correct any misunderstandings, and source more accurate data from that which had been provided.
- At least one workshop (and on occasions there were two that were held) using a Briefing Pack developed by the author and illustrated in Figure 53 on the following page. The objective of the Briefing Pack was to ensure that the clinician's fully understood a) the data inputs, b) the occupancy analytics model processing logic, and c) the meaning of the output data. The Briefing Pack structure formed the agenda for each workshop.

Following each workshop the Briefing Pack was updated with the notes of the meeting and they key findings and actions arising. These findings were then used to inform the experiments that are discussed in chapter 7. It is the findings and the subsequent experimentation that aligns this method with the recommendations for action research as proposed by McKay and Marshall (Op Cit).

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Figure 53 - Validation Workshop Briefing Pack for the Oncology Department

For the initial validation six Outpatient departments out of twelve departments were selected and these formed the URG as explained earlier. The six departments were:

1. Fracture (Orthopaedics)
2. Nuclear Medicine
3. Oncology + Haematology
4. Imaging
5. Rheumatology
6. Non-Invasive Cardiology

The number of Outpatient departments chosen was influenced by two criteria:

1. The willingness to engage in the work. The 3Ts Director advised the author of the candidate departments that he considered would actively support the process.

2. A large enough sample (50% of all the Outpatient departments) to identify any potential issues with the occupancy analytics simulation.

As expected by the 3Ts Director, the clinical users consulted in this process were very supportive of it. The model-based analysis resonated with their experiences as clinicians. Two issues emerged from the pre-workshop briefing that users were particularly interested in:

1. To understand the relationship between Operational Policy development, occupancy, energy consumption and carbon emissions.
2. The impact of Operational Policy on space utilisation.

Using Sargent's validation model (See p216) the author initiated the validation process. Having received the pre-workshop briefing participated in the questions and answer session, and verified the data sources used, the clinical users were then requested to read through the documentation and challenge the occupancy analytics model from the three perspectives:

- Data validity. Do the clinical users agree with the data values that have been used for processing into the simulation?
- Model validity. Do the clinical users agree with the model logic, and modeling assumptions?
- Operational validity. Do the clinical users recognise the model output in relation to their comprehension of 'The Real World'? (See p156)

A week after each pre-workshop briefing the Trusts' data analyst contacted each department representative and discussed any queries they had. Particular emphasis was placed on the verification of the data. During this process, different data sources were compared. Some departments used both a Patient Administration System (PAS) as well as their own departmental system. Some also used paper-based systems and diaries – hence the need for verification of correct data sources.

Where differences were found in the data used for the initial simulation, the HAM was then updated accordingly. In all cases only small differences were found. Nevertheless, any differences were then processed back into the simulation model and new results generated. The Workshop Briefing Pack was updated with the new results and then used for the Validation Workshop. Sargent (Op Cit) observes that it can often be too costly to absolutely validate a model, but that test and evaluations should be conducted so that the model can be validated for the intended application. The Case Study demonstrates that whilst there was no absolute certainty of the data, the objective of the intended application was that it should provide a range of probabilities, and that within this range, tolerance would be provided. In other words a range, within which a level of inaccuracy could be tolerated, based on the range of probabilities (the 10 and 90 percentile range).

The Validation workshop set out the objectives of the validation process in these terms (quoted original text in grey background):

- ***Workshop objectives***
  - *To answer the following questions:*
    - *Do we have confidence in the results?*
    - *Does the team have any issues with the Occupancy Analytics assumptions, or logic as described in the Briefing Pack?*
    - *Develop departmental response to Peak Load Smoothing initiative*

These objectives were reported through Section 4.0 of the Briefing pack (Fig 53 refers). The client and the In-use energy team agreed that it was very important that the leadership team within each department attended the workshops. Consequently, the Lead Consultant and the Service Manager attended. Others such as a Lead Nurse or Consultant Nurse, or Matron also attended for some of the departments being studied. This strategy was informed by the experiences of McNulty et al. (Op Cit), where they discovered that it was the clinical leadership team that are key stakeholders in any change management process.

It was clear from the workshops that confidence in Dwell Time was to be the major issue to be validated. The clinicians readily understood the potential impact of extended Dwell Time, as an indicator of departmental efficiency. Using the results from the Whole Facility Energy Model[49], and the results of space utilisation they then came to understand the consequential impacts on low energy performance and carbon emissions. In recognising how Dwell Time impacted space utilisation, this resulted in two departments, namely Nuclear Medicine and Oncology, to question their earlier

[49] Please refer to Stage 2 of the case study on p260)

advice concerning values in the HAM database. The other four departments that were validated all accepted the results of the analysis.

Dwell Time data was that it was not recorded specifically in any system, and as a consequence the author was required to rely on the expert judgment of the clinicians being consulted. With both Nuclear Medicine and Oncology, expressing concern (through the Lead Consultant) that the Dwell Time allowances may be incorrect, it was decided that there would be a need for experimentation, a finding that echoed Sargent's recommendations for testing and further evaluation in order to create confidence in the results. The need for experimentation in occupancy modelling was discussed by Liao et al (Op Cit) (Please see p116) was undertaken to understand how occupancy variables impact energy consumption. It is here where calibration of the results is carried out, in order to provide confidence that the simulation comes as close as possible to the 'real world' expectations of the clinicians.

6.9.2 - Managing the 'Real World' expectations of the clinicians

Through further discussion with each of the two departments the Dwell Time allowances were subject to much scrutiny. The Nuclear Medicine team decided to analyse Dwell Time through a review of each patient type[50]. It became apparent that there were four patient types and that for each of these a different Dwell Time was required. However, in the second case with the Oncology department, they advised that the Dwell Time should be doubled for each New and Follow-Up patient. The justification for this substantial increase was not clear, and because the author was reliant on their professional judgment (albeit that the judgment was substantially different) the author decided to accept this new requirement and to consider the impacts on the model.

Whilst the Nuclear Medicine experimentation resulted in improved space utilisation, it nevertheless still showed a large under-utilisation of space. The occupancy profile that resulted from the analysis also matched their expectation. From the Nuclear Medicine perspective, they were satisfied that the occupancy analytics model reliably forecast the impact of their operational policies so far as space utilisation was concerned.

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[50] A 'patient type' refers to the treatment requirements of each patient (see also p220)

The experimentation for the Oncology department involved much more analysis, largely because so much of their input to the workshops lacked data and was based on a range of opinions. For example, once the extended Dwell Time (doubling of) had been processed through the model, the occupancy analysis showed substantial peak occupancy later in the working day.

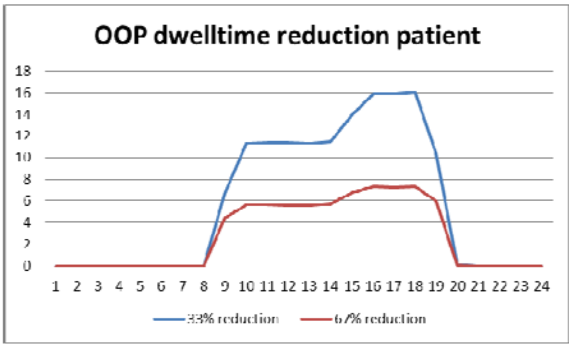

Figure 54 - Occupancy profile based on different Dwell Times for each hour of the day

The illustration clearly shows that as Dwell Time increases so too does the peak occupancy profile. This is understandable if one considers that an increase in Dwell Time means that patients spend longer in process with the consequence that for a given cohort of patients, peak occupancy will also increase. Furthermore, as Dwell Time increases it also means that more of the available clinical accommodation is utilised by patients. It is with regard to this latter point that the Oncology team reasoned that by extending the Dwell Time they could demonstrate improved forecast utilisation of patient centric accommodation. Yet the extended Dwell Time was also an indicator of potential process inefficiency. This was evidenced in practice through reports of extended Wait time in the Oncology department, possibly as a consequence of the multi-disciplinary clinics referred to earlier.

Of course none of these observations are new to operations management analysis and have been extensively documented. Tzortzopoulos et al. (2009) provide a comprehensive overview. Yet the contribution of the author is to use these strategies in order to understand the impact of them on occupancy presence profiles.

Lean healthcare initiatives such as those discussed by Tzortzopoulos et al, (Ibid) are designed to remove waste and improve the flux of patients through the process. For example, there is much evidence pointed to by the authors that identifies the impact on queuing and waiting times. It is exactly data such as this that could be processed in the occupancy analytics model. **In doing so, there is the potential for a clear alignment between organisational/ service redesign, occupancy analytics and energy consumption management. Yet in no text that the author has researched have these connections been explicitly made.**

KEY ISSUE

The comparative difference in the forecast room utilisation at 15:00hrs is 20 rooms (with 45 minutes Dwell Time) and 13 rooms (with 90 minutes Dwell time), which is illustrated in Figure 55 and Figure 56. Whilst there is a significant difference in room utilisation, the clinicians considered that the consequence on the overall occupancy in the department (zone) would also rise, as was illustrated in Figure 54

Opportunity Analysis													
Department	Descriptions		Hour of Day										
			8	9	10	11	12	13	14	15	16	17	18
Oncology OP	1)	Mean number of patients	5	15	14	13	13	14	12	7	7	7	5
	2)	Mean number of available rooms	20	10	11	12	12	11	13	18	18	18	20
	3)	90% chance that there are at least X number of unused rooms	15	5	8	8	9	8	9	15	15	14	18
	4)	10% chance that there are more than Y number of unused rooms	25	15	14	16	15	14	17	20	21	20	23

Figure 55 - Room utilisation with 45 minutes Dwell Time

Opportunity Analysis														
Department	Descriptions		Hour of Day											
			8	9	10	11	12	13	14	15	16	17	18	19
Oncology OPD	1)	Mean number of patients	4	10	10	10	10	10	12	15	16	16	9	1
	2)	Mean number of available rooms	21	15	15	15	15	15	13	10	9	9	16	24
	3)	90% chance that there are at least X number of unused rooms	17	13	13	13	13	13	9	7	7	7	11	24
	4)	10% chance that there are more than Y number of unused rooms	25	17	17	17	17	17	15	13	12	12	21	25

Figure 56 - Room utilisation with 90 minutes Dwell Time

The clinical leadership team also wished to improve their understanding of the factors that impacted Dwell Time, and the author's team wished to remove the uncertainty from their estimations. It was decided that a Dwell Time survey should be carried out. The key objective of the survey was to study the Dwell Times for three patient types and to compare the results with the data used for the simulation. It was through this process that the author sought to correlate the simulation with 'real world' events, which the author reasoned would achieve the support of the clinicians.

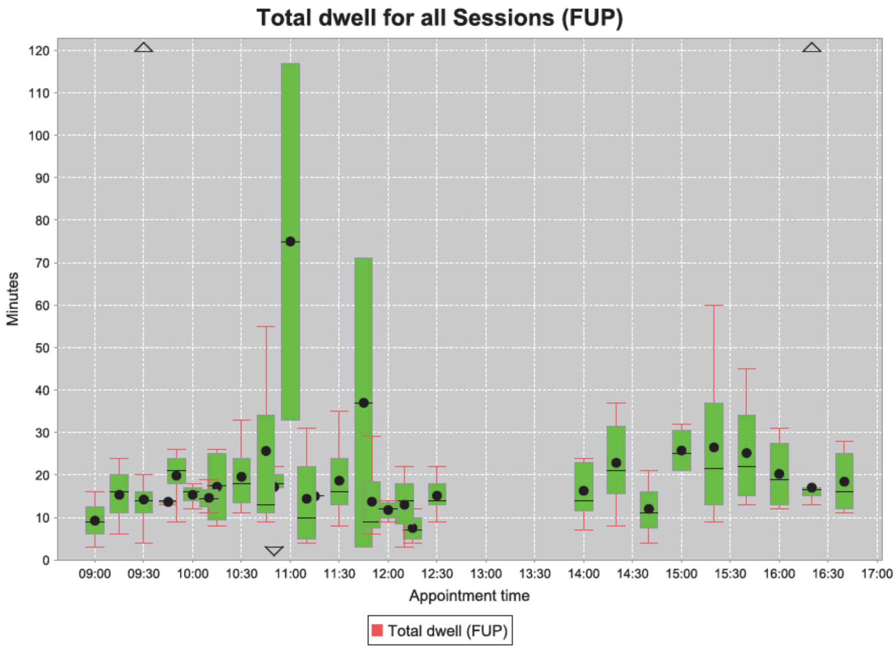

Figure 57 - Dwell Time survey results (FuP = 'Follow Up patient type)

(Source: Eleven Informatics LLP)

To facilitate the survey the author specified the design of a survey tool, implemented for a Tablet device using an Android operating system. The survey tool was designed to be used to track patients through their visits to the Oncology department. Surveyors were employed to record the time stamp of each step of the patient pathway. Data was then uploaded to a central server and passed into a reporting template designed by the author.

It was clear from the results that the largest proportion of patient Dwell Time was well within the 45 minute period allowed for in the initial occupancy study and that with an SD of 10 minutes this would encompass the 90 percentile range. The study also demonstrated the variability of Dwell Time (Mean DT: 20.86 minutes and SD: 10.76 minutes), which compared to the HAM values for the simulation as DT: 45 minutes and SD: 10 minutes. The clinicians also commented that they had not appreciated the extent of the waiting time that patients were subjected to. This was evidenced by over half of all patients not being seen within the allocated appointment start time, and having to wait at least 20 minutes from arrival (Figure 58 refers)

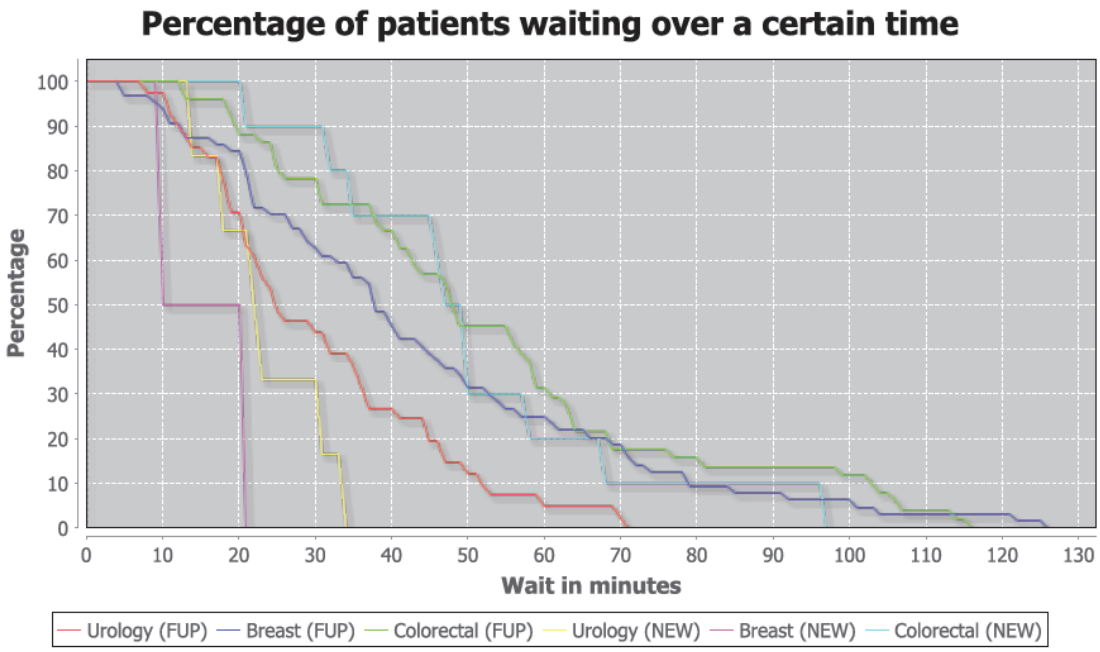

Figure 58 - Analysis of patient waiting time (Source: Eleven Informatics LLP)

6.9.3 - Experimentation with the clinicians: management of peak occupancy

It is at this stage of the action research where the activities moves from a 'consulting phase' to a 'research phase' as defined by McKay and Marshall (Op Cit).

The results of the survey clearly demonstrated the over-capacity forecast in the Oncology Department. Over-capacity was also found in all six departments studied using Occupancy Analytics. Whilst a general consensus in terms of space utilisation, had been achieved as a consequence of the validation process, the studies also showed substantial peaks in occupancy. As it is the occupancy peak that is a major factor in the sizing of the HVAC systems[51], the author reasoned that the if it were possible to control the magnitude of the peak, as well as when the time of day when the peak arose, then it would be possible reduce the sizing of the HVAC systems as well as reduce peak energy consumption.

This reasoning resulted in another sequence of experiments focused in developing an understanding of how peak occupancy could be managed. In discussing these experiments with the clinicians it became evident that they too would prefer

[51] Because coincident with the peak occupancy would be peak demand in energy - this will be clearly demonstrated by Stage 2 of the case study.

peak occupancy to be managed because this compromised the effective implementation of operational policy in the area of infection prevention control, administration (documenting patient care plans for example), creation of a stress free environment as typical examples. In response to these issues, the author conceived a strategy, which he referred to as ‘Peak Load Smoothing’ (Bacon, Op Cit, 2013).

A study of Peak Load Smoothing commences with an understanding of the aggregation of the peak occupancy within the whole hospital as was illustrated in Figure 52 earlier. The author reasoned that if it were possible to understand the factors that lead to the occupancy peak, it would be possible to control the peak – to in effect, ‘smooth the peak’ and thus reduce its potential impact, as explained earlier.

The author identified the following factors that could determine the coincidence of these peaks:

- Scheduling of patient appointments, where coincident Outpatient session times result in concurrent occupancy peaks between departments.
- Management of Dwell Time.
- Batch processing of patient types between inter-connected pathways.
- Policy concerning the number of Outpatient sessions held each day.

The obvious factor to be investigated was that of scheduling of patient appointment times. This is because these would significantly impact the flux of patients into each outpatient department. Discussions with clinicians identified much potential for this. For example some departments would run just one session (Nuclear Medicine for example) whereas others would run two sessions (Oncology for example). Other departments (Fracture for example) had been experimenting with longer working days, and thus extending sessions into the evening. Furthermore the department had been experimenting with operating three consulting rooms concurrently. However, this policy significantly impacted the Imaging department because it resulted in batches of patients arriving in Imaging from the Fracture department which they were not resourced to process. The critical reader might observe that this situation is one of the fundamental contraventions of ‘Lean’ which is to ensure process flow and which is enabled by creating conditions of ‘pull’ in down stream processes and not ‘push’ from upstream processes[52]. Clearly a ‘push’ system was being created through the batch processing of Fracture department patients.

The author proposed that ‘joined up’ Operational Policies should be developed and as such these would ensure that inter-departmental (zones) patient flux would be effectively managed (i.e. to introduce flow into the process) to ensure optimal use of resources, and avoid uncontrolled peak occupancy. The results of this work are illustrated in Figure 59 and Figure 60.

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[52] The Application of Lean thinking principles in UK healthcare can be found here: http://www.institute.nhs.uk/quality_and_service_improvement_tools/quality_and_service_improvement_tools/lean.html (Accessed July 2013)

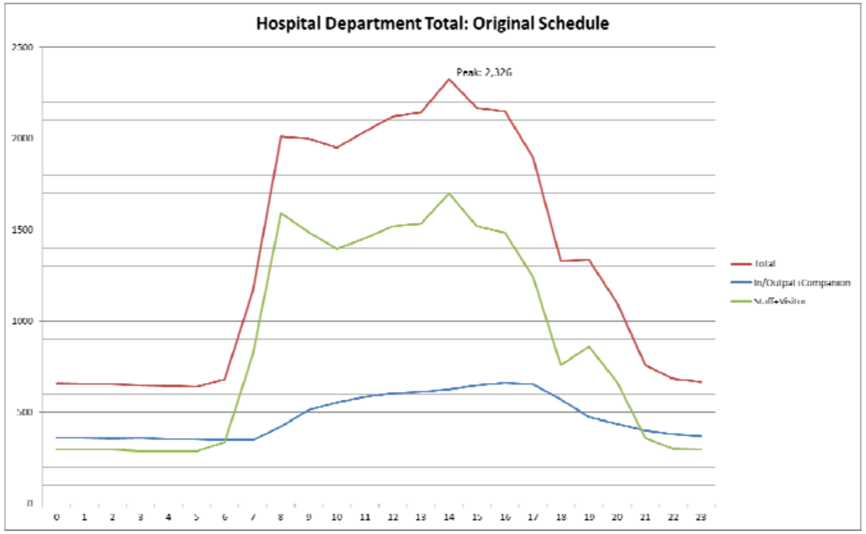

Figure 59 - Original occupancy profile for whole hospital

The occupancy profile combines the aggregate occupancy profiles for all departments.

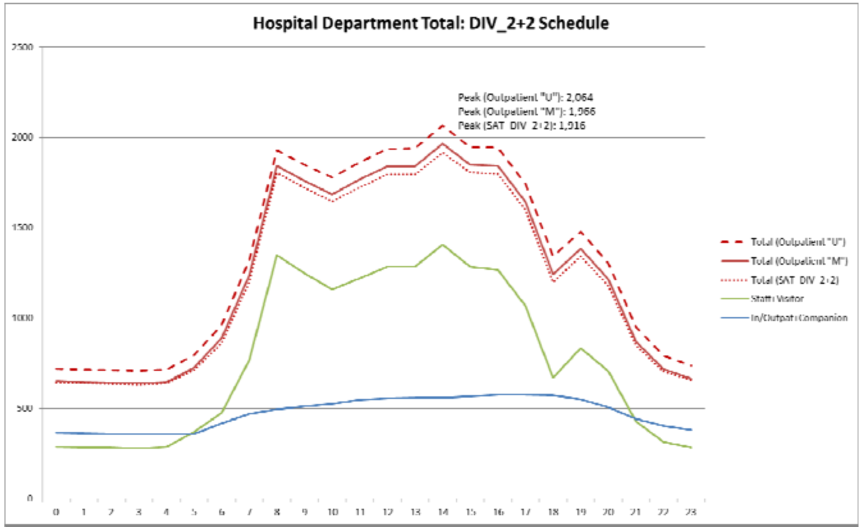

Figure 60 - Profile following Peak Load Smoothing

The occupancy profile combines the aggregate occupancy profiles for all departments, but the Outpatient departments have been ‘load shifted’, to avoid concurrent peaks in occupancy. The strategy was to optnise the scheduling of Outpatient clinics, whilst preserving the needs of the patient pathways of each patient type.

The author led a Peak Load Smoothing study and this demonstrated that an impact on the peak occupancy could be achieved. In the example illustrated in Figure 60 the peak occupancy load was reduced the upper bound occupancy to 2,064 occupants. This represents an 11% reduction. This was achieved through an extension of each working day by two hours in the morning and two hours in the evening over a 5-day working week. Clearly a greater reduction could be achieved if the hospital were to operate a 7-day working week and at least a twelve hour working day. The energy impact of this study will be reported in the next chapter.

6.9.4 - Analysis of results with clinicians: management of space utilisation

The aforementioned analysis then raised the question by the Trust: if peak occupancy load could be smoothed then surely this would liberate yet further clinical space? A following question then arose, do we (the Trust) make the hospital smaller, or do we seek to pass greater patient numbers through it by utilisation of the latent capacity?

Clearly the impact of greater utilisation could be greater energy consumption and thus carbon emissions? The Trust would need to ensure optimal utilisation of the hospital, and yet the challenge would be to achieve this and still reduce energy and carbon emissions.

In response to this potential, the Project Director asked the author to investigate the possibility of incorporating other clinical specialism's into available outpatient space. An obvious candidate was the existing general outpatients department that operated from a Victorian building. Specialism's such as Genito-urinary medicine, Podiatry, and General Vascular Surgery, would need to be considered for merging with 3Ts specialism's. The occupancy analytics team studied the potential demand from these specialism's and sought to find the best fit, from both capacity, function, clinical and operational affinity perspectives.

Whilst the study demonstrated that these specialism's could be accommodated, it also illustrated the importance of understanding peak occupancy profiles for each department. This is because the analysis showed that the peak profiles would inhibit the potential to utilise all latent capacity, notably because for obvious reasons the latent capacity exists outside of the occupancy peak. It was this observation that further reinforced the need for Peak load Smoothing. The author reasoned that removal of the peak and the achievement of an even patient flux, would create optimal opportunities for departmental space sharing. Such sharing could also offer departments that shared similar affinities (such as Cardiology and Non-Invasive Cardiology as one example) to share space outside of peak operational demands. This could result in departments remaining shut down from an energy perspective whilst functions were shared. An example of this could be during weekend working and could potentially result in significant energy saving.

The author then specified another study for the occupancy analytics team. The experiment was to understand how much latent space could be liberated should all outpatient departments be able to share under-utilised space. This was conceived a theoretical study, because the Project Director sought to understand the potential for a 'generic outpatients department'. This is one where clinical specialism's share functional space that is generic to each. One key study parameter was to apply Peak Load Smoothing to all of the Outpatient departments, based on extended working days to 22:00hrs; department peaks being spread through the day (by coordinated scheduling) and a seven day a week operating schedule.

The over capacity for the whole of Outpatients was estimated as 2,500 m^{2}, which represents over 50% of patient centric space. This is illustrated in Figure 61.

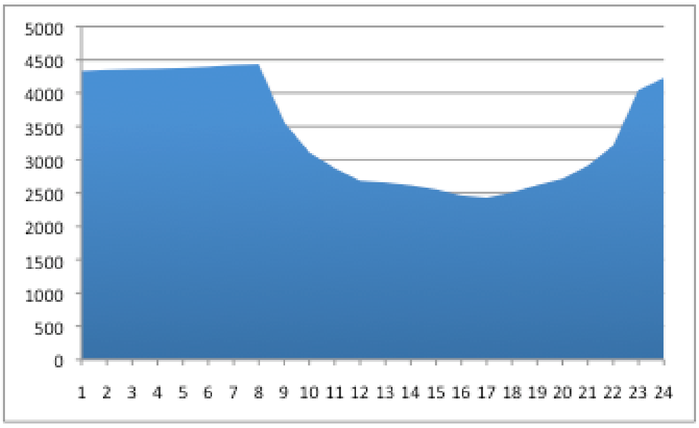

Figure 61 - Peak Load Smoothing applied to all Outpatients Departments (The shaded area represents non-utilised space over a 24 hour period)

6.9.5 - Summary of validation by the clinicians

a) Summary of findings. The occupancy studies and the experiments that were carried out identified significant potential to manage the peak occupancy within the hospital. There would be operational benefits, notably in the management of flow, (through the introduction of Lean principles), with the potential to improve efficiency. The Case Study demonstrates that through the effective management of Dwell Time the efficiency of the department (zone) directly impacts space utilisation. It demonstrated the direct correlation between changes to Operational Policies and occupancy. It demonstrated that space utilisation could be substantially improved by introducing changes to Operational Policy. Furthermore, by challenging Operational Policy the opportunities for Peak Load Smoothing demonstrated how to achieve maximum opportunities for space sharing between specialism's. (The energy and carbon impacts that arose from these investigations will be examined in the next chapter).

The Case Study also raises the possibility that Occupancy Analytics could provide a logical basis for space modelling in hospitals. The 3Ts design was based on a standard approach to health planning. The results from the occupancy studies question the validity of such an approach, and suggest that a new basis for health planning is required.

Fundamentally the question remains as to how Occupancy Analytics could impact the engineering design: the systems that manage the internal environment of the hospital and lead to the consumption of energy and emission of carbon into the atmosphere. It is now appropriate to consider the analysis from the perspective of the engineering designers.

b) Report on validation process

- Six departments were ultimately taken through the validation process. By the conclusion of it, all departments supported the analysis that was carried out.
- It will be seen in the next chapter, that a formalised 'buy-in' to the analysis was achieved, such that in the four departments approached (Oncology, Orthopaedics (Fracture), Nuclear Medicine and

Imaging) all of them signed an agreement to progressing the work further.

- The results provided the Occupancy Analytics team with confidence that the data from the simulation was sufficiently robust to be used as a basis for informing the engineering design, with 'appropriate values' with which to:
    - Obviate the need to make substantial assumptions. (For example: Occupancy diversity, approximated from Room Data Sheets).
    - Develop the engineering design in accordance with fundamental principles. (For example: Cooling load calculations to use the RTS Method using the occupancy diversity analysis, rather than 'rules of thumb', based on loads per square meter).

6.10 Conclusions from Stage 1 of the case study

To restate Research Objective 1: To make a new contribution to building engineering physics focused on understanding occupancy presence in buildings. The reasoning was set out as follows;

> *It could make good the numerous deficiencies of In-Use data, establishing the rationale in hospital organisation and management that controls the flux of people through it. Specifically it could establish the means by which occupancy presence can be determined in any part of the hospital at any hour of the day.*

- Occupancy Analytics is able to forecast the probability of occupancy presence in any zone at any time of the day in an acute hospital. The development of Occupancy Analytics has conclusively achieved Research Objective 1.

- The author discovered that operational policies were the means by which In-use could be analysed through simulation. This enables a deep understanding of occupancy presence, which hitherto has not been possible in acute hospitals.
- Without comprehensive occupancy presence data engineering designers are obliged to make substantial assumptions concerning how the facility use would impact the engineering design, and ultimately how the facility could be optimised for use. The results of the study demonstrated an occupancy load at least 30% less than that estimated from conventional practice. This result reflects the findings of research carried out in UK schools, where the where the variance between design occupancy and surveyed In-use occupancy was between 31-57%. The mean variance being 37% of forecast (C. Demanuele et al., 2010).
- It was possible to assimilate clinical information system data into a Health Activity Model database. This data could be readily used in discrete event simulation to model occupancy presence.
- The Case Study clearly demonstrated how it is possible to achieve a dialogue with the clinicians such that they were prepared to discuss changes to Operational Policy that would lead to improved space utilisation – an unanticipated benefit of Occupancy Analytics. The dialogue also demonstrated how it is possible to achieve clinical objectives, and yet also achieve engagement with the clinical leadership team in the achievement of low energy – low carbon objectives too.
- The use of organisational and service redesign strategies offer significant potential to achieve low energy – low carbon design acute hospital performance. This cannot be finally proven until Stage 2 of the case study.

This is what Robson (Op Cit) referred to in 'Real World Research' as:

> *"Explanation is concerned with how mechanisms produce events."*

However, until Stage 2 of this case study has been studied by the reader, the true impact of the '*mechanisms*' – those articulated in Operational Policy – that '*produce events*' will not be understood. This is the purpose of the next chapter.

6.10.1 - Implications for future research

Occupancy Analytics provides a logical means to analyse occupancy presence where there are explicit organisational processes operating in the facility and large flux of occupants arises. Could it be applied in other building types? Educational facilities are possibly the most obvious building type that could be investigated because large occupant flux is caused by curriculum schedules. School's too have been highly criticised for the same reason as hospital facilities in that the forecast energy consumption is rarely achieved in practice Demanuele et al. (Op Cit). Just as in acute hospitals, occupancy presence and related use was seen as the most significant factor as to why school facilities failed to achieve forecast energy performance.

The author's investigations also identified the need for an ontology of occupancy. It is important that future development work takes place using a common framework., and possibly one that could encompass other building types such as schools.

Chapter 7.0 – Case Study Stage 2: Analysis of In-use through whole facility energy modelling

7.1 Introduction

In this stage the author will report on the results of the investigation into the analysis of whole facility energy modelling pertinent to an acute hospital context in the UK. This part of the case study is a key part of the research to prove the author's proposition.

Section 7.2 reminds the reader of the research objectives and the relevant parts of the proposition that require investigation at this stage.

As with the previous stage of this case study, the author presents example from the case study plan and explains some of the key features of it. This is reported in Section 7.3. In Section 7.4 the author discusses the further requirements for the Whole facility Energy Model and Section 7.5 develops this discussion into a focus into how the occupancy analytics data is coupled with the energy simulation. The challenges of predictive simulation, notably concerning calibration and management of uncertainty in forecasting is also discussed. The author returns to current knowledge to discuss how these issues should be managed in the model and reporting. In Section 7.5 the author then compares different approaches to modelling between practice and research, in order that this knowledge informs the specification of the Whole Facility Energy Model as well as the inherent limitations of such modelling. The author discusses his strategy for addressing these limitations.

In Section 7.6 the results of the simulation are reported. This section is critical in the thesis because it explains how occupancy analytics is coupled to the energy model through the experimentation with clinical users. Soft energy budgets through user intervention in controls, and Peak Load Smoothing through organisational redesign are key strategies that are analysed in the pursuit of low energy – low carbon performance.

In Section 7.7 the author reports on the appraisal of this work by the engineering design and whole life cost team. The impact of this work on the engineering practice is discussed. Section 7.8 then develops the discussion to evaluate the energy and whole life cost impacts.

7.2 Case Study Objectives

In Chapter 5 the conceptual design issues for Whole Facility Energy Modelling were explained in the case study. In this section a case study of the implementation and results of Occupancy Analytics is now presented.

To remind the reader of the research objective relevant to the case study, this was previously stated as:

> ***Research Objective 2***. To make a new contribution to building engineering physics focused on understanding occupancy presence in buildings.
>
> *It would be achieved by investigating occupancy presence and the diversity of occupancy presence through an analysis of process and Operational Policies in acute hospitals.* ***It would be expected to facilitate significant improvements in forecast energy performance. Data would be created which the author would translate into a format appropriate for engineering design****.*

As the Research Objective, is expected to make good the deficiencies of In-use data it would be expected lead to the proving of that part of the proposition:

> *As the effective implementation of building engineering physics is compromised by a lack of 'appropriate In-use data',* ***it follows that making good this deficiency should ultimately enable improved forecast In-use energy consumption…***

The proving of this will be to demonstrate that it is possible to improve forecast energy consumption as a direct consequence of changes in organisational and service design.

In Chapter 5 the conceptual design issues for Whole Facility Energy Modelling were explained in the Case Study. In this section a Case Study of the implementation and results of Whole Facility Energy Modelling is now presented.

7.3 Detailed Stage 2 Planning

From the Project Implementation Plan for the 3Ts project the following two key objectives had been established:

a) To develop a ‘Whole Facility Energy Model’(WFEM) which will enable the In-Use energy consumption to be forecast within the approved ‘Target Range’ (Target setting work stream)

b) Using the WFEM to provide the evidence to support the case for an alternative Basis of Design.

c) To provide periodic Forecast Energy Reports to inform the decision making processes that would impact on the approved ‘Target Range’.

d) To provide the basis for target setting at departmental level.

The work was planned as part of the seven work streams, where each was modelled as was the information flow requirements between them. The work was planned as a series of three stages, and the strategy was to ensure that all seven work streams progressed such that the information flow between them could take place to maintain the momentum of the project. An example of the planning of the work streams is illustrated in the following extract from the Project Plan:

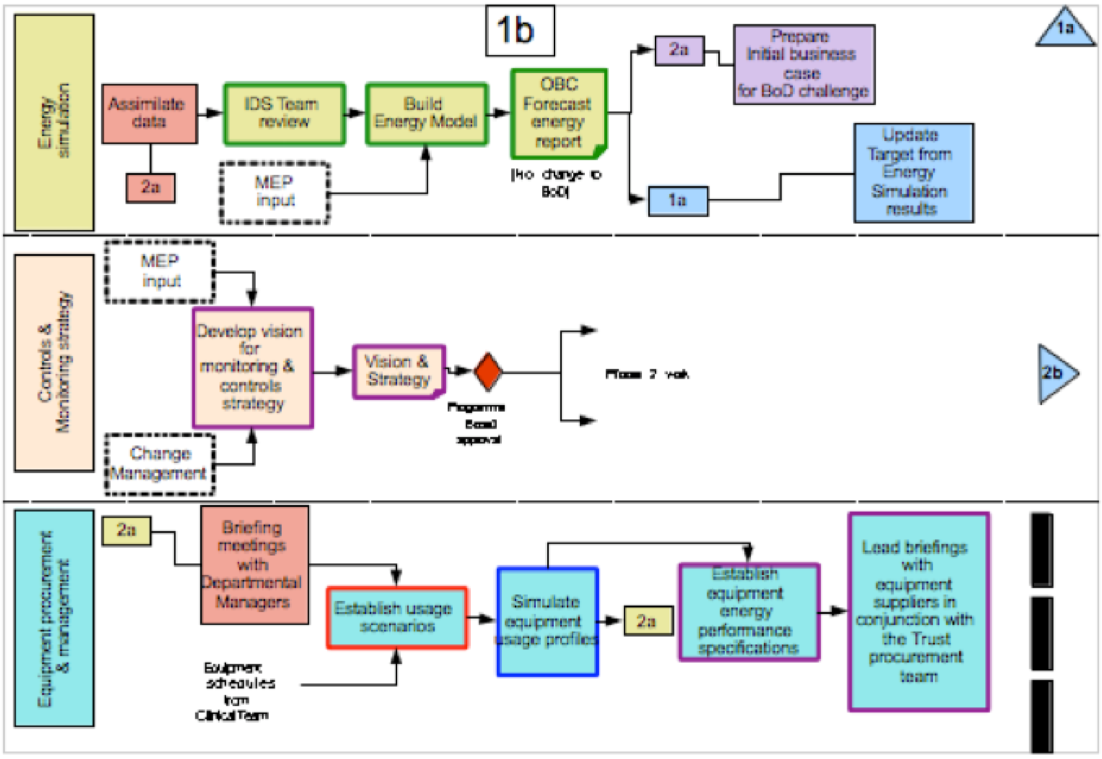

Figure 62 - Extract from the Project Implementation Plan to illustrate the WFEM work stream planning

Referring to the need to translate from the occupancy analysis into appropriate date for engineering design: (p168*)* The translation suggests the need for a 'Real World' perspective where clinical users may debate the efficacy of their organisational processes as identified by Operational Policy, and yet be required to translate approved processes into an empirical basis for processing by the supply chain.

Establishing the building geometry to build the WFEM BIM to ensure that the areas and volumes match the engineering model is essential for ensuring core data parity with the design team BIM. (The design team BIM was not sufficiently well structured to re-use it)

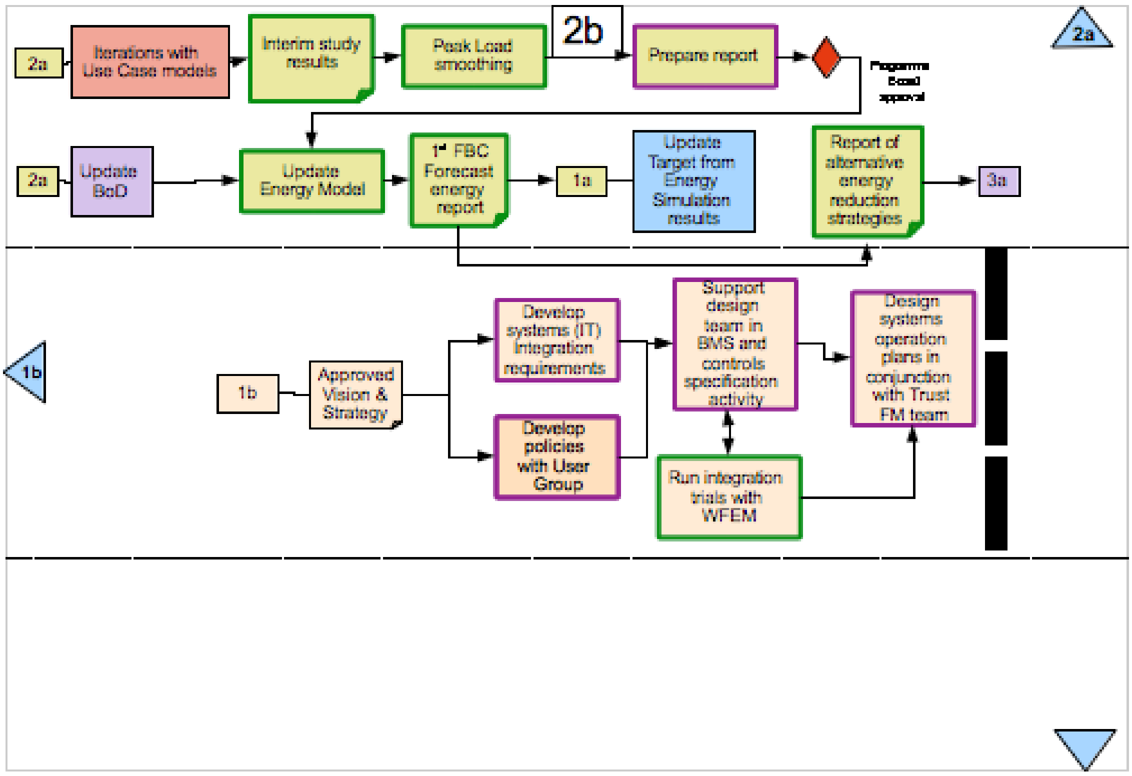

Figure 63 - Extract from the Project Implementation Plan to illustrate the WFEM work stream planning

In this stage of the plan experiments (Use Case Models) have been taking place with the URG, and these are then simulated in the WFEM.

These studies the lead into the peak load smoothing studies from the further experiments with the URG. The energy impacts of these studies are then reported through the Forecast Energy Report.

In consultation with the engineering designers energy reduction measures were investigated and the energy impacts of these were then evaluated in the WFEM.

Figure 62 and Figure 63 illustrates the planning of thee work stream in relation to the Controls and Monitoring, Equipment and Energy Modelling work streams. With respect to the latter, the two charts illustrate the key work stream components:

7. Build the Whole Facility Energy Model
8. Forecast Energy Reports
9. Iterations (Experimentation with 'Use Case Models')
10. Departmental Energy Targets

The activities required in preparation for the simulation were largely addressed in chapter 5. Having established the key concepts and translated these into requirements, the work stream activities of importance to this Case Study was to build the Whole Facility Energy Model with inputs from the Occupancy Analytics work stream and the MEP building data.

7.4 Building the Whole Facility Energy Model

The rationale for the Whole Facility was explained in Section 5.1.1 - Why Occupancy Analytics and Whole Facility Energy Modelling? The need to create this as a Building Information Model was also introduced – explained that as the author wished to carry out experiments with the model, then model parameters had to be configurable to accurately comply with the requirements of the experiment.

Yet the overriding requirement was that as occupancy presence needed to be modelled at a departmental (zonal) level of abstraction it was also necessary to model energy consumption on the same basis. To remind the reader of the reasoning for this, it is because the author wished to prove the proposition that:

> *As the effective implementation of building engineering physics is compromised by a lack of 'appropriate In-use data', it follows that making good this deficiency should enable improved prediction of In-Use energy performance.* ***Yet as it clinical users that fundamentally impact In-Use energy and carbon performance, they will require knowledge of the energy and carbon impacts of***

their working practices. With this new knowledge, it follows that if they were to understand these impacts they would then have the means to work towards further improvements in that performance though continuous improvement of their working practices.

Consequently with the need to model occupancy presence arises the need to understand the thermodynamic impacts of occupancy presence and use, along with the physical specification of the spaces in which occupancy presence is modelled. Only a BIM can satisfactorily achieve this requirement. It thus required the BIM to replicate the building design configuration as used by the engineering designers. An early decision made by the author and the energy modelling team was to restrict the granularity of the modelling to zone and sub-zone level and not at a room level of abstraction[53]. The reason for this was for two reasons:

a. It would be too complex to model occupancy data at room level, because not enough was known about the detailed departmental processes that could predictably cause an occupant to have presence in a specific space at a specific time of the day.

b. As the room planning was a in a state of change with the project team it could involve substantial abortive work to persist in maintain the model.

The critical reader might challenge the latter point and suggest that the very nature of a BIM is that it could be readily updated to reflect design changes. In theory this is certainly the case, but on the 3Ts project, the design team BIM was not mature enough at the stage in the process where the author's team required greater definition within the model. A key issue for the BIM used for energy analysis was the need for integrity of the boundaries of each zone. The BIM modellers who were responsible for the architecture could not assure these boundaries. Having reviewed the architectural model the author concluded that significant work would be required to enhance the data integrity of the model and consequently it would be preferable to build the WFEM BIM from the approved 1:200 2D dataset.

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[53] Please refer to p223 for an explanation of the rationale for this.

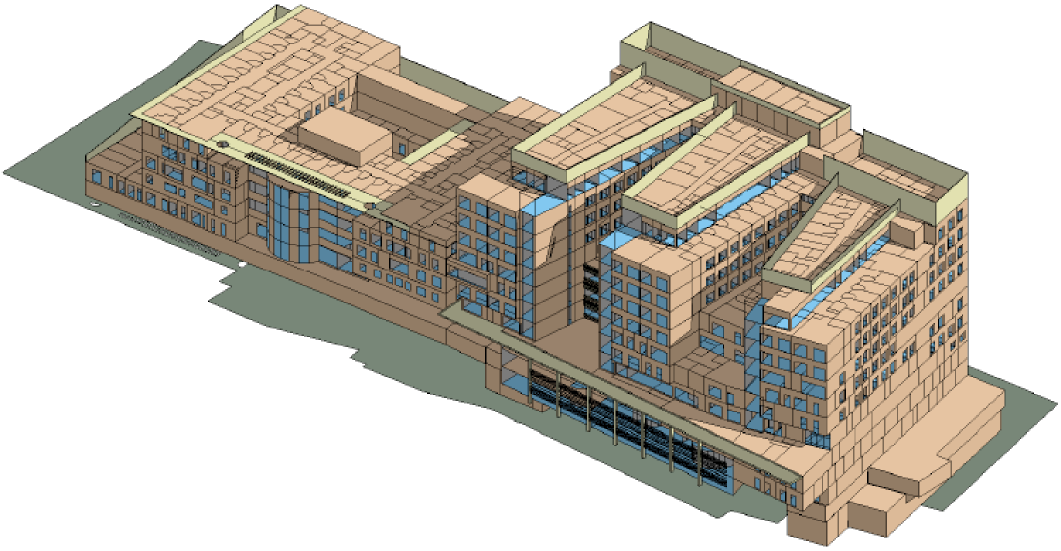

Figure 64 - The Building Information Model

Granlund OY built the model using MagiCAD[54] and Roomex[55]. The latter enables a detailed parameter set to be established for each zone and sub-zone. A key parameter was the occupancy diversity for each zone and sub-zone. The data for each of these was that provided from the Occupancy Analytics study. It was through the use of ROOMEX the latent and sensible heat gains arising from occupancy presence and equipment loads, for example, could be assimilated into the model.

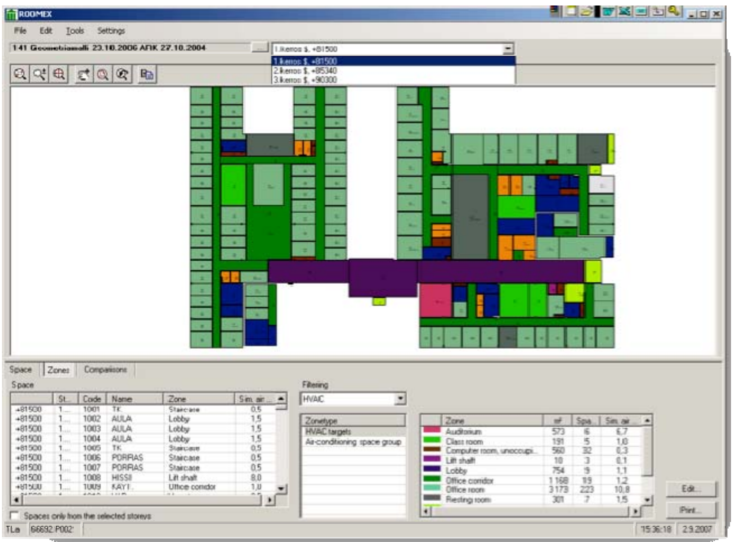

Figure 65- Example of ROOMEX space grouping (Source: Granlund OY)

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[54] See: http://www.magicad.com/en

[55] See: http://www.granlund.fi/en/software/roomex/

The architecture and building fabric specifications were provided by the project team. On completion of the model, it was then validated with the engineering team to ensure that building area, volume and geometry accorded with the architectural model as well as the engineering model that was derived from it. The conclusion of this exercise was that the Granlund OY BIM and the engineering designers BIM were sufficiently aligned to enable the energy analysis to be carried out. The energy analysis was carried out using RIUSKA.

A critical reader might ask: Why use these tools and not others? The reason was because the modellers in Granlund OY assured the author that the tools would enable the author to achieve the objectives of his analysis.

7.5 Finalising the whole facility energy modelling specification

The conception and specification for the Whole Facility Energy Model configuration was produced by the author. In addition to the key performance requirements set out in Section 5.3.4 - Summarising the key conceptual issues for Whole Facility Energy Modelling, other specific requirements for the output of the Whole Facility Energy Model were that it must:

1) Support the full diversity of use as forecast by the Occupancy Analytics study. Consequently it must model energy consumption at one hour intervals directly in response to the occupancy presence profiles *for each zone and sub-zone* (Please see also p223 for the details of this). Cooling, Heating and Ventilation loads are to be modelled from the occupancy presence and diversity data.
2) Support the full diversity of use of all imaging equipment. To model the energy consumption profile for each item of imaging equipment for the different usage states of that equipment.
3) To enable the establishing of departmental energy targets directly informed by Operational Policies.
4) To replicate the external fabric thermal performance and to use the same weather data file as that used by the engineering designers.

5) To model all energy use, regardless of Energy Performance Certificate requirements. This means that both ‘Regulated and Un-regulated’ consumption would need to be modelled. The objective would be to model all energy consumption.

One example of how Granlund demonstrated to the author that they had complied with the modeling requirements was to produce peak day cooling and heating load profiles with the occupancy profile overlaid, as illustrated in Figure 66.

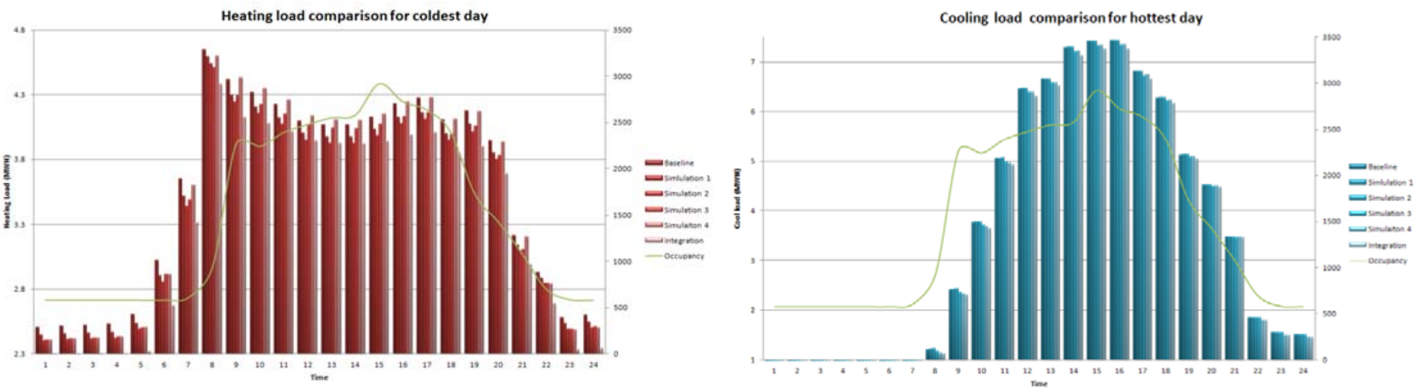

Figure 66 - Occupancy - Heating/ Cooling Load comparison (Source: Granlund OY)

This study is comparable to a consumption study over-laid with an occupancy profile (Figure 67) below. It is the close correlation between occupancy and energy consumption that the author strives to achieve in the Whole Facility Energy Model.

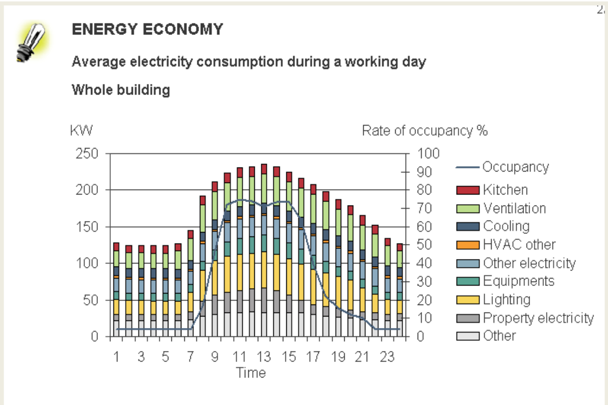

Figure 67 - Energy consumption profile overlaid with an occupancy profile (Source: Granlund OY)

The significance of the illustration in Figure 67 is that there is a mismatch between the occupancy profile and the energy consumption profile. This means that energy being consumed above the occupancy profile line is probably being wasted. This was the reason why the author specified the requirement to demonstrate the alignment between the occupancy profile and the cooling and heating load profiles.

7.5.1 - Calibration of the simulation

A key issue for the specification was how to calibrate the simulation. (T.Reddy, 2005) suggests that:

> *"Calibrated simulation is the process of using an existing building simulation computer program and "tuning" or calibrating the various inputs to the program so that observed energy use matches closely with that predicted by the simulation program."*

The author's concern with this definition is that the point of reference for the calibration is to use an existing simulation, because the need for 3Ts, as will be explained later, would be for an empirical validation and not comparative testing, Judkoff (Op Cit, 2005).

The approach of Reddy (Ibid) presupposes that the reference simulation has been calibrated against validated input values. However, Reddy does acknowledge the value of half-hourly metered data as a basis for calibration of simulation of forecast performance, but he fails to acknowledge that this is the requirement for an empirical validation Judkoff (Op Cit, 2005).

At 3Ts the challenge would be to understand how reliable the forecast of consumption would be for In-use. This is important because it returns to the original research question as to the unreliability of design team forecasts. Raftery et al. (2009) make a salient point that there is no standard accepted methodology for calibration and also that there is a general lack of complete, coherent measured data. Perhaps other industries have addressed these issues, which would point to the value of further research in this area?

In the context of 3Ts neither was there available data against a known performance baseline for a comparable building on the Brighton estate and regardless of this given the unique nature of the 3Ts building this was not possible. Unlike the

Occupancy Analytics Model where the author had access to clinical information system meta-data (forecast patient demand, daily arrivals, inter-departmental flux for example) there was no such comparable energy data. The new facilities were to be far removed in asset specification terms to the Victorian buildings that are to be redeveloped.

Consequently, the energy and carbon forecast could only be a comparative performance measure with the design team forecasts as reported in for the EPC, and based on their thermal model, which was based on all the assumptions that they had made during the design process. This is still very important however because one test of the proposition is the comparative on: to compare the forecast energy and carbon performance of a conventional engineering design process with that performance arising out of the author's methods.

For these reasons the specification for reporting required:

- Establish WFEM baseline performance using the using the core asset performance data from the engineering designers and supplemented with the occupancy analytics data.
- Using the WFEM baseline performance compare the results to the design team baseline performance.
- All experimentation to be carried out against the WFEM performance baseline.

Whilst this approach to calibration would satisfy the investigations be conducted in this thesis, it still leaves open to question as the robustness of the WFEM as a forecast of In-use consumption for the purposes of the 3Ts contract. Reason suggests that it should be much more robust than conventional practice, because though Occupancy Analytics the author has attempted to address the documented failings of contemporary simulations that make the substantial assumptions identified in the body of literature.

7.5.2 - Comparison with engineering practice approach to energy forecasting

The comparison here is made from the author's discussions with Subject Matter Expert: Runicles, who characterised the engineering design process at the stage that they were working at (RIBA Stage D) as one that the engineer will use both professional judgement and experience, supported by appropriate analysis and modelling (VOLUME 2, p42). Up to this stage he would argue that there is often not the information that is ideally required (such as that defined for the Energy Efficient Brief). Many assumptions are made, but Runicles argues that these are under regular review from one stage of the process to another. Asked whether he could see value in the occupancy presence and diversity data at RIBA Stage C or D, he affirmed that this would be valuable briefing information – providing it demonstrates benefit to the client (VOLUME 2, p52). However, Runicles also acknowledged that KS8 Energy Efficient Briefing information had never been made available to them. A summary of typical engineering design assumptions based on RIBA Stages C/D is outlined in Table 12 below.

Conventional assumptions	Proposed method
Assumption concerning occupancy density and diversity. Reliance on typical occupancy density for each space type.	• Assumptions concerning flux of highly stochastic occupancy types (but informed by schedules where available)
Assumption of the required cooling and heating loads for the whole hospital. Assumptions tested using 21 standard room types.	• No assumptions, other than the facility will be used as specified in operational policies. Heating and cooling loads aggregated from concurrent peak loads within each zone.
Assumptions concerning operation of medical equipment – some operating 24 hours a day at peak load, and other at 12 hours a day at peak load.	• No assumptions, other than the equipment will be used as specified in operational policies. Equipment schedules and assimilated energy demand profiles based on manufacturers data.
Assumptions concerning boiler capacity: assumes that boiler needs to service an empty chilled building and bring it to design temperature within a specified time period. No allowance for heat gains from occupants.	• Boiler profile designed according to occupancy demand.

Table 12 - Assumptions made in the 3Ts engineering design process at RIBA stages C/D.

An analysis of assumptions made by engineering designers in 25 office buildings in Sydney demonstrates the potential impact that these could have on the ultimate energy performance of these facilities (Steinfeld et al., 2011). Through an analysis of In-use data they found that one building was designed for a peak cooling load of 80-90W/m^2, yet its maximum cooling load that was ever experienced was39.8W/m^2 and in other years it was typically in the range of 30-40W/m^2. Whilst one building cannot be regarded as typical it is an indication of the consequences of assumptions being based on conservative ‘worst-case scenarios. However, Subject matter Expert: Bordass also raised the same issue in terms of calculation of data centre cooling loads (VOLUME 2, p94). The author's suggest that the consequences of these assumptions may result in larger than necessary equipment capacities, potentially increased building peak loads and will ultimately restrict the improvement in environmental performance. Consequently the value of the specification for the WFEM would be to avoid such assumptions having to be made, but this discussion will be returned to later in this Chapter.

7.5.3 - Comparison with theoretical approaches to energy forecasting

The literature review identifies identical approaches to practice in calibration, but has also developed tools that are rarely used in practice (Augenbroe, 2011). Augenbroe also observes the dangers of simulation forecasts in that they inherently contain many conditional assumptions, either explicit or implicit. Augenbroe argues for probability based assessments in the simulation results, recognising the inherently uncertainty in early design stages.

The author's reflection on this challenge is that it is surely a fallacy that forecasts are produced as a determined value. With many variables potentially impacting the process at each stage, a deterministic value would be one where someone had made a judgement as to what actual values (not variables anymore) should be. How could this be achieved and stand objective scrutiny? As Augenbroe further argues, uncertainties are rarely dealt with hence parameter values are based on best guesses, and even these are fraught with assumptions and expert bias.

In reflecting on these issues the author developed an approach where experimentation in both occupancy analytics and the energy modelling would establish a performance range within which the building could be expected to perform. The author also conceived that the reporting should, as will be explained in the next Section, make all assumptions explicit and should be taking place at every stage of the process. The author further reasoned, that if specific focus is made on the known variables at the early stage of the engineering design process, as identified from the literature review, the risk to the forecast expected range of performance should be substantially reduced.

Of course even this approach remains open to criticism and to quantify the residual risk would be to require detailed analysis such as that recommended by Augenbroe. An alternative and pragmatic approach would be to alert the customer to these perceived residual risks, and whilst quantification maybe possible, even the identification of these requires expert judgement, which could then invalidate Augenbroe' s argument.

7.5.4 - Reporting specification

The plan identified the need for the energy modelling team to produce Forecast Energy Reports at key stages of the project. The strategic objective of the work stream was that the WFEM would shadow the whole engineering design process, and embody all key engineering design decisions, architectural and construction decisions that could impact the final energy performance of the hospital. In this regard a key objective was that it would also explicitly model all engineering design assumptions. Throughout this process the author's aspiration was that the Trust would be able to consider alternative design, construction and, or operational scenarios and use the WFEM to report on the energy and carbon impacts of them.

A fundamental need therefore was that there should be complete alignment between the 'essential' basis of design of the engineering design team thermal model and the basis of design as replicated in the WFEM. In qualifying the basis of design as 'essential', the qualification concerns the following in relation to replication of the basis of design in both models:

1. The physical geometry and thermal properties of all external fabric elements.
2. An identical weather file.
3. The engineering strategy in terms of the method of ventilation, cooling and heating of all spaces.
4. Assumptions concerning the efficiency of heat recovery in the air-handling systems.

5. Assumptions concerning the efficiency of the Combined Heat and Power system.

There were also fundamental differences between the engineer's thermal model and the authors WFEM. These were:

- The forecast growth of patient demand.
- The occupancy profile for the whole hospital.
- The imaging equipment utilisation profile.
- Hot water usage allowances based on Finnish hospital design.
- Modelling of all Un-regulated energy consumption.

However, the modelling of engineering design assumptions in the WFEM was not possible to achieve. This was because during the period in which the WFEM was being analysed many aspects of the 3Ts project were halted pending Department of Health and Treasury approval. Consequently the author's energy modelling team did not have access to the engineering designers on the project. The omission of the engineering designers assumptions from the WFEM is considered by the author as material to any comparisons between the two models. This is because if the WFEM were to be used as intended as the basis for decision making by the Trust, then the assumptions, which might be substantial in terms of the potential impact on energy performance, would need to be modelled.

Despite this not being achieved it had been possible to determine from the engineering designers some of the key assumptions that had been made in the thermal model as outlined in Table 12 earlier.

As discussed in the literature review both practice and theory have developed different methods for the management of uncertainty. Frankel et al. (2012) provides the most relevant commentary at this stage:

> *"While design characteristics have a significant impact on long-term building energy use, building maintenance, operation and occupancy strategies are absolutely critical to the long-term performance characteristics of buildings."*

Having considered the literature, the author's intent for the forecast energy reports was to provide a performance range that would encompass variability, uncertainty and assumptions. As a forecast of In-Use, some key question would be:

Modelling

'How closely can the WFEM replicate the 'Real World?' For example how closely could RIUSKA model equipment profiles?'

'How accurate are weather files – how much could the effect of global warming impact the accuracy of them?'

Procurement

'How certain could the forecast be, when the contractor that procures the component parts of the engineering systems, do not substitute components that would compromise the performance of the system for which they have been procured?'

'How certain would the forecast be, when the assumptions concerning fabric performance are not achievable in practice?'

In-use – Clinical users

'How certain could the forecast be, when the clinical users may choose to operate the facility quite differently to that which they document in the Operational Policies?'

'How realistic is the forecast of patient demand?'

'How likely is it that a controls system could be designed that could accurately respond to the diversity of use?'

In-Use – Facility engineering

'How certain could the forecast be, when facility engineers may choose to over-ride calibrated control settings and allow the performance of engineering systems to degrade over a period of time?'

'How certain could the forecast be, when systems are not rebalanced following changes of use in the facility?'

As has been discussed earlier (For example: Augenbroe, Op Cit) the challenge with these issues is how to quantify uncertainty and paradoxically, what confidence could the team have in such predictions anyway? As was discussed in Stage 2 of the case study, an explicit means of assessing the uncertainty is to attempt experiments that would enable the team to model the sensitivities of different variables. Experts could advise on which of the foregoing factors are most likely to have the greatest impact on the accuracy of the forecast, and then these could be the candidate uncertainties that then need to be modeled. The outcome of such experiments would then enable the sensitivities of each uncertainty to be modelled.

In discussing these issues with his team it was concluded that In-Use- clinical users factors would be the most likely to cause substantial variance between forecast and actual performance. This is because the other factors in Procurement and Facility engineering could be more likely controlled through effective specification, management, and compliance testing. Whereas variances in clinical use maybe much harder to control. It was therefore agreed that these factors should be subjected to experimentation once the Forecast Energy Report had been produced. This approach was informed by the literature review and notably from Picco at al. (2014). The reader will recall the following list of early stage causes of substantial variation in out-turn energy performance:

1. Indoor air temperature
2. Air change rates
3. Occupancy
4. Metabolism
5. Equipment

It would be clinical users that could potentially impact all five causal factors. It might be argued that the first two are made as a consequence of engineering decisions, but the last three are certainly impacted by operational policy and working practices.

7.6 Reporting

The First Forecast energy report made the following observations:

a. Forecast energy performance 29.9 GJ/100m^3 compared to the engineering designers comparable estimate of 52.2 GJ/100m$^{3.}$ However, the engineers EPC calculation against a benchmark building is 44GJ/100m^3.

b. Forecast energy performance would be 280.8kW/m^2.[56]

c. Un-regulated energy consumption was calculated as 14% of the total building consumption.

d. The carbon saving potential is complex to calculate because it needs to be calculated based on the performance of the CHP system, and the forecast amount of electricity to be used from the National Grid relative to that used from the CHP. In theory the CHP should meet all demand, but this cannot be guaranteed.

e. Imaging equipment electricity consumption is forecast to 20% of that forecast by the engineers.

f. Departmental energy budgets based on current operational policies were reported.

The First Forecast Energy Report failed to report on a performance range as specified. Conventional practice for the modellers was to present a value for the performance based on chosen values from the range within the simulation. This is influenced by the ability of the modelling software to process such variances. To achieve this requirement the modellers would have had to produce model variations for the different parameter sets, because the software could not accommodate multiple values.

Despite thus failure, the report Figure 68 does achieve a comparison between the engineers design and the In-Use forecast Baseline. However, the author's requirement was to understand the impact of variances in the range of probabilities of occupancy presence and diversity in each zone, aggregated for each into whole hospital energy model.

[56] Please see comments that follow on next page concerning the authors reporting requirements

Energy Conf.	Composition	Design forecast kWh/m2	Baseline (Southampton) kWh/m2
Regulated Energy demand	Domestic hot water	43,7	21,4
	Heating, other	0,0	0,2
	Heating, spaces	75,1	57,9
	Heating, AC system	51,5	31,3
	HVAC, cooling energy	59,7	41,9
	HVAC, fans	248,8	48,1
	HVAC, other electr.	0,0	0,0
	Equipment electricity	0,4	0,4
	Lighting electricity	44,8	36,4
Unregulated Energy demand	Equipment electricity	207,7	40,4
	Lighting electricity	2,8	2,8
Whole Building Primary Energy Demand	Lighting electricity	47,6	39,2
	Equipment electricity	208,1	40,8
	HVAC, cooling energy	59,7	41,9
	HVAC, other electr.	38,9	48,1
	Total Heating	119,0	110,8
	Total Electrical energy	354,3	170,0
	Total Building Energy	473,3	280,8
	Regulated Energy		238
	Unregulated Energy		43
Savings, heating			
Savings, electricity			
Oveall Energy Savings	-	-	-
Energy consumption	Boiler Gas consumption	51,8	54,8
	CHP Gas consumption	448,4	459,0
	Total Gas consumption	500,2	513,8
	Chillers electricity	4,7	3,4
	CHP electricity generation	154,3	156,1
	Building Electricity needs	299,3	131,4
	Total Electricity consumption	145,0	-24,6
Delivered energy	Energy cost / m2 (£)	-	13,08
	saving potential	-	-
CO2 emission	Total Building CO2 emission kg/m2	172,2	101,7
	saving potential	-	-
Energy performance	Heated area (Gj/100m³)	52,2	29,9
Energy performance	Entire Building w/ regulated energy only (GJ/100 m3)	49,2	19,9

Figure 68- Forecast energy report from Whole Facility Model (right hand column)

The substantial difference between the author's forecast of performance and the engineering designers forecast was clearly substantial. Having validated the geometry, the engineering design team and the author's team then discussed the potential reasons for the substantial difference between the two forecasts. It was concluded that:

1) The occupancy diversity forecast by the author's team was substantially different to that assumed by the engineers. The specification for the WFEM required that energy consumption profile should follow the occupancy profile as closely as possible. This was because there were

discussions taking place with the Project Director, the Department of Health and the Principal Supply Chain Partner, concerning the possibility of derogation from the HTM's. This would potentially provide much greater flexibility for engineering the services to respond to the users needs in each space, in preference to a standard that defines air-change rates based on the functional definition of a space.

2) The imaging equipment utilisation profile was substantially different to the assumptions made by the engineering designers. The author had gathered detailed energy profile data for the different equipment types directly from some of the manufacturers and this provided a sound basis for the energy consumption modelling. In contrast the engineering designers had assumed that imaging equipment would remain in full use, throughout the whole of the operating period and they had also assumed generic power consumption for each item of equipment.

It was concluded that the author's team should develop a dialogue with the clinical leadership team such that experiments could be carried out to investigate the following strategies.

1. A Controls and Monitoring strategy would be developed that would enable the engineering systems to respond to the substantial occupancy diversity.
2. Work with the clinicians to investigate alternative working practices with the objective of smoothing peak loads.

The reasoning for these two strategies was to understand if the author's proposition could be realised In-use (Please refer to Section 7.4 Building the Whole Facility Energy Model), which expected users to take responsibility for energy consumption – a concept conceived as 'soft energy budgets[57]', should they be empowered with appropriate information in order to make informed decisions. The Peak Load Smoothing strategy was discussed in the previous chapter (Please refer to Section 6.9.3 - Experimentation with the clinicians: management of peak occupancy).

[57] A soft energy budget is one that is not mandated, but is one that is used for evaluation of performance to inform users of the potential need for change.

The two strategies were then combined into one energy impact study to consider the impact of user intervention through organisational redesign (achieved through the development of Operational Policies) informed by low energy – low carbon objectives. It was also agreed that through this work the potential uncertainties of the accuracy of the Forecast Energy Report could be tested.

The timing of these two studies followed the completion of the Occupancy Analytics validation process referred to earlier. This was considered important by the author because there needed to be consensus with the clinical leadership team as to the validity of the results of the Occupancy Analytics work stream. These studies were thus designed to build off this work and to inform the negotiations with the clinical leadership team for the establishment of refined departmental energy budgets, based on new policies and measurement norms. (Which is beyond the scope of this Thesis).

7.6.1 - User intervention in control

The approach taken by the author in developing the controls strategy was informed by the post-occupancy work of (Bordass et al., 2007). In the introduction to their publication they write:

> *"Better controls are an important way of saving energy and reducing carbon dioxide emissions. Usually they are a more cost-effective way of saving energy than adding renewable energy systems. To invest in renewable energy without first making sure that the controls are as effective as possible would be a waste of resources".*

The authors then pose the question: What are controls for?

> *"User controls are provided for two main reasons:*
>
> *To allow users to select the conditions they need; or more precisely to avoid conditions they don't need. People tend to exercise control when entering or leaving a space, or if they find the conditions don't suit them.*

The authors continue with this statement, which is of particular relevance to the arguments developed in the Thesis:

1. ***To help ensure that systems operate efficiently, thereby reducing a building's carbon dioxide***

> ***emissions rather than contribute to them.*** *People will tend not to exercise control if the environment is not troubling them."*

Stevenson and Humphries, (2007) carried out a post-occupancy review of the Dundee Maggie Centre[58] in Scotland. The user responses to the semi-structured interviews suggested that if users had some control over their environment they were more inclined to tolerate perceived sub-standard conditions, compared to those that did not have control.

Implementation issues for user intervention in control is investigated by Wang et al. (2011b). The author's explain how to design a user centric control system using agent based system design. Henze and Neumann (2011) discuss an implementation using model-based control designed to achieve optimal performance in terms of objectives such as lowest energy use, lowest energy cost, carbon emissions and such like.

These considerations pose interesting and potentially conflicting requirements: to what extent should users be provided with control (and in doing so to behave responsibly) versus automation systems designed to optimise building performance for stated performance objectives? Bordass et al (Op Cit) would no doubt argue for simplified systems of control, but this might this be counter to the need for optimisation? Yet it could also be the case that complex systems may not be able to respond to the substantial diversity of use experienced in a hospital, (or in any other complex facility) and as such could they ever be expected to optimise performance with that substantial diversity of use? Furthermore complex systems can often require complex maintenance. This was the experience of the BSUH Facilities Management team, which the author interviewed as part of the briefing process for the controls strategy. The team found that the supply chain was often not sufficiently skilled to maintain complex systems designed and installed on the existing hospital estate. Another example concerned critical system components such as sensors that when replaced due to failure, were replaced with sub-standard ones that could not operate within the same performance parameters as the one that was replaced, with

[58] See: http://www.maggiescentres.org/

the consequential degradation of system performance. It was this reasoning that the author conceived the control strategy for 3Ts (original content in grey background):

The controls strategy proposed for 3Ts has been conceived in response to the fact that in the majority of acute hospitals (and we have yet to find one that does not) the environmental control systems are managed by a Building Automation/ Control system, designed to maintain acceptable environment for all users, and predicated on the function definition of each conditioned space.

These systems deliver environmental control to a specification of performance founded in serving standardised assumptions concerning use of space, and best practice guidance as to levels of conditioning to be achieved relative to the type of space. Sensors will detect indicators of key indoor air quality and adjust systems within specified parameters.

Yet it is the needs of people, and the functions that are performed within each conditioned space that are important, and not so much the functional definition of the space. To achieve low carbon performance, these standardised assumptions concerning use, and the associated guidance as to the levels of conditioning to be achieved, must be challenged. This is because research clearly shows that these to excessive carbon emissions.

It follows that the required for low carbon performance must be designed for the needs of the users of the space, and the functional demands on the conditioning requirements based on that use. Different uses will thus place demands on the environmental control system and a control response will be required to meet that specific need. The question arises as to what should be the most effective control strategy?

There are two obvious control strategies that would be able to meet the varying functional needs of the conditioned spaces:

- *An automated control system able to respond to the varying demands on the use of the space.*
- *An intervention control system where users set controls according to the varying demands of the space.*

The former would require sophisticated sensors in order to measure the key components of air quality. It would be appropriate where users did not wish to participate in the control of the spaces in which they worked, (or in some cases, such as patients) where they were being cared for).

The latter strategy is predicated on the willingness of the users to take control of key spaces according to the changes needs based on the use of each conditioned space. In this strategic approach, it is envisaged that key spaces will be controlled according to three standard conditions, which would be able to respond to the known forecast demands of use of each space. It is this latter option that is proposed for 3Ts. It is predicated on the understanding that users will take responsibility (and some will also become accountable) for the energy use within the department that they work.

As discussed by Firlie (Op Cit) engagement with the clinical leadership team was considered essential if user intervention in control was to deliver sustained performance against energy targets. This is because the consultant leadership determines the operational policy and delivery of clinical outcomes in their department (specialism). This need for user engagement was emphasised by the Sustainability Development Unit (Op Cit) in these terms:

"Every NHS staff member should be able and encouraged to take responsibility for energy consumption and carbon reduction."

Consequently for 3Ts the questions was: " Could we have confidence that the clinical users would actively participate in the control of energy consumption and if so would the clinical leadership team be willing to take the lead in this?" To this end the author produced a departmental briefing document, to provide a basis what he called a 'hearts and minds' meeting (after Champy (Op Cit)) – where people must understand the need for change – to be convinced of the need for change). An extract from this document is set out here in grey background:

Energy Budgets

The objective of this work will be to discuss the principles involved in establishing a soft energy budget for your department. The budget will be developed from the occupancy and energy modeling studies carried out last year. This work will form the basis for a discussion with you and specifically to agree the principles of:

- *How a realistic budget would be developed.*
- *Those aspects of the budget that you could have direct control over and so manage the budget.*
- *Working practices and operational policy requirements that could impact the budget.*

- *Staff involvement in directly managing your departmental energy budget.*

The discussion could also focus on any issues/ sensitivities that you would wish to discuss concerning the establishment of an energy budget and the future management of it.

The Forecast Energy Report was translated into an assessment for the departmental energy budgets. The intent was that this would be used as a benchmark against which the operational energy reduction measures identified below could be assessed.

Energy distribution in zones			INTEGRATED			BASELINE		
			TOTAL ENERGY					
Zone Code	Operation	Area	Min	E%	Min2	Max	Zone E	Max
		m²	MWh	%	kWh/m2	MWh	%	kWh/m2
Z00 Carpark	non -24hr	22281.70	1124.48	4.47%	50.47	1124.48	4.37%	50.47
Z01 ENT	non -24hr	1282.50	386.29	1.53%	301.20	384.13	1.49%	299.52
Z02 COMMUNICATION	non -24hr	2239.40	330.29	1.31%	147.49	430.36	1.67%	192.18
Z02a Communication waitting area	non -24hr	1097.00	213.26	0.85%	194.40	266.65	1.04%	243.07
Z02b Communication corridor	non -24hr	11385.20	484.74	1.93%	42.58	487.02	1.89%	42.78
Z03 MEDICAL PHYSICS	non -24hr	1004.70	94.50	0.38%	94.06	96.22	0.37%	95.77
Z04 RADIOTHERAPY	non -24hr	2910.40	946.71	3.76%	325.29	945.70	3.68%	324.94
Z05 CALL CENTRE	24hr	396.50	35.65	0.14%	89.91	38.80	0.15%	97.87
Z06 DISCHARGE LOUNGE	non -24hr	681.10	113.34	0.45%	166.41	117.83	0.46%	173.00
Z07 RHEUMATOLOGY	non -24hr	458.80	177.60	0.71%	387.09	178.69	0.69%	389.47
Z08 PLANT ROOM	24hr	2593.10	375.36	1.49%	144.75	391.30	1.52%	150.90
Z09 TRUST HQ	non -24hr	401.70	36.82	0.15%	91.66	33.42	0.13%	83.19
Z10 NUCLEAR MEDICINE	non -24hr	1432.30	570.43	2.27%	398.26	589.79	2.29%	411.78
Z11 NON INVASIVE CARDIOLOGY	non -24hr	1259.30	574.17	2.28%	455.95	587.01	2.28%	466.14
Z12 THERAPIES	non -24hr	454.60	50.10	0.20%	110.21	45.56	0.18%	100.22
Z13 PRIVATE PATIENTS	24hr	604.40	283.14	1.12%	468.47	486.08	1.89%	804.24
Z14 EBME	non -24hr	429.70	44.42	0.18%	103.38	38.10	0.15%	88.66
Z15 BSMS AND CIRU	non -24hr	1803.90	395.26	1.57%	219.11	397.98	1.55%	220.62
Z16 ONCOLOGY SUPPORT AND PALLIATIVE CARE	non -24hr	1032.50	148.92	0.59%	144.23	137.69	0.54%	133.35
Z17 NEUROSCIENCES	non -24hr	1666.50	584.47	2.32%	350.72	590.53	2.30%	354.35
Z18 FM	24hr (Mo-Fr)	1385.50	215.82	0.86%	155.77	221.09	0.86%	159.58
Z19 ONCOLOGY DAYCARE	non -24hr	1240.10	133.12	0.53%	107.35	135.95	0.53%	109.63
Z20 ONCOLOGY OUTPATIENTS	non -24hr	987.60	370.95	1.47%	375.61	366.70	1.43%	371.31
Z21 IMAGING COLD	non -24hr	3048.80	946.57	3.76%	310.47	956.19	3.72%	313.63
Z22 FRACTURE	non -24hr	1230.00	426.48	1.69%	346.74	432.50	1.68%	351.63
Z23 ONCOLOGY WARDS	24hr	2574.00	2142.31	8.51%	832.29	2114.37	8.22%	821.43
Z24 IMAGING HOT	non -24hr	2413.30	297.03	1.18%	123.08	305.05	1.19%	126.40
Z25 AMU & AMBULATORY CARE	non -24hr	1147.60	530.86	2.11%	462.58	534.21	2.08%	465.50
Z26 STAFF CHANGE	non -24hr	868.80	82.65	0.33%	95.13	116.43	0.45%	134.01
Z27 CIS WARDS & OPD	24hr	2389.00	1815.30	7.21%	759.86	1831.03	7.12%	766.44
Z28 MULTIFAITH	24hr	228.90	30.91	0.12%	135.03	34.80	0.14%	152.04
Z29 PAL	non -24hr	82.50	8.63	0.03%	104.61	8.95	0.03%	108.53
Z30 CRITICAL CARE	24hr	4458.90	3496.81	13.89%	784.23	3514.17	13.67%	788.13
Z31 MEDICAL WARDS	24hr	5644.80	4405.59	17.50%	780.47	4432.36	17.24%	785.21
Z32 NEUROSURGERY WARD	24hr	2288.10	575.56	2.29%	251.55	589.94	2.29%	257.83
Z33 NEUROLOGY WARD	24hr	1586.10	1189.25	4.73%	749.79	1183.70	4.60%	746.30
Z34 STROLE WARDS	24hr	1842.20	1241.00	4.93%	673.65	1241.24	4.83%	673.78
Z35 MEETING/TEACHING/SIMULTION SUITE	non -24hr	1137.60	91.25	0.36%	80.22	103.90	0.40%	91.33
Z36 DOCTOR MESS	24hr	194.80	29.23	0.12%	150.03	28.46	0.11%	146.11
Z37 RELATIVES O/N STAY	24hr	79.90	54.43	0.22%	681.22	52.28	0.20%	654.29
Z38 MANAGEMENT OFFICE	24hr	148.80	22.63	0.09%	152.06	25.46	0.10%	171.08
Z39 CAFE	non -24hr	748.40	92.75	0.37%	123.93	119.86	0.47%	160.15
Total		**91,141**	**25,169**	**100%**	**276**	**25,716**	**100%**	**282**

Figure 69 – Departmental energy budgets

In the illustration it is the 'Baseline' column that provides the basis for the benchmark. (The 'Integrated' column refers to the impacts of other Energy Reduction Measures outside the scope of this thesis).

The intention for this benchmark is that it would provide the upper bound tolerance for energy performance measurement, i.e. where users would not intervene in energy performance In-Use. The lower bound performance would be calculated from the impact of user intervention strategies that will be discussed on the following pages of this Case Study. Continuing with the controls strategy, the authors briefing to the clinicians (grey background text is the original content from that briefing):

Peak Load Smoothing

The objective of this work will be to understand how Operational Policy (and particularly that which impacts inter-departmental operations) impacts the peak occupancy within your department. The objective of this work will be to investigate 'could-be' scenarios where changes to Operational Policy could be made to reduce peak occupancy whilst ensuring that patient safety and well-being is not compromised. These concepts were discussed in the validation process carried out last summer, and to which there was general agreement.

The work will be undertaken in the form of a discussion to explore options for changing working practices and then to evaluate the occupancy and low energy – low carbon impacts of each.

As explained in Stage 1 of the case study, the author reasoned that by addressing the peak occupancy within each department, the energy consumption demands of each department could also be managed. Substance to this reasoning can be found in the Australian study of peak load demand in Sydney office buildings Steinfeld et al. (2011). The investigators found that initiatives could be planned with the users to reduce peak energy consumption, just as the author has envisaged for the acute hospital.

The author then conducted a series of workshops with the leadership teams, both individually (as departments) and collectively as a User Reference Group (URG). The purpose of these sessions was to 'win over the leadership hearts and minds', in other words to appeal to their sense of responsibility and concern over the potential for their working practices to cause harm to the environment through excessive energy consumption and carbon emissions. This is the philosophy behind the work of the international organisation called *Health Care without Harm*[59].

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[59] See: http:// www.noha.org

"*First Do No Harm" ... Together with our partners around the world, Health Care Without Harm shares a vision of a health care sector that does no harm, and instead promotes the health of people and the environment.*

The focus of this organisation is to work with clinical users. Their research has found that it is the clinical users working practices that can significantly impact the environment, and as such they must be engaged in areas such as facility operations and materials specification. It is this emphasis on clinical engagement that was central to the authors strategy for buildings controls and using the knowledge gained from facility operations to inform users such that they are able to continuously improve the energy and carbon performance of the hospitals in which they work.

The workshops were very successful. The clinical leadership team in each department all stated their firm intent to work with the author in an investigation into the development of Soft Energy Budgets through user intervention in control and to experiment with options concerning Peak Load Smoothing through Organisational redesign. These initiatives will now be reported.

7.6.2 - Experimentation - Soft Energy Budgets through user intervention in control

It is here where the action research transitions from the ‘consulting phase’ to the ‘research phase’ as proposed by McKay and Marshall (Op Cit).

The concept of soft energy budgets was discussed at meetings of the whole department, usually at a team meeting, or with the leadership team within a department. The author led these meetings, and explained the low energy – low carbon strategy for 3Ts. The style of the presentation was informal, because the author sought to develop a dialogue with each department. The author sought to engage with the ‘hearts and minds’ of the team.

The leadership was, on the greater part, already familiar with the low energy – low carbon concepts through engagement with the occupancy analytics work. However, at team meetings the majority of those attending would not have been familiar with the key concepts.

Q: Why the need for a soft energy budget?

A: Because it is clinical users that make many of the decisions that impact energy consumption, and it is users that have the potential to continuously reduce consumption through evolution of their Operational Policies and working practices, for example:

1. The energy performance of an MRI scanner, for example, is directly impacted by the specification for it. The clinical users that specify such machines often do so without this knowledge. For example the stand-by power consumption of an MRI can be almost as much as the In-Use consumption, but some machines have been designed to be much more efficient at stand-by. Some machines provide much fast scanning time than others with a direct impact on energy consumption, whilst others use energy recovery technologies to further reduce demand.

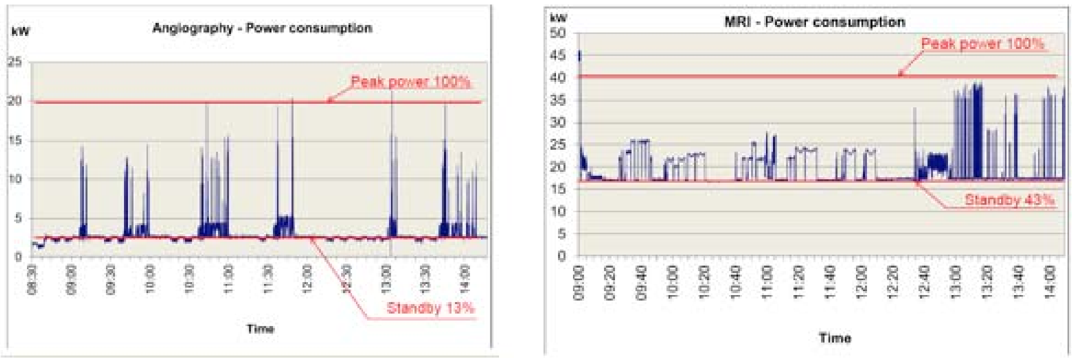


Figure 70 - Energy consumption profile of MRI scanners (Source: SINTEF, Norway)

2. During operation of the machine, some types of machine can be turned off, but this will depend on the type of imaging machine, because some types cannot be turned off, but where they can be, they are commonly left turned on as illustrated in Figure 71. Where they can be turned off this would result in lower energy consumption and the associated carbon emissions. The energy report previously discussed showed that the potential energy savings could be a factor of five less when compared to imaging machines never put in standby mode (207kWh/m^2

compared to 40.8kWh/m^2). This is illustrated in Figure 70 which shows a typical usage profile, which is very different to that assumed by the engineering designers for 3Ts. From this Case Study the evidence is that with managed use of Imaging equipment the proportion of energy used could be as low as 15% of total energy use. However without managed use, the proportion could be as much as 50%. Unpublished source from SINTEF in Norway where they surveyed the use of imaging equipment in two hospitals showed that the relative proportion of use was 22.5% of the total hospital energy consumption.

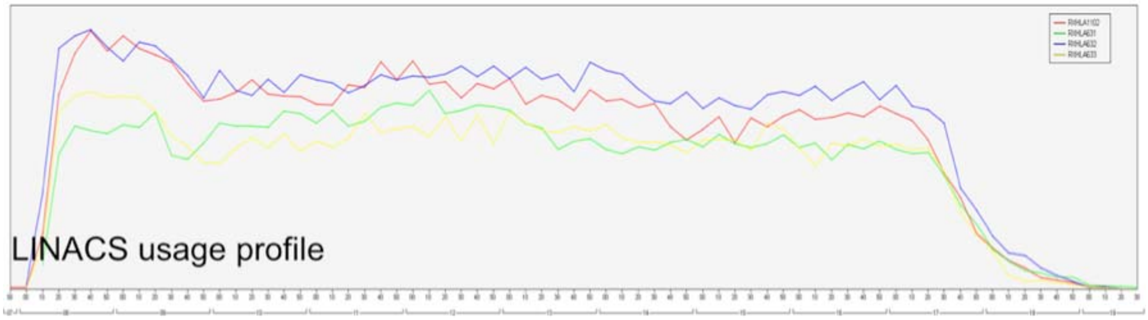


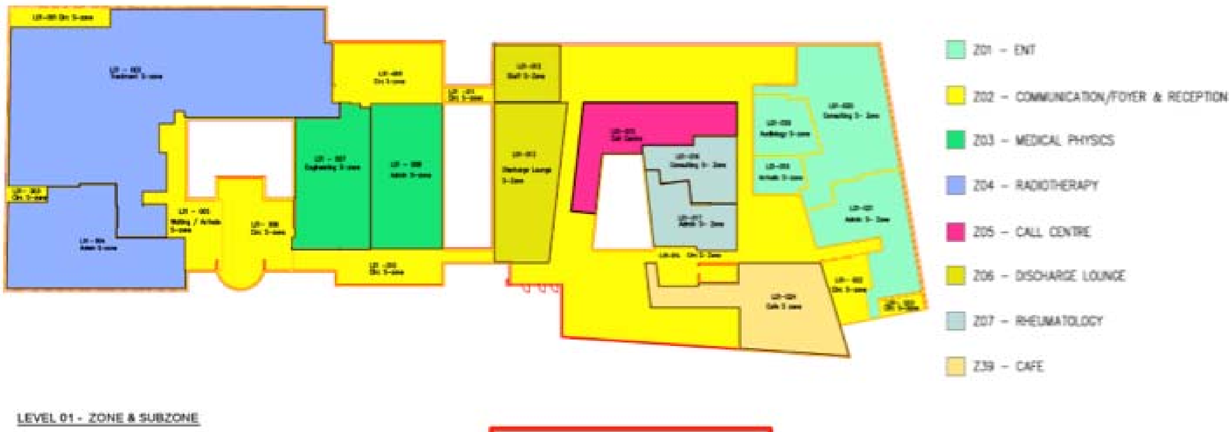
Figure 71 - Operational profile of a LINACS machine (Source: BSUH, UK)

Risk factor: The potential for energy reduction in the use of Imaging equipment is substantial. However, should equipment not be specified that enables efficient workflow, speed of workflow, and error reduction (Imperfect images – requiring re-scans for example), then some of this potential is lost. The Case Study demonstrates what is theoretically possible to achieve, and whilst the results were discussed with the Imaging lead for the department, it was concluded that a more detailed analysis of work-flow would be required.

Q: What other aspects of Operational Policy potentially lead to greater energy consumption and so impact the soft energy budget?

A1: The usage profiles of departments vary considerably during the day. The Case Study provides evidence for the opportunity for space between outpatient departments that share similar operational and functional affinities, during certain operating periods. The evidence is that some outpatient departments are under- utilised during most mornings of a week, because the consultants are carrying out ward rounds during the morning.

On other occasions consultants only work certain days of a week, and then the remainder of the time they are working at another location. These provide the opportunities for space sharing, and if exploited to the full potential would be an important component of the data used in Figure 61 illustrated earlier. The opportunity will arise at certain periods of the day, and is to match the available under-utilised space with the demand for space from another department. By this means one department could be in set-back mode for longer periods during the day than would otherwise be the case. The evidence for this will be found in the occupancy schedules described in Stage 1 of the case study, and is also illustrated in Figure 72 below. The result should be lower energy consumption and the associated carbon emissions, which will be reported later in this Case Study.



Department		Hour of Day																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
ENT	M	0	0	0	0	0	0	0	28.1	36.2	68.7	69.8	68.8	69.8	79.6	98.2	73.3	71.3	70.9	46.1	6.66	0	0	0	0
	L	0	0	0	0	0	0	0	5	7	59	58	59	58	61	75	64	60.2	62	18	1	0	0	0	0
	U	0	0	0	0	0	0	0	51	65	80	80	77	80	107	122	84	81	82	71	13	0	0	0	0

Department		Hour of Day																							
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Rheumatology OP	M	0	0	0	0	0	0	3.28	4.44	12.9	18.1	18	18.8	18.1	19	17.6	11.8	12.3	10.2	4.19	0	0	0	0	0
	L	0	0	0	0	0	0	0	0	8	14	13	14	14	14	11	8	8	5	0	0	0	0	0	0
	U	0	0	0	0	0	0	7	9.1	19	24.3	23	24	23	24	23	16	17	14	9	0	0	0	0	0

Figure 72 - Example of the potential for sharing facilities between departments during low occupancy, where another department could take up the low space utilisation of another.

Figure 72 illustrates the potential over-capacity in Rheumatology to be absorbed into over-capacity in the Ear, Nose and Throat (ENT) department between

07:00 – 12:00 hrs[60]. A space utilisation study had demonstrated that unused consulting rooms could be shared with other operationally compatible functions. If this potential were realised, it could mean that on certain days of a week the Rheumatology department would not be bought back from night-time set back until the middle of the day. This would be one means by which Operational Policy could be optimised to reduce energy and carbon impacts of use.

A2: Less related to Operational Policy, and more related to personal responsibility concerns the willingness of users to consider what level of comfort they require in their place of work within the department. As was investigated in the literature review, an individuals' tolerance for warmth, cooling or air quality is dependent on a number of factors, and these are usually not possible (without complexity) to control through automated systems. Indoor air quality sensors, CO2 sensors are means by which automated monitoring and control is possible. The users are therefore encouraged to take personal responsibility for only using the minimum energy within the space that they are working. The author proposed the concept of room control 'scenes', which provide a level of pre-set room conditions agreed with the clinical users. By this means the benefits of automation are combined with the benefits of user intervention.

Four control scenes were envisaged by the author: a) Design default (HTM compliant), b) Scene1: Partial use, and c) Scene 2: Low use, d) Set-back. Figure 73 illustrates the scenarios that were agreed with the Nuclear Medicine department.

- In the Set-back scene the room temperature would be allowed to float back to 18^0 C and design conditions achieved when In-use within 30 minutes.
- Scene 2 was planned as the most aggressive control, when In-use. The control would allow the room temperature to float by +/- 2^0 C, turn off all room lighting and enable only task lighting. Within this scene setting the user would target small power use. This could achieve a 20% reduction *on the occupancy profiled use*, in small power

[60] For an interpretation of the tables in the Figure please refer to Stage 1 of the case study.

consumption based on use of small devices and use of technology to turn off office systems when not in use. The energy impacts of this strategy will be reported later in this Case Study.

Zone (Group)	Sub Zone (Activity)	IDS Ref	Notes	Design		Scene 1		Scene 2		Set-back % of 24hr period
Nuclear Medicine										
	Radiopharmacy office - 3 people	L02-020	Room control	Full occupancy:05:30 - 14:00hrs	08:15-9:00 - 2 people	2 people	60% WD	1 person 2hrs each morning		60
	Radiophysicist office - I person	L02-018	Room control	Full occupancy	08:00 - 12:00	Set back	30% of working day			60
	Consultant offices - 2 people	L02-020	Room control	Full occupancy - Cons + vistor	30%	Single person:	(50% of working day)	Set back	20% of WD	60
	Registrar office - 4 people	L02-020	Room control	Full occupancy (Rare event)	10%	Twin occupancy:	50% of working day	Single occupancy:	40% of working day	60
	Hot Desk office - 4 people	L02-020	Room control	Maybe once or twice a week full occupancy.		One-two people	60% of working day			60
	Consultation/ Examination	L02-018	Room control	70% of working day full occupancy		Set back	30% of working day			60
	Consultation/ Examination (other 2 offcies)	L02-018		Full occupancy	50% of week	Set back	50% of week			
	Office - 4 people	L02-020	Room control	Full occupancy	80%	Set back	20% of working day.			60
	Radiopharmacy suite	L02-017	Preset conditions	Full 30 ac hr	50% of working day	10 ac hr	50% of working day			
	All other spaces		Sub-zone control							60

Figure 73 - Scene analysis for Nuclear Medicine

The author qualifies the small power consumption in terms of *occupancy profiled use*, because the small power load forecasts in the Whole Facility Energy Model were profiled by forecast occupancy demand, and a per occupant small power allowance.

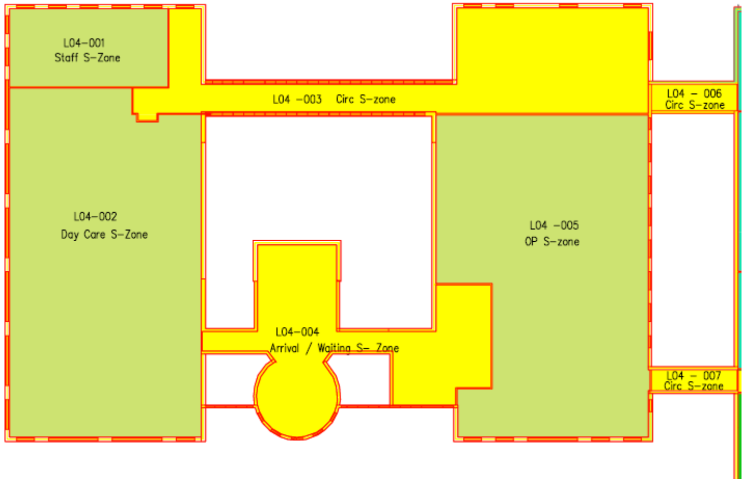


Figure 74 – Zone LS04-005

In the example illustrated here the Zone LS 005 is designated for Outpatients. It will comprise consultant's offices, consulting rooms, examination rooms, and waiting areas for example. The energy consumption analysis from the Whole Facility Energy Model shows the forecast loads from lighting and equipment (small power) total about 17 W/m^2. These loads are shown to vary according to the forecast occupancy profile provided by the Occupancy Analytics study.

This analysis is directly comparable to those of Dunn and Cook (Op Cit, 2005), where they concluded that lighting and small power allowances in UK offices should be in the range of 12-25 W/m^{2,} compared to standard guidance of 40 W/m^2.

L4-005	Infiltration	Heat transfer	People	Lighting	Equipment	Windows	Total
1	0.0	0.8	1.2	1.9	2.1	1.0	7.0
2	-0.1	0.7	1.2	1.8	2.0	0.8	6.4
3	-0.3	0.6	1.1	1.7	1.9	0.8	5.8
4	-0.4	0.5	1.1	1.6	1.8	0.7	5.3
5	-0.4	0.4	1.0	1.5	1.7	0.7	5.0
6	-0.4	0.3	1.0	1.5	1.6	1.3	5.3
7	-0.4	0.3	0.9	7.2	7.7	1.9	17.6
8	-0.2	0.3	1.5	7.7	8.2	2.3	19.7
9	0.0	0.3	4.4	7.8	8.3	2.7	23.6
10	0.4	0.4	5.5	7.9	8.4	3.2	25.9
11	0.7	0.5	5.8	8.0	8.5	4.3	27.8
12	1.0	0.7	5.9	8.0	8.6	5.6	29.8
13	1.3	0.8	5.9	8.1	8.6	3.6	28.3
14	1.4	0.9	6.5	8.1	8.7	3.9	29.6
15	1.5	1.0	7.2	8.2	8.7	4.9	31.6
16	1.5	1.1	7.0	8.2	8.8	6.0	32.5
17	1.4	1.1	7.1	8.3	8.8	5.4	32.1
18	1.3	1.1	7.2	8.3	8.9	4.3	31.2
19	1.2	1.2	6.1	8.4	8.9	3.2	29.0
20	1.0	1.2	2.9	8.4	9.0	3.0	25.5
21	0.8	1.2	1.6	8.5	9.0	1.7	22.8
22	0.6	1.2	1.5	2.6	3.0	1.4	10.2
23	0.4	1.1	1.4	2.2	2.4	1.2	8.7
24	0.2	1.0	1.3	2.0	2.2	1.1	7.8

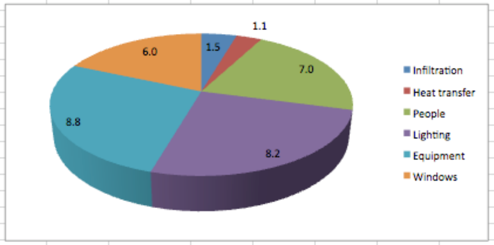


Figure 75 - Energy Consumption analysis for Zone LS04-00

The reader is reminded of the consequences of the over-estimation of these loads as discussed in the Sub-section:

How to forecast service demand from patients on imaging equipment, clinicians and other resources? (p197). Returning to Figure 73 the experiment was to consider the implication of reducing these loads still further through responsible occupant behaviour. This would put the consumption at the lower end of the Dunn and Knight recommendations.

7.6.3 – Experimentation - Peak Load Smoothing through organisational redesign

Stage 1 of the case study explained the outcome of the Peak Load Smoothing analysis in terms of the impact on clinical space. In this Case Study the author explains the impact on energy consumption. A key part of the Peak Load Smoothing strategy was to consider how departments could work relative to each other:

1. To ensure that departmental peaks did not coincide.
2. Inter-departmental patient flux is managed in such a way as to manage peak occupancy.
3. Space could be shared to avoid having to bring accommodation from set-back mode[61] to operating mode.

A workshop comprising representatives from six departments was held, and which was constituted as a User Reference Group. It was agreed that users would work together as proposed by the author. Three initiatives were suggested by the group:

- To model the cancer services patient pathways and using this knowledge to study the interface issues between Nuclear Medicine, Radiotherapy, and Oncology.

[61] This is where the control system specification allows the room to fall back to a predetermined condition when it is not in use.

- To investigate the operational interface between the Imaging department and the Fracture department and thus avoid operational peaks between the two departments.
- Nuclear Medicine would study how it could change their operational policy

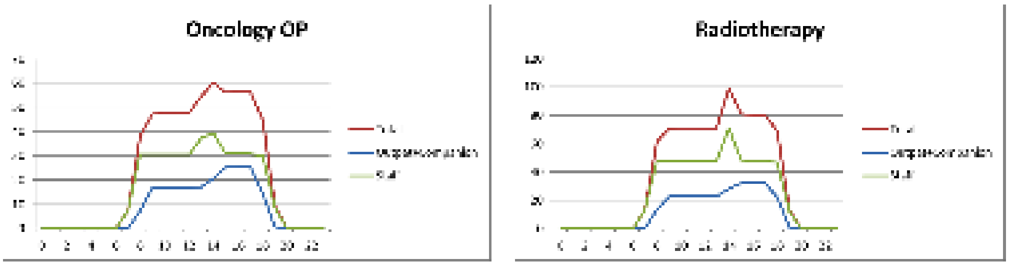
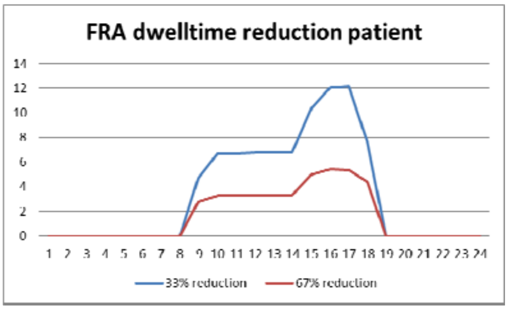


Figure 76 - Peak occupancy profiles in 2 connected 'schedule led' departments

Figure 76 illustrates the potential for Peak Load Smoothing. It is clear that all three departments share similar Outpatient occupancy profiles (The blue line in the lower plot of the three). Through the development of Operational Policy the potential to avoid the coincidence of the three occupancy profiles and thus smooth the peak occupancy is the subject of the investigation. Discussion within the URG identified it was not just appointment scheduling that could be the means for smoothing the peak, but other factors too.

The Oncology team could work to reduce the Dwell Time (Please refer to Stage 1 of the case study for a detailed discussion concerning this), and in doing so this would be expected to move the peak patient occupancy to earlier in the day. The Nuclear Medicine department proposed holding a two-session day, and thus reducing the mid afternoon peak, and processing more patients in the morning. As all of these departments are what were referred to as 'schedule led' departments, they would have much greater control over the peak occupancy than compared to a 'demand led' department such as the Fracture and Imaging departments.



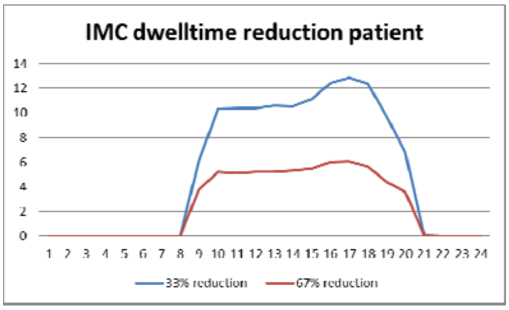


Figure 77 - Occupancy profiles in two 'demand led' connected departments

The illustration in Figure 77 does not show the peak patient occupancy in the Fracture department being reflected in the Imaging department. This shows a situation where the Imaging department was controlling the flux of patients from the Fracture department. Whilst this Operational Policy provided the Fracture Department with a smooth flow, it created significant waiting in the Fracture department, which is evidenced by the peak occupancy in that department. In discussion at the URG it was clear that changes in Operational Policy in one department could negatively impact the workload planning of another. This was discussed in Stage 1 of the case study. This study clearly demonstrated the operational advantages of developing ‘joined up’ operational policies through organisational redesign, in other words coordinated policies and management change between connected departments. At the URG both leadership teams agreed to collaborate on this work.

Yet as explained in the introduction to this sub-section, it was the forecast reduction in energy and carbon that was the principal driver for this work, and not so much the organisational benefits. That is not to suggest that the organisational benefits were not important, because they were. Without theses potential benefits the clinical users may have been reluctant to engage in the process. The objective of this work was to investigate the proposition that through organisational redesign low energy – low carbon objectives could achieved.

The rationale for peak load smoothing in this regard is that it would be expected to reduce the demand on the plant infrastructure capacity, because as was explained in the literature review, it is the peak cooling and heating loads that are the principal factors that influence capacity.

The author's argument here is that peak loads should not be assumed by engineering designers to be matters outside of their sphere of influence. On the contrary, the author proposes that engineering designers should enter into a dialogue with users to explain the impact of their working practices on peak loads and seek to investigate the means by which these could be reduced. This is the purpose of Peak Load Smoothing and the author suggests that this should be an important element of the briefing process.

KEY ISSUE

However, in terms of the Case Study, the opportunity to negotiate this aspect of energy reduction with the engineering designers was not possible because the project was stopped pending Department of Health and Treasury approval. Whilst the potential remains to do this, the argument that it should lead to a reduction in plant infrastructure sizing remains unproven.

7.6.4 - Making sense of the experiments: correlating occupancy presence with energy consumption

As was explained earlier in this Case Study the results of the foregoing experimentation were then processed within the Whole facility Energy Model. The objective of this study was to demonstrate how it is possible to directly correlate working practices with the energy and carbon impacts of them. It was because the Whole Facility Energy Model was able to model both occupancy and the impacts of use, such as the energy impacts of the working practices in the operation of Imaging equipment, that the energy impacts of this assessment became possible to achieve.

The potential for this study would be to create a new norm for the measurement of energy consumption: kWh/per patient type. The need for this measure is a) because kWh/m2 does not reflect the energy impact of improved patient flux – the more patients passing through the department, the greater the potential energy impact. b) A patient focus provides a tangible measure that clinical users can focus on, and so strive for continuous improvement in energy reduction. It would help them ask questions such as: "how could we reduce the energy consumption for each patient episode?" c) The data could be used to inform the departmental energy budgets.

The author commissioned a study to consider this aspect of energy management. It was an obvious means by which granular occupancy, and energy data could be modelled by using the concept of a 'patient pathway' through the facility. The patient pathway is the physical route by which the patient passes through the hospital as they are processed either with one department or another, on each episode as they visit the hospital. Conceptually the author's idea was that a patient centric pathways analysis could be the means by which two perspectives could be reconciled:

- The clinicians could seek to understand the optimal clinical outcome for the patient as well as
- The smallest energy and carbon impact.

This concept is illustrated in Figure 78 (Please also refer to Figure 29 on page 147 to view this in greater detail). It is through the development of Operational Policy that the author proposed that the two perspectives be reconciled.

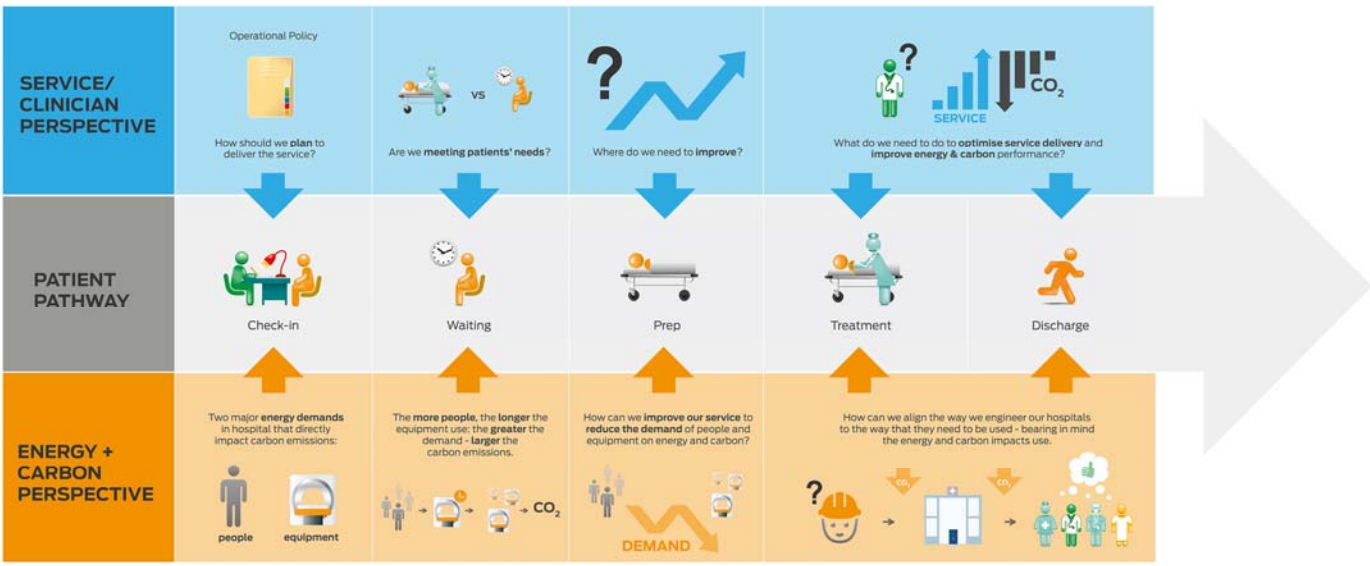


Figure 78 - Conceptual illustration for the analysis of a patient pathway

Through such a model of analysis this could prompt the question: "*For each patient episode within our department, how could we reduce the energy and* *carbon impacts of each*?" The author proposed that it would the aggregation of the energy impacts of each pathway that could then become the foundation for the soft energy budgets of each department. The author then commissioned an experiment carried out at by Professor Augenbroe at Georgia Tech University using the author's Occupancy Analytics model as a foundation for the pathway analysis. Granlund provided the zonal hourly energy profiles to compliment this study.

The author reasoned that this analysis would be possible because as will have been understood from the hourly occupancy analysis Table 11 and the hourly energy consumption analysis Figure 75 it is now possible to correlate patient type, presence and associated energy consumption in time and space.

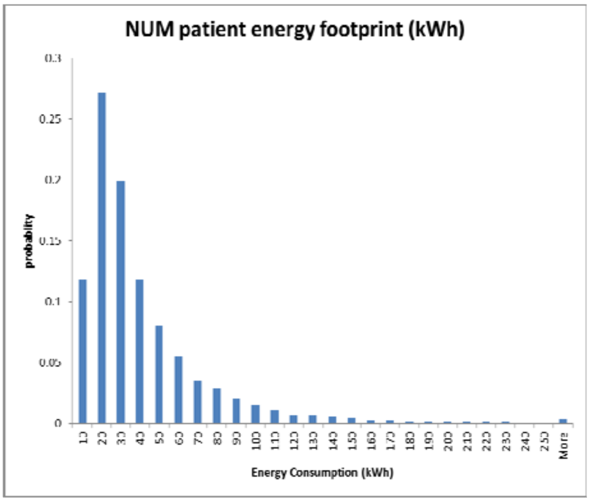


Figure 79 - Nuclear Medicine energy footprint experiment

The results of this analysis are illustrated in Figure 79. From this study it can be calculated that there is a 70% probability that no more than 40kWh of energy would be consumed by a nuclear medicine patient episode. This analysis provides an insight into the opportunities for reducing this quantum through experimentation with Operational Policy and working practices. This is another area of investigation that could further understanding of the energy impacts of In-use.

Yet none of these strategies could be successfully achieved if it were not for an engineering system strategy that would compliment them. Thus it is to ensure that the way in which users plan to use the facility through Operational Policies is coupled with the engineering systems strategy. Conversely it is also fundamental that the users understand the potential of engineering systems to enable them to achieve low energy – low carbon hospital operations. In the context of the design of schools in the UK, this issue was found to have the greatest impact on the divergence between forecast energy use and actual consumption In-use. It is at this point that the engineering designers assessment of this work needs to be reported.

7.7 Evaluation of the Forecast Energy Report by the engineering designers

The engineering designers were requested by the client to consider the impact of the occupancy analytics work on the engineering design. Specifically they were asked: "Had you had this information at the start of the design process, how would it have impacted the design?" In answering this question the engineering team made the following four observations[62] (grey background text is the original content from that briefing):

Observation 1

"The ERMs (Energy Reduction Measures) 'In use' model does indicate a more dynamic analysis of occupation and detailed equipment load analysis for the 'Day 1' building and its operation, which may be useful in consideration of overall system diversity for selective central plant. However, it should be noted that ERM study of occupancy potential provides an alternative data-set for analysing simultaneous demand across the whole 3Ts development."

"These requirements are utilised to identify the occupancy within a department or zone, which in turn determines the 'peak' demand for that respective area. The summation of these peaks with diversities for operational areas and usage is applied for the whole building and its building services systems and plant."

"The simultaneous demand within a local space or department may well realise a peak occupancy and usage in excess of this and thereby require the peak demand and design criteria to be compliant with the appropriate healthcare and industry design guidance documents such as HTM's and HBN's to be satisfied."

"Accepted that ventilation is often related to occupancy, equipment loading and utilisation, however, the models utilise largely fixed ventilation rates in compliance with the HTM's and are therefore in terms of ventilation fan power are determined by the buildings physical volume."

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[62] All of the following quotations in this section have been extracted from a project document produced by the engineers on the project, and are reproduced with the approval of the 3Ts Project Director.

The dynamic analysis of occupancy was observed as a significant difference between conventional practice and Occupancy Analytics, because it demonstrated a significantly wider diversity of use than had been anticipated by the team. The diversity of use could impact significantly on energy consumption if, the engineering systems were designed to adapt to this level of diversity.

These comments also underline the importance of understanding peak demand, and start to explain the potential impact of the peak demand on the design of the engineering systems. This observation also relates to the ventilation strategy in relation to compliance with Health Technical Memoranda (HTM). The extent of clinical spaces that must be serviced according to the HTM requirements accounts for a substantial proportion of them – in the order of 75-80%. This potentially compromising the ability to size systems according to occupancy demand, because the controlling factor would no longer occupancy, but building volume.

Beggs et al. (2008) challenge this argument, which is one that the author advanced on the project. The author's reason:

> *"**One potential weakness of simply quoting required air change rates is that this approach takes no account of patient density—the ventilation rate is determined solely by the room volume, rather than the number of occupants**. In reality, as ward occupancy levels increase, bioaerosol production within the space also increases. Any increase in the number of beds in a ward space will be accompanied by a corresponding increase in the number of nursing staff and visitors, all of whom will liberate microorganisms into the air. Indeed, even a modest increase in the number of patients may result in a substantial increase in bioaerosol production. **Thus, if a ventilation system is required to control the bioaerosol level in a ward space, then it may be desirable to link its specification to ward occupancy levels in some way.***

The author argues that this is a good example of adherence to 'standards'[63] without considering the operational impacts of In-use. The assumptions within the HTM's are often not explicit. In the case of an air-change rate for a single bedroom, what level of occupancy could be supported by six air changes per hour[64]? Without understanding the occupancy profile of a single bedroom, such as how often more

[63] In parentheses because HTM's are not standards but advisory documents.

[64] The standard of ventilation required by HTM 03-01.

than say 3 occupants are in the space (patient, and two visitors, or a patient, nurse and clinician) then how could the ventilation rate be empirically analysed based on need? Surely this would be dependent on the occupant types and their needs for fresh air and comfort conditions. For example, how often would clinical procedures be carried out? Operational Policy should inform this. In doing so, how many occupants would now be in the single bedroom, and what would be the specific needs of these occupants: environmental comfort or clinical safety? Interestingly it is because of this issue that ASHRAE limits the number of occupants to specified rooms (Beggs, Ibid). The authors make the point that in the UK, unlike the US:

> *"…ward ventilation systems are generally specified in terms of providing patient comfort and minimizing energy costs rather than for clinical reasons."*

This suggests that slavish adherence to the HTM (in this case HTM 2025) is counter to the objectives of the HTM in that without understanding occupancy use, how can the objectives of the HTM ever be satisfied? (Grey background text is the original content from that briefing):

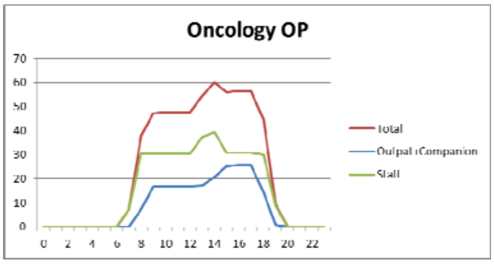
Observation 2

It should be noted that the ERMs growth allowance is only for occupancy. Although occupancy and utilisation is inextricably linked to system capacity and energy consumption it does not typically allow for enhanced or changed models of clinical care and / or equipment, especially when considered over the much longer life span of the 3Ts development.

It is here where the engineers also consider not just the impact of occupancy on the system sizing as it relates to the capital investment of plant to meet current forecast demand, but they are also considering the impact of future changes in clinical care.

Author's reply: Impact of Health Technical Memoranda

The Occupancy Analytics study provided a detailed analysis of the peak occupancy profiles within each zone of the hospital.



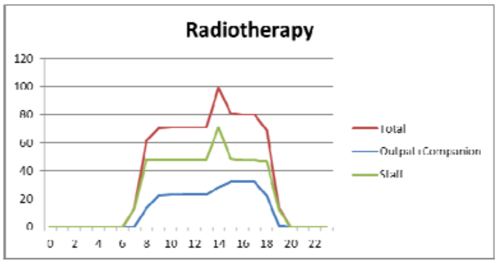


Figure 80 - Occupancy profiles within two zones of the hospital (Plot illustrates the number of occupants at each hour of the day)

Simultaneous demand was identified as a key design requirement by the engineers. The engineers estimated the simultaneous demand through a study of mid-day peak demand from an estimate of diversity assimilated from the Room Data Sheets. They also correlated it to their experience of cooling and heating loads of similar hospitals. Occupancy profiling was not considered in these calculations. The consequences of this method of calculation for plant sizing are that:

3. It does not recognise the diversity of use demonstrated by Occupancy Analytics. This is important because the implication on plant sizing is that despite the diversity of use, the engineering systems are sized according to the maximum potential demand of each space, which is based on building volume – the volume of air to be changed over a one hour period, 365 days per year. Consequently the opportunity to reduce the potential over-sizing of space is substantially reduced because of the need to comply with the technical requirements imposed by the client that require the engineers to deliver an HTM compliant design.
4. It effectively multiplies the occupancy because Room Data Sheets do not recognise that each occupant accounted for can only be present in one space at a time, and not within multiple spaces at any point in time.

As explained earlier in this Case Study the challenge for low energy – low carbon hospital design is made complex because of HTM requirements. With respect to the design of hospital ventilation systems there much conflicting advice and the premise that the use of air-change rates would control airborne spread of infection has been widely questioned. A literature review carried out by the York Health Consortium concluded:[65]

> *"….it is difficult to draw definite conclusions regarding the efficacy of ventilation systems in terms of infection control due to several uncontrollable variables being involved, which may also impact on the infection rate."*

A similar study carried out (Li et al., 2007) concluded:

> *"There is insufficient data to specify and quantify the minimum ventilation requirements in hospitals, schools, offices homes and isolation rooms, in relation to the spread of infectious diseases via the airborne route."*

These findings also resonated with the 3Ts Project Director, because in an initiative carried out by the Trust to substantially reduce hospital acquired infections (HAI), they found that infection rates reduced by the same amount regardless of the age of building and type of ventilation. The facility that had the highest infection rate was one of the Trust's most recent buildings. This suggests factors other than ventilation systems have a greater impact on HAI. Both the York study and the subsequent study by Li at al (Ibid), point to the need for new research in this area. It could also be inferred from the perspective of this Case Study that increasingly onerous ventilation rates (air-changes per hour) lead to little meaningful improvement in HAI, and on the contrary incur a substantial liability in terms of energy consumption and carbon emissions. Elsewhere in Europe there are widely conflicting standards.

[65] See:http://www.birmingham.ac.uk/Documents/college-mds/haps/projects/cfhep/psrp/finalreports/PS041-FinalReport2011.pdf

Standard	Calculation	Fresh air m3/h
CEN	LAF 0,3 m/s x 3 x 3 m	1200
DIN	som CEN	do.
HTM	25 1/h x 160	4000
ASHRAE	4 1/h x 160 og 20 1/h x 160.	640

Figure 81 - Different ventilation standards - a study by SINTEF

In the example in Figure 81 by the Norwegian research organisation called SINTEF they studied different standards for Operating Theatres and found that the UK HTM's were by far the most onerous.

The author asked that Granlund compare the ventilation standards for single bedrooms. They also found the UK HTM requirements were twice as onerous as those in Finland (grey background text is the original content from that briefing):

- *Ward room airflow of 6 air changes per hour seems high when compared to Finnish standards.*
  - *If the room height is 2.7 m it is equivalent of approx 3.75 L/s/mÇ. It is also quite demanding to supply that amount of air and still avoid draft in occupied zone.*
- *In Finland the air flow rate is specified according to number of persons or area as shown in table 1, below.*
  - *If the air flow rate per person, according to new recommendations, is 30 L/s/person and a one person patient room is 12 m^2, the air change rate is then 3.33 air changes an hour.*
  - *If a chilled beam is installed in the room, the air flow rate per area, according to new recommendations, is then 24 L/s per person, for the example above. This corresponds to 2.67 air changes an hour. If the cooling capacity to offset the heat load is 53 W/m^2 the chilled beam capacity is then 436 W (636 W - 200 W).*

Ward room	No of persons	Air flow rate L/s/person	Air flow rate L/s/m²	Note
Small, supply air cooled	1	10	2.5	Finnish building regula-tions D2 2010
Large, supply air cooled	4	10	1.5	Finnish building regula-tions D2 2010
Supply air cooled		30	2.5	Recommendation
Supply air cooled + room unit			2.0	Recommendation. Room unit = chilled beam

The HTM requirement exacerbates the poor energy and carbon performance of UK hospitals. To counter the impact the HTM requirements it would require them to be challenged. The Department of Health in the UK provides a facility for this called ‘derogation’. It requires the applicants to demonstrate why compliance should be derogated and to provide expert opinion explaining the impact of derogation should it be granted. Comparative studies such as these would form part of the evidence to support a case for derogation.

Author’s reply: Making allowance for future flexibility

It was explained earlier that the engineering team argued that as future models of clinical care will inevitably change, then this could impact the demand of the engineering services: The issue of concern here is that the optimisation of occupancy can only be based on a forecast of probability of use, and thus if the fundamental principles of clinical care were to be challenged, then surely this would impact the occupancy profile of the hospital and by extension the design of the engineering systems?

The author’s argument is that in a conventional engineering design process the client is often unaware of the impacts of future changes in clinical practice on the engineering design of the hospital. Furthermore, there should be visibility between the assessment of such changes and the corresponding allowances for changes in future capacity. On the 3Ts project there had been no explicit dialogue in this regard, and the assumption that had been made by the engineering team was that any change would result in the need for further growth of capacity. However, this assumption was proven to be incorrect when the BSUH Trust forecast a reduction in demand of a number of services that the Trust expected to provide. Changes in Department of Health Policy for example in the consolidation of key services such as Pathology or Nuclear Medicine, could mean that such services maybe removed from many acute facilities. Another threat concerns the changes in the way that clinical services are commissioned, for example through the introduction of Approved Quality Providers[66]. These changes will directly impact acute hospitals because clinical services would be transferred from the hospital into the community, thus reducing demand on centralised services and improving patient choice. The impact of the

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66 An example can be found here: http://supply2health.nhs.uk/AQPResourceCentre/Pages/AQPHome.aspx

transfer of services that have historically been provided by acute services is now attracting wider debate.[67]

The author argues that whilst Occupancy Analytics provides the evidence based ‘minimalist capacity perspective’, the traditional engineering approach, suggested by this Case Study would lead to a more expansive perspective, which represents the opposite end of the spectrum of forecast capacity. With a transparent analysis of capacity risk the Trust would be able to make an informed position as the ‘right-sizing’ of the facility based on the new knowledge provided by Occupancy Analytics.

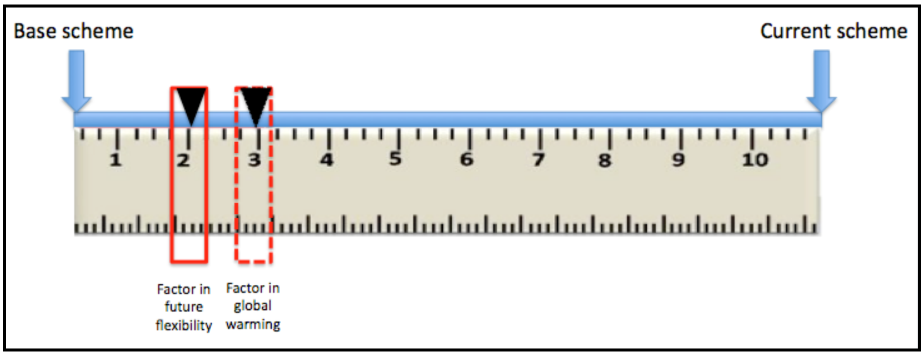

Figure 82 - 'Right-sizing' facilities and engineering systems

The illustration in Figure 82 explains the author’s conceptual thinking concerning these issues. Occupancy Analytics provides the ‘Base scheme’ in terms of the minimal requirements to meet the forecast demand of patients. The conventional engineering approach, which contains allowances for risks factors suggests facility and engineering systems sizing based on conservative risk assessments and ‘worst-case’ scenarios (noted as ‘Current scheme’). The science does not provide sufficient evidence for the ‘worst-case scenario’, which could be influenced through fear of failure rather than an objective assessment of the risk factors that might impact the ‘right-sizing’ of the facilities and engineering systems. Occupancy Analytics provides a scientific basis for analysis of potential risks, of which future flexibility needs, decentralisation, and the potential impact of global warming on weather data files are three out of many possible scenarios.

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67 http://www.theguardian.com/society/2012/dec/18/hospitals-specialising-community-healthcare-future-nhs

7.7.1 - Further experimentation: Alternative ventilation strategy

The Occupancy Analytics studies also challenge the conventional ‘top-down’ process adopted in the engineering design for the 3Ts project. With occupancy profiles for each department as well as an ability to manage the peak occupancy as previously discussed in this Chapter the opportunity exists to design the engineering systems from a ‘bottom-up’ perspective. In doing so, departmental dedicated air handling units could be sized according to the demand of the department (zone) that is being served. It was with this approach that the engineering team carried out a review of the scheme using the occupancy diversity studies to inform what could be a new strategy for the HVAC design. The first consideration was to investigate the potential impact of the substantial diversity of use forecast by the Occupancy Analytics study. In doing so the engineers accepted the author’s argument that zones could be characterised as either a) static, or b) dynamic. The former applied to areas such as Wards where the patient occupancy remains largely static.

The engineers concluded that there was a strong argument to investigate the partial use of a variable air volume (VAV) system in contrast to the constant air volume (CAV) system on which the original engineering strategy had been based. In parallel with this consideration was an engineering review of the sizing of all the air-handing systems in response to diversity forecast by the Occupancy Analytics study.

No	Item	Nominal Capacity	ERM Study Estimated LOWER Bound Capacity	ERM Study Estimated UPPER Bound Capacity	Quantity	Type	Location	Preferred Manufacturer	Proposed model details	Comments	Proportion of Rooms / Spaces with VAV or CAV terminal units
	AHU 1-08 - Nuclear Medicine (Cold)	3.84 m^3/s @ 325Pa			1	Packaged Supply & Extract Unit	Basement Plant room	McQuay	Units to include: inlet and exhaust dampers, bag and panel filters, heating and cooling coils, internal attenuators, supply and extract fans, heat recovery. Unit Configuration Double Deck; Panel type EASDALE 50; Insulation type Foam; Aluminum Profile Anodized; Outer skin material Grey Plastisol; Inner skin material Grey Plastisol;	Good clinical grade unit with F7 filtration & run-around coil heat recovery (c/w pump pack etc). Refer to Trust spec on Asite	N/A
	AHU 1-09 - FM	4.10 m^3/s @ 325Pa	3.70 m^3/s	3.30 m^3/s	1	Packaged Supply & Extract Unit	Basement Plant room	McQuay	Units to include: inlet and exhaust dampers, bag and panel filters, heating and cooling coils, internal attenuators, supply and extract fans, heat recovery. Unit Configuration Double Deck; Panel type EASDALE 50; Insulation type Foam; Aluminum Profile Anodized; Outer skin material Grey Plastisol; Inner skin material Grey Plastisol;	Good commercial grade unit with F7 filtration and thermal wheel heat recovery	75%
	AHU 1-10 - Non-Invasive Cardiology	3.50 m^3/s @ 325Pa	3.15 m^3/s	2.80 m^3/s	1	Packaged Supply & Extract Unit	Basement Plant room	McQuay	Units to include: inlet and exhaust dampers, bag and panel filters, heating and cooling coils, internal attenuators, supply and extract fans, heat recovery. Unit Configuration Double Deck; Panel type EASDALE 50; Insulation type Foam; Aluminum Profile Anodized; Outer skin material Grey Plastisol; Inner skin material Grey Plastisol;	Good commercial grade unit with F7 filtration and thermal wheel heat recovery	75%
	AHU 1-11 - Imaging	4.6 m^3/s @ 325Pa	4.35 m^3/s	3.70 m^3/s	1	Packaged Supply & Extract Unit	Basement Plant room	McQuay	Units to include: inlet and exhaust dampers, bag and panel filters, heating and cooling coils, internal attenuators, supply and extract fans, heat recovery. Unit Configuration Double Deck; Panel type EASDALE 50; Insulation type Foam; Aluminum Profile Anodized; Outer skin material Grey Plastisol; Inner skin material Grey Plastisol;	Good commercial grade unit with F7 filtration and thermal wheel heat recovery	50%
	AHU 1-12 - Imaging	2.55 m^3/s @ 325Pa	2.45 m^3/s	2.05 m^3/s	1	Packaged Supply & Extract Unit	Basement Plant room	McQuay	Units to include: inlet and exhaust dampers, bag and panel filters, heating and cooling coils, internal attenuators, supply and extract fans, heat recovery. Unit Configuration Double Deck; Panel type EASDALE 50; Insulation type Foam; Aluminum Profile Anodized; Outer skin material Grey Plastisol; Inner skin material Grey Plastisol;	Good commercial grade unit with F7 filtration and thermal wheel heat recovery	50%
	AHU 1-13 - Imaging	1.27 m^3/s @ 325Pa	1.20 m^3/s	1.05 m^3/s	1	Packaged Supply & Extract Unit	Basement Plant room	McQuay	Units to include: inlet and exhaust dampers, bag and panel filters, heating and cooling coils, internal attenuators, supply and extract fans, heat recovery. Unit Configuration Double Deck; Panel type EASDALE 50; Insulation type Foam; Aluminum Profile Anodized; Outer skin material Grey Plastisol; Inner skin material Grey Plastisol;	Good commercial grade unit with F7 filtration and thermal wheel heat recovery	50%
	AHU 1-14 - Fracture Clinic	2.64 m^3/s @ 325Pa	2.40 m^3/s	2.15 m^3/s	1	Packaged Supply & Extract Unit	Basement Plant room	McQuay	Units to include: inlet and exhaust dampers, bag and panel filters, heating and cooling coils, internal attenuators, supply and extract fans, heat recovery. Unit Configuration Double Deck; Panel type EASDALE 50; Insulation type Foam; Aluminum Profile Anodized; Outer skin material Grey Plastisol; Inner skin material Grey Plastisol;	Good clinical grade unit with F7 filtration & run-around coil heat recovery (c/w pump pack etc). Refer to Trust spec on Asite	75%

Figure 83 - Engineering analysis of the impact of the Occupancy Analytics study

The engineers also concluded that the combined sizing of the air-handling units (AHU) could be reduced by up to 25% depending on the extent of VAV that would be deployed in the scheme. Figure 83 illustrates an extract from the engineer's report that considers each AHU and the potential impact on sizing as a consequence of the partial implementation of VAV. The assessments were not based on empirical analysis, but on expert judgement, sufficient to provide the Trust with an understanding of the potential benefits of managing the engineering services to key spaces within each zone, such that the high diversity of use could ensure that spaces were not conditioned unnecessarily, which would have been the consequence of the use of a CAV system. The engineers' assessment is set out on the far right hand column of the illustration. It identifies the percentage of spaces within each zone that might conceivably be serviced with VAV.

The engineers also considered the impact of the new Occupancy Analytics data on the other engineering systems:

a) Chiller system (up to 20% capacity reduction)
b) Heating system (up to 22% capacity reduction)
c) Boiler (up to 13% capacity reduction)

Another difference in the modelling of occupancy impacts was that the engineers also excluded the major imaging equipment usage from their assessment (grey background text is the original content from that briefing):

> *Should the detailed equipment usage alter the design criteria input this will affect the energy consumption, particularly in relation to 5 day or 7 day operation. Furthermore if peak cooling loads for equipment are able to be significantly lower, then this may reduce ventilation rates.*

It has already been demonstrated that the engineer's estimation of imaging equipment loads was a factor of five in excess of what was modeled through Occupancy Analytics. However they did not model the plant infrastructure impacts of this. Yet as explained in their comment, this could also impact the sizing of the air handling units. It would certainly be logical that they would, because a) The design allows for dedicated AHU's for the imaging equipment installations, and b) the substantial energy consumption reported by the engineering designers would be expected to result in corresponding heat-gains to the spaces in which the equipment is being operated.

7.7.2 - Summary of the evaluation by the engineering designers

It has been explained earlier, that the design strategy adopted by the engineering designers was largely driven by a 'top-down' approach where having analysed 22 room types, they then applied peak heating and cooling load factors to a thermal model.

In contrast the 'bottom-up' approach of the author was to analyse all zones within the hospital and from this analysis to develop a deep understanding of In-use. Furthermore, the approach was to work with clinicians to reduce the demand on engineering services through experimentation with Operational Policies.

The engineering review did not satisfactorily address the question: how would the design process change, as a consequence of this new data? It prompted a review of AHU sizing for example, but only within the constraints of the basis of design predicated on engineering standards. However, it did not cause a return to engineering design from first principles of design, which is what the author's analysis was seeking to achieve.

The engineering assumptions, and particularly those in relation to allowances for future growth, were not changed either and remained at between 5-15% for future growth. It was also apparent that the Principal Supply Chain Partner, (that could eventually construct the hospital) had also allowed for a 15% contingency for future growth (in addition to the engineering design contingency) in their forecasts. They argued that at the scheme design stage of the hospital, these allowances were typical. In contrast the Occupancy Analytics model was based on the Trusts' forecast of patient growth, and thus provided an empirical basis for future growth. The author argues that assumptions need to be explicit and as such uncertainties at each stage of the design process should be made quantified. Furthermore, where these uncertainties can be modelled the output of the modelling should become an important element of the risk management process. Figure 82 illustrated earlier, conceptually illustrates a means by which these issues could be evaluated. Yet, in the evaluation of these risks the energy and carbon impacts of each needed to be considered. It was the work with the User Reference Group that was discussed earlier where these risks were considered.

The Case Study has also provided a valuable insight into the factors that lead to the sizing air handing equipment. Earlier in this thesis the author alluded to the possibility that an improved understanding of occupancy presence could also lead to an improved understanding of the factors that determine the ‘right sizing’ of the engineering systems. The Case Study has demonstrated that occupancy presence has less of an impact when significant areas of the hospital have to be conditioned according to Health Technical Memoranda (HTM). In these areas the dominant factor is air volume, and not occupancy, because the requirement is to ensure a minimum number of air-changes per hour. It follows that if HTM’s were to be challenged (because, as has been explained, the science that informs them is poor) then it is conceivable that the ‘right-sizing’ arguments could be reconsidered.

From this Case Study we can understand the potential for users to directly influence energy consumption by taking responsibility for consumption, and to do this through development of Operational Policy and changes in working practices. The case study suggests how the users could also directly intervene in control by seriously considering the comfort and working conditions that they require. To do this, the potential need for incentivisation was discussed. This was not developed further because it is beyond the scope of this thesis.

From this Case Study we can now also appreciate how the needs of users can be correlated with the engineering design strategy. It is Operational Policy that determines much about energy consumption, through the management of patient flux, which results in the diversity of use of spaces and of Imaging equipment. Whilst it remains unproven that management of peak loads can result in lower capital costs through smaller plant sizing, the study does suggest the potential for further research in this area.

7.8 The impact of In-use strategies on forecast energy performance and Whole Life Costs

Referring back to the author’s research philosophy and the need for critical realism to correlate mechanisms with events. It is here where the impact of the mechanisms that drive energy performance need to be understood. Figure 84 illustrates the update to the Forecast Energy Report, produced as a consequence of the experiments with the URG and the engineering designers review.

Model info	Building	Baseline, CAV	Baseline +2°C, Scene 1 CAV	Baseline +2°C, Scene 2, CAV	Baseline +2°C, Scene 2 + Small Power 10 -> 2 W/m2, CAV	Baseline, VAV	Baseline +2°C, Scene 1 VAV	Baseline +2°C, Scene 2, VAV	Baseline +2°C, Scene 2 + Small Power 10 -> 2 W/m2, VAV
	Area	1432,2	1432,2	1432,2	1432,2	1432,2	1432,2	1432,2	1432,2
	Volume	6144,5	6144,5	6144,5	6144,5	6144,5	6144,5	6144,5	6144,5
	Height	4	4	4	4	4	4	4	4
	Heated Volume	6144,5	6144,5	6144,5	6144,5	6144,5	6144,5	6144,5	6144,5
	Energy Reduction Measures								
Energy Conf.	Composition	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2
Regulated Energy demand	Domestic hot water	21,4	12,8	4,3	2,6	21,4	12,8	4,3	4,3
	Heating, other	-	-	-	-	-	-	-	-
	Heating, spaces	14,9	49,4	32,3	50,0	3,0	4,9	6,3	17,5
	Heating, AC system	80,9	34,5	25,6	27,0	24,0	18,6	17,7	19,2
	HVAC, cooling energy	95,8	73,9	72,2	56,1	43,7	35,2	33,8	27,9
	HVAC, fans	62,8	55,0	55,0	43,3	24,4	23,5	19,8	17,7
	HVAC, other electr.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Equipment electricity	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Lighting electricity	46,9	46,9	46,9	46,9	46,9	46,9	46,9	46,9
Unregulated Energy demand	Equipment electricity	123,4	123,4	123,4	83,9	123,4	123,4	123,4	83,9
	Lighting electricity	-	-	-	-	-	-	-	-
Whole Building Primary Energy Demand	Lighting electricity	46,9	46,9	46,9	46,9	46,9	46,9	46,9	46,9
	Equipment electricity	123,4	123,4	123,4	83,9	123,4	123,4	123,4	83,9
	HVAC, cooling energy	95,8	73,9	72,2	56,1	43,7	35,2	33,8	27,9
	HVAC, other electr.	62,8	55,0	55,0	43,3	24,4	23,5	19,8	17,7
	Total Heating	117,2	96,7	62,2	79,5	48,4	36,3	28,3	41,0
	Total Electrical energy	271,4	254,8	254,1	196,5	212,1	207,8	203,6	159,7
	Total Building Energy	388,6	351,5	316,3	276,0	260,6	244,1	231,9	200,7
	Total Building Energy (GJ/100m³)	32,6	29,5	26,5	23,2	21,9	20,5	19,5	16,8
Energy consumption	Boiler Gas consumption	57,9	47,8	30,7	39,3	23,9	17,9	14,0	20,3
	CHP Gas consumption	485,5	400,5	257,5	329,4	200,6	150,4	117,2	169,9
	Total Gas consumption	543,4	448,4	288,2	368,7	224,5	168,3	131,2	190,1
	Chillers electricity	7,7	5,9	5,8	4,5	3,5	2,8	2,7	2,2
	CHP electricity generation	165,1	136,2	87,5	112,0	68,2	51,1	39,9	57,8
	Building Electricity needs	240,7	231,2	231,0	178,6	198,2	196,6	192,8	150,7
	Total Electricity consumption	75,7	95,0	143,5	66,6	130,0	145,4	153,0	93,0

Figure 84 - Energy impact results of user intervention in control

The basis for the report illustrated in Figure 84 is on an analysis of the user intervention strategies, and the engineering designers assessment of the ventilation strategy. Granlund were requested to consider the energy impacts from three perspectives:

i. Diversified peak demand as a consequence of Peak load Smoothing.

ii. CAV versus VAV benefits (A system that would be capable of responding to the diversity of use of the outpatient spaces)

iii. The user intervention in controls strategy (as illustrated by the example from the Nuclear Medicine department).

The results of the analysis demonstrated the significant energy reduction benefits assimilated for the whole of the Outpatient spaces. These are set out in Table 13

Measure	**Baseline kWh/m2**	**Experiment kWh/m2**	**Improvement %**	**Comment**
Total Building Energy with VAV versus CAV	388.6	260.6	32	Based on the engineering designer's estimation of the proportion of CAV to VAV in Outpatient spaces.
User intervention in control using 'Scene 2'.	276.0	200.7	27	Based on an analysis of Nuclear Medicine and applied to the whole of the outpatients departments.

Table 13 - Results of experiments in user intervention in control

This analysis was not subjected to further investigation by the engineering designers because of the cessation of the project, but nevertheless the simulation demonstrates the potential. It also suggests (acknowledging the assumptions made in the analysis) the potential target range from within which future analysis could take place:

a) Engineering designers forecast: 52.2 GJ/100m^3

b) Forecast Energy report (Based on CAV and no user intervention): 29.9 GJ/100m^3

c) Forecast based on VAV and aggressive user intervention in control: 16.8 GJ/100m^3

The potentially significant impact that users could have on the energy consumption of the acute hospital is substantial. These results mirror the findings of the study by Steinfeld et al. (Op Cit) where they conclude in their study that: "*there is significant potential for energy efficiency and demand management policies to achieve office building peak load reductions.*". The results also provide the values for the range of performance suggested by the illustration in Figure 82. Once the further analysis has taken place they could then provide the basis for decision making as to the most effective CAPEX/ OPEX strategy for the 3Ts project. It is now appropriate to discuss the potential benefits in terms of the Whole Life Costing for the user intervention strategy.

7.8.1 - The Whole Life Cost Impact of In-use energy reduction strategies

The Trust commissioned consultants to carry out a whole life cost impact study using data provided by the engineering designers (CAV/ VAV analysis), the Principal Supply Chain Partner (CAPEX impacts for a modulated system) and the author's energy impact studies. The results of the analysis are illustrated in Figure 84 and Figure 85.

The top right hand side of the illustration shows the results of the analysis when inflation in energy costs rises at a rate of 15% per annum, which was considered by the team to be a reasonable possibility. At this rate of rise, the payback for the improved modulation to support the user intervention in control is five years. The 30 year discounted saving is forecast to be £14.3m. At 10% inflation the pay back period would now be six years. The 30 year discounted saving is forecast to be £8.8m. The forecast energy reductions were calculated by by independent consultants to lead to a 22% reduction in carbon emissions when compared to the engineering designers scheme, based on a CAV system.

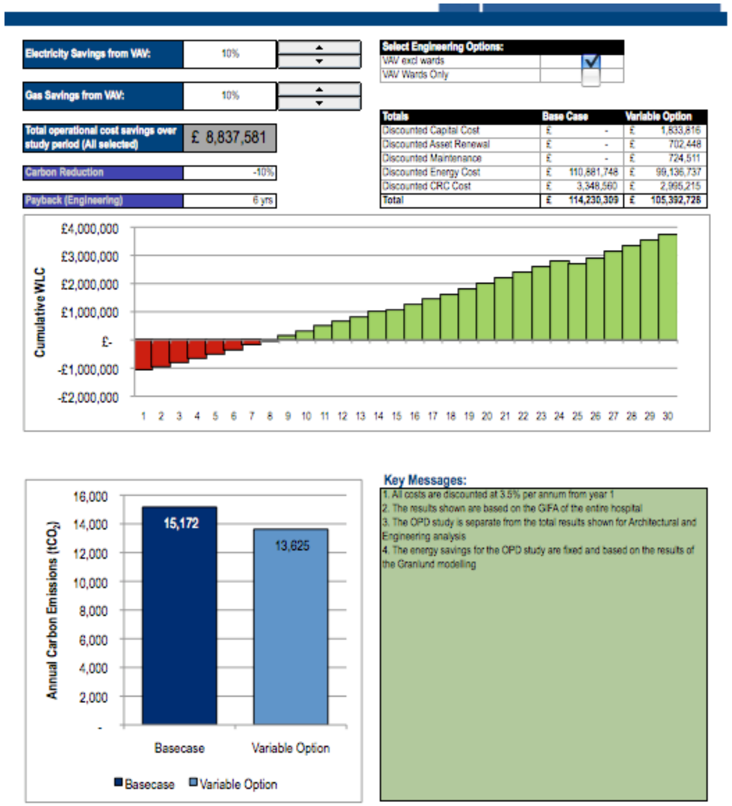

Figure 85 - Whole Life Cost Analysis (15% fuel inflation)

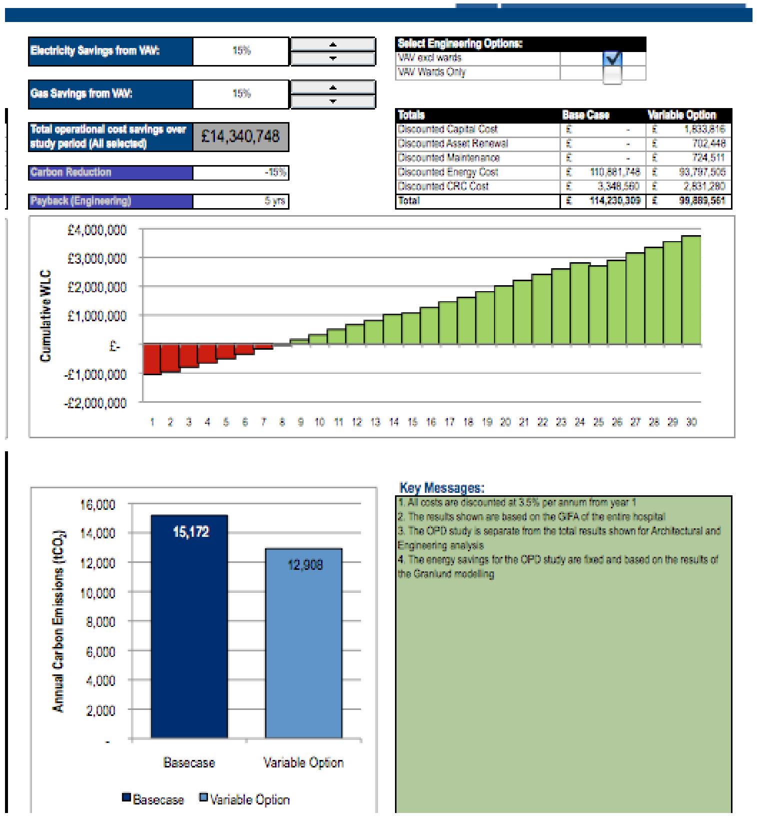

Figure 86 - Whole Life Cost Analysis (10% fuel Inflation)

7.9 Conclusions from Stage 2 of the Case Study

To restate Research Objective 2: To make a new contribution to the In-use energy performance of an acute hospital through organisational redesign.

> *It could enable users to understand the impacts of their organisational processes on energy consumption associated carbon emissions. To achieve this it would require the impact of organisational processes on energy and carbon emissions to be modelled.*

The case study identified how:

- The clinical leadership could make an impact on reducing energy consumption through organisational redesign and how by the use of two methods a) occupancy analytics and b) whole facility energy modelling they can come to understand how to manage these impacts.
- User intervention in control could deliver substantial energy improvements should the control systems be configured to facilitate such an intervention.
- It is possible to work with clinical users to investigate the energy and carbon impacts if In-use, and to go as far as establishing departmental energy budgets.[68]

In these terms the research objectives were achieved in the case study. In terms of the propisition, how does the case demonstrate the validity of this?

> *Yet as it is clinical users that fundamentally impact In-Use energy and carbon performance, they will require knowledge of the energy and carbon impacts of their working practices. With this new knowledge, it follows that if they were to understand these impacts*

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[68] Their willingness to sign-up to an agreement that affirms their commitment to such an approach and thus provided the project leadership with confidence that clinical users would be willing to actively engage in the low energy – low carbon objectives of 3Ts.

they would then have the means to work towards further improvements in that performance though continuous improvement of their working practices.

The case study identified areas of operational policy, such as inter-departmental working and management of patient flux, as well as the potential for user intervention in control, all of which were forecast to result in a reduction in energy consumption. The engineering designers and the life cycle cost consultants assessed the energy and carbon impacts of these measures. Whilst the reported CAPEX benefits were disappointing, but the OPEX benefits showed substantial potential for saving.

However, these reductions would only be possible if the strategy for the engineering design were to be aligned with the way in which users wished to operate the building and manage the environment responsibly. The case study explained the assessment carried out by the engineers focused on investigating the system impacts of this new knowledge. The review by the engineering design team did not fundamentally address how the new data would impact changes to the design process, and this was disappointing, but it remains a possibility for future research. The case study also demonstrated the following:

- The potential for the new knowledge concerning occupancy presence to be used as the basis for a new measurement norm of kWh/per patient. This suggests that for all patient types the energy consumption profile could be modelled. With a patent centric focus the energy consumption could me more relevant for users than norms based on the building area or volume. This will be discussed in the next Chapter.
- The logic of using the norm to create a departmental energy budget: a means by which continuous improvement in energy performance could be facilitated. This is essential if the NHS is to make absolute reduction in carbon emissions brought about by significant reduction in energy consumption. This will also be discussed in the next Chapter.
- The potential for the significant reduction in energy consumption that would be required in UK acute hospitals. A forecast performance of

280kWh/m^2 is equal to the best performing Scandinavian hospitals. With an engineering strategy supporting the diversity of occupancy this has the potential to reduce by consumption to 260kWk/m^2 for the whole hospital and with an aggressive user intervention, where users make some sacrifice to personal comfort (potentially ameliorated through appropriate attire) then 200 kWh/m^2 is potentially possible – although unlikely – because hospitals are characterised by many different people, personal needs, and physiological tolerances.

- The forecast energy reductions were calculated by independent consultants to lead to a 22% reduction in carbon emissions when compared to the engineering designers scheme, based on a CAV system.

In all of these instances there are areas of In-Use that may not be considered by engineering designers in the briefing process, where typical practice appears to rely on formulaic codes and simulation based on many assumptions. The author recognises that assumptions have to be part of all analysis, but understanding which assumptions concerning In-use have the greatest potential impact is what the author has sought to illuminate in this case study. This leads to the next section: The Energy Efficient Brief.

7.9.1- Implications for future research

There have been a few instances in this case study where the author has identified the need for further research. Whilst the case study has answered the research objectives, in answering them further questions come to the fore. For example:

- There appears to be a paucity of research concerning power loads in acute hospitals in terms of how measured data could inform new standards. The work of Dunn and Knight (Op Cit, 2005) provides an insight into this potential. The author's user intervention in control strategy could be developed into further research, particularly in terms of users willingness to actively manage energy consumption.

- There appears to be a paucity of research concerning large power loads from imaging equipment in acute hospitals. The author's work with a Manufacturers Reference Group provides an insight to this potential. However, in order to model this occupancy demand profiles for each service would be required.

- There is a clear need for a measurement framework. The author's work on patient centric performance measures, and departmental energy budgets provide a focus for such needs. Raftery (Op Cit) explains the need in these terms:

  "There is a clear need for a complete, coherent and effective measurement framework so that it is possible to measure real operational performance of buildings."

- Substantial work in lean healthcare and other efficiency initiatives would offer a rich resource for analysis in both occupancy presence impacts as well as the consequences on energy consumption and the associated carbon emissions. This potential needs to be investigated further.

- The author has provided an insight into the potential of a new norm for energy benchmarking based on a patient centric measure. The measure offers the intriguing possibility of measurement of intensity of use. Furthermore because the measure is derived from operational policy it offers the potential for clinicians to understand how to control the energy and carbon impacts of each patient pathway. Further research is required here.

- The study into departmental energy budgets was curtailed by the project being halted awaiting the Department of Health and Treasury approval. The research need is to understand how to develop the budgets constructed from the patient centric measures. Studies into incentivisation and management of user behaviour in managing these budgets could be another are worthy of investigation. Connection to the Applied Behavioural research community may provide a new dimension to the research.

- The author believes that there is a significant issue for the UK in terms of its adherence through the HTM's to ventilation standards based on air change rates rather than being based on volume/rate per person, as is adopted in much of Europe. The initial investigations by the author showed that there is potential to achieve necessary indoor air quality commensurate whilst recognising the need to reduce energy consumption associated with moving large volumes of air in an acute hospital. As Beggs et al (Op Cit, 2008) have commented: there is too little knowledge in this area of research.

Chapter 8.0 - The Energy Efficient Brief

8.1 Introduction

In this Chapter the author discusses how the outputs arising from the two methods described in the case study should be considered as part of a process change within the In-use and project initiation phases of the lifecycle of the acute hospital. In the two stages of the case study the author learned that it would be possible for In-use process improvement initiatives to create HAM data which could be stored in an In-use database. The author's experimentation with the clinician leadership teams within five departments demonstrated this opportunity.

In this Chapter the author envisions that in planning of new projects during the facility life cycle, the data from the HAM would then be translated into the Energy Efficient Brief. It would be informed by the Whole Facility Energy Modelling methodology that would enable energy and carbon targets to be established for the new projects, based on planned developments in operational policies.

In Section 8.2 the author reminds the reader of the third and final research objective and which also leads the investigation into the final part of the proposition. The discussion provides the insight into the above mentioned potential. The author will argue that an In-use process that assimilates acute hospital operational performance data into the HAM of the In-use database would represent significant progress towards the alignment of the In-phase to future projects within the acute hospital. In doing so, the author will argue that the evidence from the case study suggests that improved energy and carbon performance and improved predictability of performance should be possible.

Section 8.3 discusses the need for enhanced brief. It also discusses a challenge for the design of acute hospitals with respect to the establishment of appropriate energy targets.

In Section 8.4 the author proposes how the two methods comprising Occupancy Analytics and Whole Facility Energy Modelling could be used to further develop the latest RIBA Plan of Work 2013. In Section 8.5 the author then presents a proposed scope for the Energy Efficient Brief. This is intended to assimilate the learning acquired through the literature review and the case study. Throughout the earlier chapters the author has identified what he regards as 'Key Issues', all of which impact the Energy Efficient Brief – these are referenced in the proposed scope of the brief.

8.2 Research objective

The final research objective to be considered is Research Objective 3. To remind the reader this was explained as:

> *The research objective is to make a new contribution to the briefing process, called 'The Energy Efficient Brief', such this brief would provide the data required for the engineering teams at an early stage of the project process.*
>
> *It would be achieved through assimilation of the knowledge gained from the literature review, and the case study and assimilating the learning from this work into a template for an In-Use overlay to the RIBA Plan of Work 2013.*

As the research objective is expected to assimilate the learning from previous chapters the investigation must now be focused on how the process methods should be applied to deliver the Energy Efficient Brief. The author will consider the questions as to how the sought after alignment between working practices and desired energy outcomes could be achieved? In answering this question, the proposition is partially answered. The expectation of a substantially improved performance then remains to be discussed.

> *…Through a process of negotiation, engineering design strategies and In-Use working practices could become closely aligned, where such alignment would be documented in the Energy Efficient Brief. The expected result would be improved forecasting and substantially improved In-Use energy performance and carbon emissions.*

8.2 Overview: The need for the Energy Efficient Brief

The concept of the Energy Efficient Brief was discussed in the literature review Section 3.2.6 - Critical analysis of KS8: CIBSE Design Framework, p85 and identified in Section

3.4 Gaps in our knowledge, p131. Described succinctly, the need for the Energy Efficient Brief is to: ‘systematically elicit user requirements that impact low energy low carbon performance of the acute hospital’. The elicitation of user requirements is a well understood objective of the traditional briefing process (Bouchlaghem, 2000). However, the requirements of the energy efficient acute hospital brief transforms a traditional briefing focus typically predicated in answering only the ‘*what*’ of the function and space required to one that needs to answer the question of ‘*how*’ the facility is to be used. According to Dawood et al. (2013) there appears to be a paucity of research into this aspect of the briefing process. The author suggests that understanding the ‘how’ is a feature of the Energy Efficient Brief, the need for which was strongly emphasised in the interviews with the Subject Matter Experts.

This observation poses the question as to how has this need been addressed by other means within the construction industry? Might others have identified this need by other means, and perhaps with a different solution to that need? The closest example of the need is that described by Soft Landings (Way and Bordass, 2005). The needs expressed by the authors are:

1. Greater clarity and better communication during the briefing stage
2. More effective building readiness (for occupation)
3. Better fine tuning to improve the performance of the end product
4. Better feedback to improve future products.

The authors argue that Soft Landings, if used as they intended, should deliver better buildings, which achieve far closer matches between the expectations of the client and the users and the predictions of the design team. Certainly the aspiration of the author that what is delivered in better matched by the expectations of the client and predications of the design team. Whilst the author can find no published data of evidence of actual improvement delivered by this method, if it were to be properly implemented and if meaningful data were to be collected and processed then it would go someway to addressing the substantial lack of In-use data that Subject Matter Expert Bellew noted earlier in he interview: *"we simply do not have it".* It is not relevant in this thesis to investigate why, for at least 10 years Soft Landings has failed to answer his basic question. This is not to discount the potential value of it, but the author argues that it is fundamentally flawed. The author argues that:

1. The stated Soft Landings briefing process does not adequately address the issue of 'appropriate data' for the effective engineering design of the building. The evidence for this is that Soft Landings only collects actual energy consumption data, what is described as 'just a few data sets'. What value is this, when the drivers of energy consumption remain unknown? For example the work of Menezes (Op Cit) demonstrated all to clearly the disconnect between actual energy consumption In-use and the operational occupancy profile of an office building (p114). More recent work analysed this issue in much greater detail, but arrived at the same conclusions that published occupancy profile data for office buildings substantially varies with such detailed analysis (Duarte et al., 2013). Even the most recent version of CIBSE Guide A (2015), fails to address this issue, and still relying on generic guidance. This suggests that if any data has been gleaned from Soft Landings it remains unpublished and not accessible to the wider industry.
2. The Soft Landings process makes a very simple assumption that Post-Occupancy evaluations will inform the subsequent briefing process on new facilities. Yet as the author has demonstrated in this thesis, the briefing process requires fundamental change (certainly in acute hospital design), if it is to adequately engage with users to align engineering requirements with users needs. The author argues that in this thesis that the need is for analytical briefing model of In-use (Occupancy Analytics) to ensure such a correlation. This then leads to an issue of fundamental concern with Soft Landings: If the briefing process is flawed, and engineering system design is inadequately correlated to the In-use occupancy profile of the building, then what can be the value of measuring energy consumption In-use, based on a flawed set of assumptions? What is the value of measuring consumption In-use when

the Soft landings framework makes no mention of establishing the occupancy diversity profile of the building, such as measured by Duarte et al (Ibid)?

3. The author is unable to find any mention of the requirements to achieve a calibrated building against the design intent. The only reference is to 'O&M' manuals. Without a calibrated building how can a post-occupancy study objectively and quantifiably establish the reasons for any divergence between client expectations, engineering designer's intent and the facility performance In-use?

It is in this chapter that these briefing challenges will be discussed, and in particular how greater collaboration between the end users of the acute hospital and the engineering design team can deliver the information required for effective engineering design of low energy –low carbon acute hospital facilities.

Returning to the results of the case study what new knowledge has been gleaned the study and how might that understanding inform the scope of the Energy Efficient Brief? The author's answer to this question is illustrated in Figure 87. It should be evident from this illustration how the Energy Efficient Brief bridges the philosophical divide between In-use and building engineering physics.

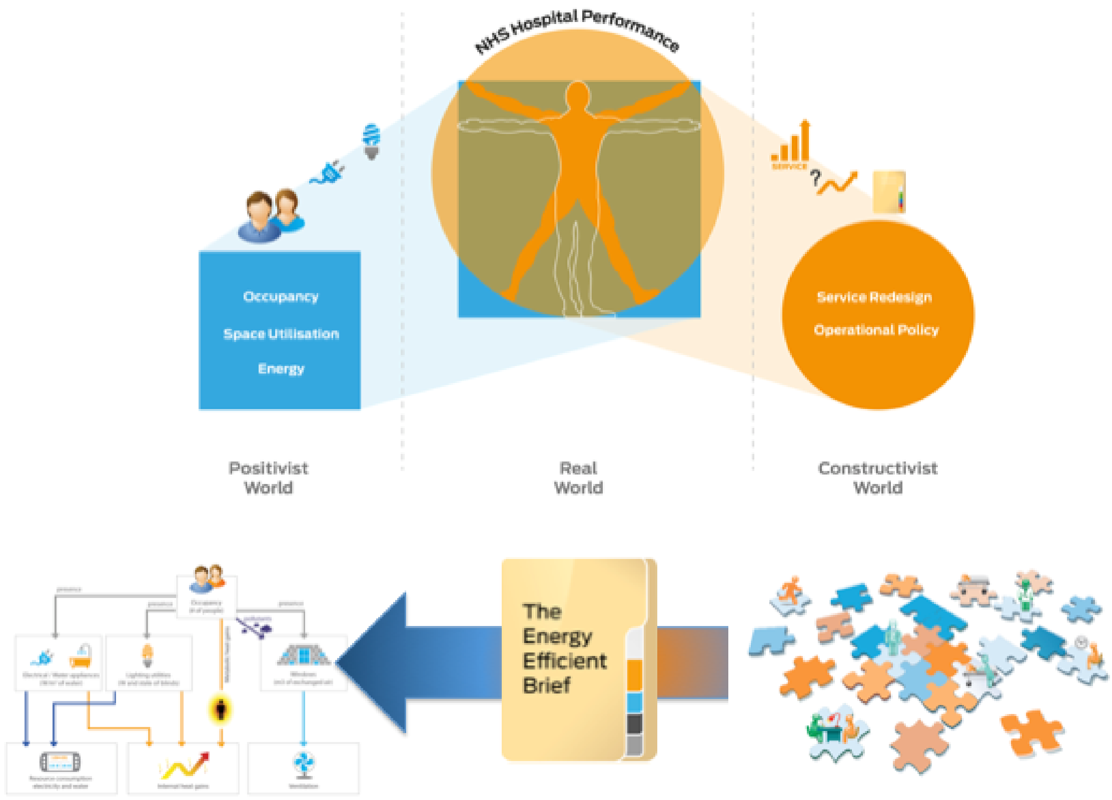

Figure 87 - Uniting Occupancy Analytics and Whole Facility Energy Modelling through the Energy Efficient Brief

Tested strategies using these two methods in Stages 1 &2 of the case study:

1) ‘Joined-up’ operational policies through peak load smoothing.

2) Soft Energy Budgets through user intervention in control and patient centric energy and carbon reporting.

In the illustration above the author is attempting to convey how the collaborative work in improvement initiatives of clinicians and service delivery managers in the acute hospital would be transformed into data for the Energy Efficient Brief using the occupancy analytics methodology. This would then be communicated to the engineering design team for their analysis using building engineering physics. This is described in Research Objective 3 (p144). It is through this example that the reader will now appreciate that it is a process that needs to couple In-use with the briefing of new projects. This will be discussed later in this chapter.

Application of the occupancy analytics methodology during In-use would involve recording the results of operational improvement initiatives in the HAM as described in case study stages 1 &2. By this means the acute hospital would build a record of all components in the HAM for each department. Indeed the HAM would be a key component of an In-Use database, the use of which would provide an empirical basis for future simulation modelling (M. Kishk et al., 2003). The author proposed in Case Study 1 that it would be through the means of the occupancy analytics methodology that diversity tables would be produced from the processing of HAM data. With the HAM data being a part of the scope of the In-Use database the implication would be that for each development project the translation of clinical performance improvement via the HAM into the Energy Efficient Brief could be achieved.

Just as the Occupancy Analytics method could be used to record the results of all process improvement initiatives, so too could the Whole Facility Energy Modelling method be applied to record the energy impacts of each. This would presuppose that there would be metering / sub-metering of services within each department of the acute hospital, because without such metering it would not be possible to achieve this correlation. Results of each study would be processed through the Whole Facility Energy model, and the output would then be calibrated using actual metered data. An In-use database would be deployed to record all of the results associated with each process improvement initiative. Data would be streamed to the In-use database from the BMS. By this method too, the Whole Facility Energy Model could inform the establishment of energy performance targets for each department (or organisational unit accountable for energy performance) as well as targets for new developments, based on an analysis of In-use.

To summarise; it would be through a combination of the two methods that:

- It would be possible for an acute hospital to develop new operational policies with a focus on low energy – low carbon performance.
- The means would be available by which In-use data could be used for empirical validation of simulation models for future developments.

- Informed Target setting would be possible for new developments

How does this potential align to current knowledge? Research identifies numerous perspectives of what should comprise the In-Use database.

- A basis for future energy modelling: (Hitchcock et al., 1998), Raftery et al. (Op Cit, 2009), US Department of Energy: http://eere.buildinggreen.com/
- A basis for understanding building performance: (M. Kishk et al., 2003) (CIBSE, 2006a), (Todd and Fowler, 2010)

Certainly much of what is required to measure building performance is well documented through the aforementioned investigations. However, the author has found no examples of In-use databases designed to manage business/ clinical user performance metrics that would process data such as described by the Health Activity Model. The may explain the comment by Raftery et al. (Op Cit) that our industry lacks *'a complete, coherent and effective measurement framework'*. In other words the need to is join the myriad of In-use perspectives into a coherent whole. The author envisages that such a framework would become an essential resource for the briefing of new facilities. In none of literature that the author has studied has there been any systematic examination of such a framework. Perhaps it is the lack of appreciation of process, but whatever the reason, without it a structured dataset able to be used seamlessly from the In-use phase to the briefing phase on new projects appears to be an important need. The Energy Efficient Brief maybe the method for information/ data transfer, but the measurement framework will ensure that effective data re-use is possible across the 'Great Divide'. The author would expect that an occupancy ontology would be part the foundation of that framework. It is now appropriate to discuss the requirements of the Energy Efficient brief.

8.4 Summary of key contents of the Energy Efficient Brief

In Table 14 that follows is a summary of the information requirements gleaned through the literature review and case study. The reader will also have noticed 'Key Issues' have been identified through each chapter of this thesis. These have also been used to inform the key content of the Energy Efficient Brief.

Whilst not documenting an Energy Efficient Brief, Pless et al. (2011) in identifying the key requirements for an energy performance based contract for a large, low energy building set out what they consider to be the key requirements to be met. By means of validation of the author's analysis, they make the following recommendations:

1. Set EUI goal based on expected space density.

Comment: This is exactly the principle of occupancy presence studies. (EUI – Energy Use Intensity)

2. Demand side goal only.

Comment: This is an element of setting an absolute target. It could be described as setting of targets for the asset specification.

3. Include all expected loads in the building

Comment: This accords with the authors Whole Facility Energy Model specification.

4. Provide typical operational schedules for all plug load profiles.

Comment: This accords with the author's occupancy and small power diversity analysis. However, the occupancy study does not need to resort to 'typical schedules', but provides schedules of probability.

5. Provide typical operational schedules for indoor air quality.

Comment: This accords with the spirit of the author's recommendations. However, such a 'typical operational schedule', would not satisfy the demand of different patients and staff types in an acute hospital.

The remaining requirements relate to the performance contract and less concerned with the energy efficient briefing requirements.

Section	Scope	Guidance
Introduction	▪ Context for the Energy Efficient Brief.	Business drivers for the overall project. How are these drivers expected to influence the energy efficient requirements – is there a correlation?
	▪ Introduction to the low energy – low carbon objectives of the project. Key project drivers.	Aspiration of future energy performance. Do these objectives inform asset specification objectives, and or In-use objectives?

Table 14 - Proposed contents of the Energy Efficient Brief

Section	Scope	Guidance
Operational Policies	▪ Summary of Operational Policies that explain the key principles of how In-use will be aligned low energy – low carbon objectives of the project. ▪ Directory of Operational Policies and the repository location of each.	Individual NHS Foundation Trusts would have developed operational policy templates that establish key objectives for In-use energy consumption aligned to In-use.
In-use energy targets for all organisational units. (For investigation please refer to Section 5.3.3)	▪ For each organisational unit define a target range of energy performance. (Key Issue p82). ▪ Schedule of norms for each patient type. ▪ Measures of equipment energy consumption performance In-use (Key Issue p138).	Reference organisational benchmarks from a national building performance repository. Define assumptions and risks to target. WFEM datasets.
Occupancy presence and Diversity data.	▪ Tables for each organisational unit.	Reference the version of operational policies and HAM data used in the analysis.
Health Activity Model. (For investigation please refer to Section 6.4)	▪ Provide data for HAM. ▪ Directory of HAM data entry forms and repository location of each.	Use standard HAM data entry forms.
In-use service delivery innovation and impacts of organisational redesign.	▪ Studies of patient pathways and innovation in service delivery will identify the required space relationships. (Key Issue p216) ▪ The HAM data model will be updated with the required inter-functional process flows. ▪ Discovered impacts between service design and energy consumption (Key Issues p113 & p178)	New models of delivery of health services will inform the early stage planning.
In-use requirements	▪ Users tolerances for indoor thermal quality. ▪ User intervention in control policies. (Key Issue p 63) ▪ Zone type definitions. Zone operating schedules and space sharing polices.	Specify all zone types and tolerance for each patient type. Specify acceptable performance ranges for all zone types.

Table 14 continued

Section	Scope	Guidance
Key standards that impact low energy-low carbon performance.	▪ Assumptions as to application of standards in setting energy and carbon targets. ▪ Risks to low –energy-low carbon performance. (Key Issue p85).	Risk management plan Consider uncertainty and sensitivity issues

Table 14 continued

Where the author differs from the work of Pless et al, (Ibid) is in the required dialogue with the users, so to help them understand how their working practices can help to drive down consumption. To summarise the key differences between the author's analysis and that of Pless at al. these are:

1. The engagement of users though organisational and service redesign that enables an analysis of use to be optimised with low energy - low carbon performance.
2. The detailed analysis of occupancy presence based in organisational processes and which avoids the need for 'typical schedules'.
3. The detailed analysis of 'plug loads' and diversity of use, which avoids assumptions needing to be made, and where the literature review has demonstrated that large errors can arise.
4. The analysis of energy consumption modelled on occupant (patient) type, leading to the establishment of departmental (zonal) energy targets.

8.3 Proposed modification to the RIBA Plan of Work 2013

The current RIBA Plan of Work 2013[69] has evolved the previous Plan of Work into a framework of activities that respond to contemporary demands of

[69] Please see: www.ribaplanofwork.com

construction projects, embracing sustainable design, new forms of procurement, new forms of production and the increasingly prevalent use of advanced design technologies such as Building Information Modelling. It was also designed to recognise the work carried out on the earlier Plan of Work in 2011, known as the ‘Green Overlay to the RIBA Outline Plan of Work’ (RIBA, 2011a).

The author discussed the development of the Plan of Work with Subject Matter Expert, and lead author of the work Mr Dale Sinclair.[70] From this interview the author learned of the thinking that shaped its development. Fundamentally the intent was to create an adaptable framework that would enable the plan to be tailored for specific projects, quite unlike the earlier Plan of Work, which was largely prescriptive. Furthermore, the Plan of Work was widely regarded as having significant shortcomings with regards to sustainability. It was to address these shortcomings that the ‘Green Overlay’ was produced (Ibid).

In the authors study of the Green Overlay it was found that a clear intent is to develop a sustainability strategy that evolves into a sustainability assessment through the briefing and design development stages (up to Stage C) and then on into Technical Design (Stage E). There is reference to assistance in preparation for commissioning, training, handover and future monitoring of performance (Stage L). The Green Overlay is supported by what is referred to as Supplementary Guidance that explains more detail of the activities.

8.3.1 - How well does the Green Overlay address the communication of In-use requirements?

1. The Green Overlay is a schedule of tasks and sustainability checkpoints at each stage of the project. In terms of empirical data requirements it identifies the need for:

   a. Environmental and performance targets,

   b. Energy efficient services design and design techniques.

   Where the author argues for an explicit process for the management of In-use knowledge into the engineering design process, the Green

[70] Please refer to VOLUME 2: Appendix A1.6, p107

Overlay provides little evidence to further this understanding. In RIBA Stage L, (the earlier Plan of Work), the Green Overlay mentions the need for post-occupancy review lessons – but there is no clear articulation of the type of information and data that would properly inform the process. In this regard the work of Donn et al. (2012) provides one insight, albeit incomplete from the author's perspective of In-use.

2. Data capture from In-use is the foundation for building performance analysis (Bordass, Op Cit, 2004). There is little reference made to the application of standards in the Overlay that are focused on In-use performance, although there is passing reference to guidance. For example, with Green Overlay activities such as the need to establish targets as outlined above, why is there no reference to at least TM22 (Op Cit) for example? How could meaningful targets be established without accurate data to inform them?

3. Engagement with users. The Overlay discusses the need to involve facility management (Stage E) and users in reviewing environmental control systems to ensure that there is a match between expectation and design. This presumes that facility managers understand the In-use operational issues of the organisation that they support. Yet without accurate data how could this be achieved, because studies consistently demonstrate that poor estimation of occupancy can lead to poor thermal quality? Dunn and Cook (Op Cit, 2006), (Gou and Lau, 2013).

The Green Overlay only partially addresses the communication of In-use requirements, but does so from the perspective of the built environmental professional and fails to include sufficient guidance from the perspective of the building user.

8.3.2 - The need for a process perspective to achieve low energy – low carbon acute hospital performance

From the forging, the author argues that the Green Overlay partially answers the need to understand the impact of In-use on the engineering design process. Yet the question remains as when and how to initiate the Energy Efficient Brief into this process? Leach et al. (2012) provide a useful insight into key considerations at each stage of the design process. However, just as is the case for the RIBA Plan of Work 2013, and to a lesser extent the Green Overlay, the work of Leach et al, fails to explain the need for data and information flow from what they refer to '*As Operated Stage'* into the '*Early Design Stage'*.

To explain how this might be achieved the author proposes a new overlay to the RIBA Plan of Work 2013, just as there are 'Sustainability Checkpoints' in the current Plan of Work. Furthermore, the author proposes that there should also be much greater focus on data capture through the process to support the empirical needs of the analysis (some of which is referred to in the Green Overlay). The proposed integration with the RIBA Plan of Work 2013 is illustrated in Figure 88. This could be referred to as the 'Near to Zero Overlay', or the 'Low Energy – Low Carbon Overlay'.

Stages	0	1	2	3	4	5	6	7
Tasks	**Strategic Definition**	**Preparation and Brief**	**Concept Design**	**Developed Design**	**Technical Design**	**Construction**	**Hanover and Close Out**	**In Use**
Current Core Objectives	*Identify Client's Business Case and Strategic Brief and other core project requirements.*	*Project Objectives Project Outcomes Sustainability Aspirations*	*Prepare Concept Design...including proposals for building services systems*	*Prepare Developed Design including coordinated and updated proposals for ..building services system.*	*Prepare Technical Design...to include all building services information...in accordance with the design programme.*			*Undertake In-use services in accordance with Schedule of Services...*
Current Suggested Key Support Tasks	*Review feedback from previous projects*	*Consideration of Common Standards to be used*	*Prepare Sustainability Strategy ...and Operational Strategy...and Risk Assessments*	*Review and update Sustainability Strategy...and Operational Strategy...and Risk Assessments*	*Review and update Sustainability Strategy...and Operational Strategy...and Risk Assessments*	*Review and update Sustainability Strategy...and implement Handover Strategy*	*Carry out activities listed in Handover Strategy*	*Conclude activities listed in Handover Stategy including Posy-Occupancy Evaluation.*
Near to Zero Energy Checkpoints (Low energy - low carbon performance)	Review **Facility/ Estate Strategy** with **Strategic Plan** for the business/ organsation.	Establish Near to Zero **Energy Target Range** for new/ refurbished facility informed by In-use data in the **Energy Efficient Brief.**	Align **Operational Strategy** with Near to Zero **Energy Target Range.**	Narrow Energy Target Range based on design and operational decision making.	Publish all key design criteria that are intrinsic to the forecast **Energy Target Range.**	User Group representatives work with Facility Engineers and Contractor to finalise **Handover Strategy.**	Run training sessions for occupant groups in use and control of the building to achieve Near to Zero Energy performance.	Periodic review of **Facility/ Estate Stategy** aligned to **Strategic Plan** for the business/ organisation.
	Agree key In-Use operational strategy objectives and document in **Strategic Brief.**	Inform project objectives with forecast analysis of In-use. Execute Occupancy Analytics studies.	Align **Concept Design Strategy** with **Operational Strategy** and **Policies** where appropriate. Produce initial business / departmental energy targets.	Ensure **Design Strategy** and **Operational strategy** remain sycronised. Establish **Engineering Controls Strategy.**	Develop **Controls Specification** in conjunction with **Operational Policies** and In-use processs and requirements.		Compliance testing, system commissioning, and callibration. Compare test results with Whole Facility Energy Model.	Maintain and operate the facility to support business strategy and Near to Zero operations (inc Supply Chain). Optimise energy and carbon performance In-Use.
	Consider need to build, refurbish, extend, or relocate.	Carry out risk assessments of **Common Standards** and their potential impact on Near to Zero objectives.	Carry out **Risk Assessments** to energy target range based on uncertainty and sensitivity analysis. Simulate design options where appropriate, using In-use data.	Develop Near to Zero designs including building services strategies designed using fundamental principles. Update risk assessment from Stage 2.	Carry out failure analysis of critical systems to understand impact of failure on Project Outcomes. Develop **Construction / Manufacturing Compliance strategy.**	User Group and Facility Engineers develop integrated In-use and systems maintenance plan. Coordinate with Technical Design stage failure analysis.		Optimise facility performance through Whole Facility Energy Model processing In-use data.
Information Exchanges		Establish project database with all briefing information and In-use data	Maintain project database and Whole Facility Energy Model with all briefing, design and engineering decisions	Maintain project database and Whole Facility Energy Model with all briefing, design and engineering decisions	Maintain project database and Whole Facility Energy Model with all briefing, design and engineering decisions	Maintain project database and Whole Facility Energy Modelwith all procurement and construction impmentations and compliance test data.	Maintain project database and Whole Facility Energy Model with all procurement, construction implementations, compliance test data, and systems commissioning callibration data.	Manage data stream from BMS to In-use database. Maintain database.

Figure 88 - Proposed overlay to the RIBA Plan of Work 2011

8.3.3 - Key features of the proposed overlay

Stage 0: Strategic Definition and Stage 7: In-Use

There is no linkage defined in the Plan between these two stages. Given the body of knowledge that exists concerning the failing to understand (learn from) In-use in the briefing, design, and procurement of new or refurbished facilities, this would seem to be a significant omission. This need is actually recognised in the Green Overlay in Stage B - Design Brief, but without 'appropriate data' such as identified in the literature review this requirement is unlikely to achieve what the author's of the Overlay aspire to.

The author discussed this omission with the author of the RIBA Plan of Work and he agreed that creation of an explicit linkage between the two stages would be desirable.[71]

Stage 7: In-Use

It is here where the processing of In-use data should take place, and was illustrated earlier in Figure 87 and described in the text that followed. In building types other than acute hospitals, The Energy Assessment and Reporting Methodology: TM22 (Op Cit) can be used for the identification of some of the key data sets. However, the author's analysis in this thesis demonstrates a much wider scope of data is required concerning In-use, so that the key data sets have meaning, such discussed by Kishk et al. (Op Cit). CIBSE recognises the importance of this (please refer to p19 of this thesis). The analysis of KS8 (p85 et seq) also identifies other key data required in this regard. The work of Donn et al. (Op Cit, 2013) is also relevant here.

The author's proposal for the analysis of In-use was described earlier in Section 8.2. It would thus provide the core information for the Energy Efficient Brief. It would also be through the analysis of In-use data that the subsequent Stage 0 could have a rich dataset to inform the strategies important to be addressed at this stage.

[71] Unfortunately the author was unable to obtain approval of the author to the transcript of the interview and thus able to use the transcript to expand on the discussion that took place.

Stage 1: Preparation and Brief

It is at this Stage where the Energy Efficient Brief would be created and which would compliment the other briefing documentation. It would be informed by Occupancy Analytics studies where the coupling between In-use requirements and the early stage impacts on engineering design strategy could commence.

At this stage also, a project instance of the Whole Facility Energy Model could also be created; potentially using In-use calibration data for the early stage configuration, to support early analysis of concept options as part of this stage. The methods that could be used in the analysis of In-use briefing and energy and carbon impact analysis would be those set out in Stage 2 of the case study. Uncertainty and Sensitivity analysis as has been identified from the literature review should be considered at this stage. This would also support the risk strategy identified by the current Plan of Work.

The use of the Whole Facility Energy Model as a decision support technology is envisaged for the 'Information Exchange stream' of the Plan of work. As a BIM it would also support the 'information drop points' required of the Plan. However there is a need for such a data resource to be a continuum through the project stages (M. Kagioglou et al., 2000). In this work a legacy archive is proposed and this provides a resource to the project at each stage.

The need to review the impact of standards, particularly advisory standards should be reviewed at this stage – what the Plan refers to as '*Common Standards'*. In the literature review the author explained the impact that advisory standards can have on the objective to achieve low energy – low carbon performance, if not near to zero energy performance. The Whole Facility Modelling method could inform the risk assessment here.

Stage 2: Concept Design

It is at this stage where operational policy development, through service design planning needs to inform the concept design options. The occupancy analytics methodology would enable these service design options to inform space planning and standards. It could also provide the key data for the early stage strategic options for the engineering strategy. By this means a closer coupling could be achieved between

In-use needs and engineering design. This should lead to improved predictability of performance – one of the key themes of this thesis.

The uncertainty and sensitivity analysis should also be continued into this stage in order that the potential impact of briefing, architectural and engineering decisions can be understood. Focus should be give to those early stage decisions, identified from the literature review, known to have the greatest impact on the predictability of out-turn energy performance.

A key issue developed from Stage 1, will be the establishment of a target range of energy and carbon performance. The emphasis on a range in preference to an absolute target is because there are many variables and associated probabilities at this stage of development, (Augenbroe Op Cit, 2011). A target range would be a means by which the customers' expectations of performance could be managed, because it would focus attention on the key issues in the Energy Efficient Brief that would impact that performance.

Stage 3 onwards

The forging provides as an overview of the application of the two methods of Occupancy Analytics and Whole Facility Energy Modelling in the RIBA Plan of Work 2013 up to Stage 2. The results of these studies would be used to inform the Energy Efficient Brief. Figure 88 illustrates how this work could then be progressed into the later stages of the Plan from Stage 3 onwards.

8.3.4 - Target setting

One of the key challenges that was identified by the author earlier in this thesis concerns the means by which targets of building energy performance are established. A key challenge for a project team would be concerned with establishing a reasoned basis for such a target. The author argued of the need to a) establish targets based on intensity of use, and b) to establish targets that lead to substantially improved energy consumption – well beyond that in Encode (Op Cit) for acute hospitals. The Near to Zero Energy in Buildings being advocated by the European Commission as explained earlier is contemporaneous evidence of the need for substantial change in the way that acute hospitals in the UK are engineered and operated. The author proposed in Stage 2 of the case study the creation of patient centric benchmarks.

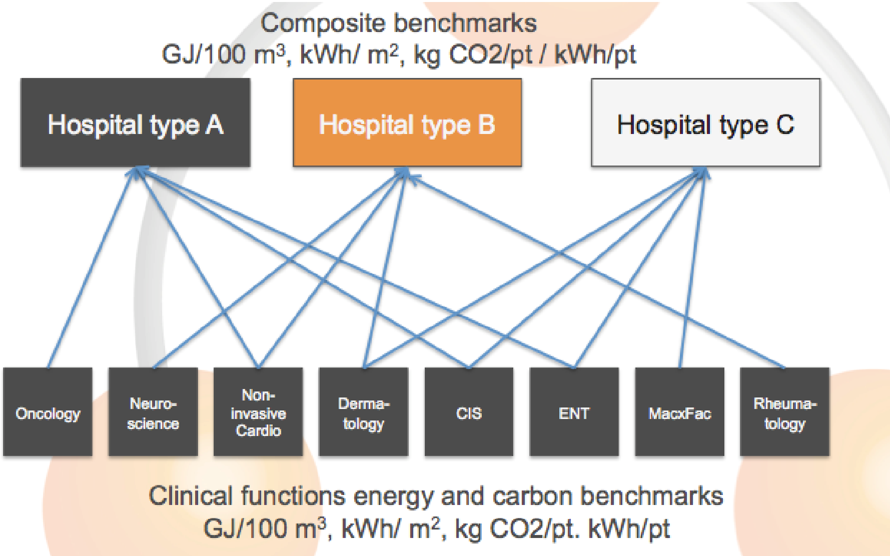

Figure 89 - Measurement of energy performance at organisational unit level would enable comparative benchmarks between different acute hospitals

In Figure 89 the author illustrates the potential of such benchmarks to inform target setting as proposed in both the Green Overlay and the RIBA Plan of Work 2013. Such a proposal would enable the use of a variety of measurement norms in addition to establish appropriate targets (either absolute or a range). In the literature review the author found acute hospital energy targets, such as defined in Encode 07-02 (Op Cit) as having little value, because an acute hospital is not a defined entity, but an amalgam of functions all of which have very different energy needs. Most acute hospitals buildings in the UK are likely to have a different amalgam of functions and thus establishing target performance based on representative benchmarks is very difficult if not impossible. Only relatively recent implementations of sub-metering have enabled energy consumption to be measured at a finer level of detail than has hitherto been possible and thus offers the potential to measure the energy performance of each functional unit. This need is also recognised by Leach et al. (Op Cit, 2012) and in the context of schools they were able to establish zonal targets, where zones requiring similar climate and function were defined. Energy targets were then allocated to each zone. This concept also aligns with the author's strategy implemented on 3Ts (Please see Stage 1, Section 6.6 of the case study, p223).

The author reasons that a patient centric target (kWh/pt) would be more meaningful to clinical users than one based on area or volume. The author suggests that such a focus could enable clinical users to identify where energy consumption could be reduced within each patient pathway. This was discussed in Stage 2 of the case study. Furthermore through the use of departmental energy budgets (or 'Soft Energy Budgets') such as reported in Stage 2 of the case study, the means to create composite benchmarks for acute hospitals comprising different functions would possible. Such a proposal places the emphasis at departmental level, or clinical specialism level, where users could be accountable for control of consumption and which has been correlated to the working practices of the clinical users.

The additional value of a patient centric benchmark of energy performance is that it could also provide the operational policies that impacted the benchmark. The author argues that this meta-information is needed because it would enable clinical users to understand how to manage development in operational policies designed to achieve low – energy – low carbon outcomes in acute hospitals[72]. This could be valuable information for discipline centric strategies designed to both reduce consumption, and achieve high performing clinical outcomes. It follows from this argument that when establish new performance targets that they are informed by the strategies deployed by each clinical specialism (department) and thus the overall acute hospital target is informed by In-use. It is this information that should be documented in the Energy Efficient Brief.

Associated with each departmental target could be further meta-information that explains the context for the hospital, and for example, the engineering standards that were used in the engineering design that impact energy performance (such as ventilation standards), or the operational policies that would provide data concerning the patient types, or equipment types and intensity of utilisation. It would be this meta-information that would then enable directly comparable UK acute hospital performance with acute hospitals in other European countries. At present it is very

[72] It was this need that Bordass referred to in the evaluation of Display Energy certificates discussed earlier in this thesis, where he argued for validated occupancy data.

difficult to both compare and understand the reasons for any apparent differences either between acute hospitals in the UK, or between UK hospitals and acute hospitals in Europe, because there is very little contextual data available.

8.5 Conclusions

In this Chapter the author has sought to establish the means by which the conclusions from the case study could be leveraged in a briefing, design and engineering process. The author has explained how this could be achieved using the RIBA Plan of Work 2013.

The means to assimilate both In-use operational and energy consumption data at organisational (departmental) level of the acute hospital has the potential to transform the management of energy consumption, and facilitate a deeper analysis of In-use.

Through the Green Overlay and the Plan of Work there is a clear need to communicate the requirements of In-use. The author’s proposed overlay to the Plan of Work using the data from the two new methods: occupancy analytics and whole facility energy modelling should be an important means of facilitating the achievement of greater predictability of performance and much improved absolute performance.

The author’s investigations have determined that:

- The Energy Efficient Brief would provide the focus for translation of In-use requirements into ‘appropriate data’, as evidenced by Occupancy Schedules (Stage 1 of the case study). However the functionality of this has not been tested on an engineering design project. The concept remains to be proven.
- Occupancy Analytics and Whole facility Energy Modelling could provide the empirical basis for energy and carbon target setting and composite benchmarks of departmental performance. Operational Polices would provide the contextual information for those targets. The concept for this remains unproven until it can be demonstrated that such targets derived from this analysis can be achieved in practice.

- A low – energy – low carbon overlay to the RIBA Plan of Work could compliment the Green Overlay, which might focus in future on the 'soft' issues of sustainability (sustainable materials specification, local impacts studies and waste management and so forth), whereas the proposed overlay would focus on the 'hard' issues of building performance, the management of data from In-use and the establishment of energy performance metrics informed by In-use. The utility of such an overlay remains unproven, until it has been thoroughly tested in application on projects.

The investigation in this Chapter explains the mechanisms by which the alignment anticipated in the proposition could be achieved.

> *…Through a process of negotiation, engineering design strategies and In-Use working practices could become closely aligned, where such alignment would be documented in the Energy Efficient Brief. The expected result would be improved forecasting and substantially improved In-Use energy performance and carbon emissions.*

The emphasis on 'could' in the last two conclusions is because these are unproven, but the product of logical reasoning from the author's investigations. Whether the methods would deliver the expected substantial improvements sought in the proposition remains unclear and points to the need for further research.

8.5.1 - Implications for future research

- Through the analysis of In-use the author has recognised the potential of clinical process improvement strategies to provide the data required for the HAM. Stage 1 of the case study, presented experiments in process improvement measures that would then impact occupancy flux and in so doing impact space utilisation and the associated energy consumption. This was demonstrated to provide essential diversity data for the engineering design of efficient systems to provide the required indoor air and thermal quality. However, further research could identify other significant opportunities to reduce energy consumption and still improve the quality of service delivery. The research would require the identification of occupancy data such as that identified for the HAM and then to investigate how this data would impact the requirements documented in the Energy Efficient Brief.

- The use of the Whole Facility Energy Model in the support of In-use energy management alongside the Building Management System. The prescient vision of Selkowitz et al. (1998) was an early statement of intent in this regard. The research need would be to document a framework and the full dataset as envisioned by Raftery (Op Cit) and Kishk et al. (Op Cit).
- The investigation into the engineering process impacts of Occupancy Analytics and Whole Facility Energy Modelling warrants further research. The author's proposed overlay of the RIBA Plan of Work 2013 illustrates the potential to integrate low energy – low carbon In-use operations into the Plan of Work through an enhanced understanding of In-use (Stage 7). The need is to analyse the full dataset envisioned above, and develop guidance as to the integration needs with respect to the engineering design process.

Chapter 9.0 - Summary and Conclusions

9.1 Overall summary

The author commenced this thesis with the observation that over nearly three decades acute hospital energy and carbon performance in the UK has not improved in overall terms. Furthermore the predictive potential energy and carbon performance at the design stage has been unreliable; in fact so unreliable that In-use performance can rarely be correlated with it.

The context for this apparently poor performance is the UK Governments obligations under the Climate Change Act 2008 (Op Cit), the objective of which is to reduce carbon emissions by 80% by 2050. A more recent commitment by the European Commission is to achieve Near to Zero Energy Buildings (NZEB's) for the public sector by 2018. Whilst the standard is still being consulted on with Member States, the stated objective clearly requires that a major shift in building performance is required.

Evidence was produced to demonstrate that it is the performance of buildings In-use that is largely responsible for the poor overall performance. In other words, all asset improvements have largely been nullified through occupant In-use practices and behaviour. Yet this finding alone could not explain the poor predictability of design team forecasts. The author speculated that perhaps the reasons for poor absolute performance and the poor forecasting of performance are directly related. It was these two observations that led to the initial research questions.

To investigate the reasons for this situation the author posed two research questions and sought to understand if there is a failure in building engineering science or if the failure is caused through the inadequate application of the science. The conclusions from the literature review led to a detailed examination of the gaps in our knowledge. In considering the precise point of departure for the author's work, the author produced a proposition, which envisioned how low energy – low carbon acute hospitals could be engineered through deep understanding of In-use. It was from the proposition and detailed analysis of the point of departure, that the author defined three research objectives. With these three objectives as a focus, the author considered the research methodology to be used; one that would lead to the substantiation or rejection of the proposition.

In the consideration of the original research questions and the subsequent research objectives the author explained his philosophical position. Using the powerful icon of Vitruvian Man the author explained his belief that the ‘great divide’ between positivist ontology and constructivist epistemology could be reconciled in critical realism. This divide is a feature of current acute hospital design, where there engineering designers typically have a poor understanding of In-use, and conversely, clinical users in the acute hospital have a poor understanding of the impacts of their working practices on building engineering physics. The author’s research investigated the possibility of reconciling these two perspectives by means of the ‘Energy Efficient Brief’. The author’s philosophical position founded in positivist ontology sought an explanation of how In-use requirements could be translated into what practitioners of building engineering science refer to as ‘appropriate values’. He argued that the revelatory case study of both In-use operations of the acute hospital and the energy and associated carbon impacts of In-use would enable the proposition to be investigated.

The case study investigated two novel methods proposed by the author: Occupancy Analytics and Whole Facility Energy Modelling. Whilst the literature clearly demonstrates that the subject focus of both methods is not new, it is the methods themselves that are the author’s contribution to new knowledge. Later in this Chapter the author will discuss this contribution in more detail.

In the penultimate chapter the author investigated the concept of the Energy Efficient Brief, which as a concept is not new either. However, the literature review identified that it has been inadequately defined and even most recent studies of In-use fail to acknowledge the need to translate the needs of In-use into the critical information required for effective and efficient engineering design to achieve low energy – low carbon acute hospital performance.

9.2 Summary and discussion of the research

9.2.1 - Summary of conclusions from the research

From the literature review (p134) the author discovered the following gaps in our knowledge:

1. The critical datasets required to inform building engineering physics such that forecasts if In-Use energy can be considered to be reliable.

   Specifically a gap in our knowledge concerns the potentially critical importance that building occupancy datasets have on building engineering physics and in particular the impact of building occupancy on accurate energy performance and the forecast analysis of In-use.

2. What data could potentially be available from In-use that would provide 'the appropriate values' required for the mathematical models on which building engineering physics is based.

   Specifically a gap in our knowledge concerns the lack of knowledge of what data could be available from In-Use such that it could be used to inform engineering briefs and model design and to validate forecasts of energy use.

3. What is required to inform the 'Energy Efficient Brief', such that the requirements arising from 2.0 above can be effectively communicated into 1.0 above.

   Specifically a gap in our knowledge concerns lack of knowledge as to the content of an informed Energy Efficient Brief and specifically the means by which In-Use requirements need to be analysed to inform that brief.

The author carried out a detailed examination of the precise point of departure, through an analysis of all key texts (p137). The author sought the opinion of Subject Matter Experts in the verification of his analysis of gaps in our knowledge. These were confirmed.

It was from this analysis that the author then developed a proposition and it was from this proposition he developed three research objectives. These research objectives were shaped by the author's philosophical position.

The proposition, restated below was an attempt by the author to reconcile these gaps in our knowledge through a new form of dialogue between the engineering design team and the clinical users of the hospital.

> *As the effective implementation of building engineering physics is compromised by a lack of 'appropriate In-use data', it follows that making good this deficiency should ultimately enable improved forecast In-use energy and carbon performance. Yet as it is clinical users that fundamentally impact In-Use energy and carbon performance, they will require knowledge of the energy and carbon impacts of their working practices. With this new knowledge, it follows that if they were to understand these impacts they would then have the means to work towards further improvements in that performance though continuous improvement of their working practices. Through a process of negotiation, engineering design strategies and In-Use working practices could become closely aligned, where such alignment would be documented in the Energy Efficient Brief. The expected result would be improved forecasting and substantially improved In-Use energy performance and carbon emissions.*

The author then assimilated three research objectives from this proposition and these were then used to consider the most appropriate research methodology. Whilst the author has a strong belief in positivist ontology, he was also aware of the need to use a methodology that would cross the 'divide' between this philosophy and the socially constructed epistemology of In-use. A mixed method in the form of revelatory, and longitudinal case study was selected because in the research objectives (p166) there was a clear need to understand 'how' engineering design and the needs of In-use can be reconciled in an engineering design process. In designing the case study, the author was aware that he had access to substantial data from his work on leading the low energy –low carbon strategy for a major new hospital project in the UK.

9.2.2 – Occupancy Analytics: Summary of main conclusions and unique contribution

Summary: In considering the proposition, the research objectives, and the current body of knowledge the author developed two methods, one of which he refers to as Occupancy Analytics, which is a unique invention of the author. The objective of this method is to have a framework within which occupancy presence and occupancy demand on energy consumption can be analysed. These objectives are not new – researchers have sough to understand these questions for some years. Yet current models of analysis are imperfect and research as recent as last year (2013) continues to seek such an understanding.

The following summarises the conclusions from Stage 1 of the case study in Chapter 6:

- Occupancy Analytics establishes the means to forecast the probability of occupancy presence in any zone at any time of the day in an acute hospital. It was possible to assimilate clinical information system data into a Health Activity Model database. This data could be readily used in discrete event simulation to model occupancy presence. The development of Occupancy Analytics has conclusively achieved Research Objective 1. **[Claim for unique contribution]**
- The Case Study clearly demonstrated how it is possible to achieve a dialogue with the clinicians such that they were prepared to discuss changes to Operational Policy that would lead to improved space utilisation – an unanticipated benefit of Occupancy Analytics. The dialogue also demonstrated how it is possible to achieve clinical objectives, and yet also achieve low energy – low carbon objectives too. The author discovered that operational policies were the means by which In-use could be analysed through simulation. This enables a deep understanding of occupancy presence, which hitherto has not been possible in acute hospitals. This understanding led to the use of organisational and service redesign strategies where it was found that these could offer significant potential to achieve low energy – low carbon

design acute hospital performance. **[This informs the claim for unique contribution – see next section 9.2.3]**.

- Without comprehensive occupancy presence data, engineering designers are obliged to make substantial assumptions concerning how the facility use would impact the engineering design, and ultimately how the facility could be optimised for use. The results of the study demonstrated an occupancy load at least 30% less than that estimated from conventional practice. This result reflects the findings of research carried out in UK schools, where the where the variance between design occupancy and surveyed In-use occupancy was between 31-57%. The mean variance being 37% of forecast (C. Demanuele et al., 2010).

Discussion: The author argues that the study of Occupancy Analytics informed by the analysis of acute hospital operational policies is a significant innovation because it avoids the need for theoretical models of In-use that research investigators have commonly been obliged to develop, and which are often considered as approximations of reality.

Where other investigators have resorted to surveys to develop current state models, the author has been able to use clinical information system data to analyse the occupancy impacts of In-use practices. The author discovered that it was also possible to use forecast patient demand supplied by the Trust to forecast the probability of future state of occupancy presence within each department.

It was in the literature review of organisational and service redesign that the author discovered a significant body of knowledge that could conceivably be used as a basis for further studies in occupancy analytics. It occurred to the author that if these studies were able to generate occupancy data such as that required by the HAM, then it would be possible to process this within the Whole Facility Energy Model too. So far as the author is able to determine there is no precedent for this work.

It was with this understanding that the author developed the method of peak load smoothing, which is the outcome of studies into organisational and service redesign. The author reasoned (as set out in the proposition) that if clinical users understood the impact of their operational policies and working practices they might be disposed to change them and yet still achieve desired clinical outcomes. The evidence from the author's investigations proved that this would be possible, and furthermore the clinical leadership teams in four departments signed an agreement to do so. The work with the clinical users will be discussed further in connection with Whole Facility Energy Modelling.

Implications: This new knowledge means that rather than engineering design simply reacting to knowledge of In-use, there exists the possibility to collaborate between clinical users with deep knowledge of In-use and engineering designers with deep knowledge of engineering strategy. However, for such a collaboration to be effective, the energy and carbon impacts of operational policies and working practices needs to be understood, and translated into the Energy Efficient Brief. This was identified as one of the gaps in our knowledge. Thus the case study proved that it is possible to translate knowledge of In-use into appropriate data for use by engineering designers, such that they need no longer make the substantial assumptions of In-use that have a substantial impact on energy performance In-use and the reliability of forecasts of energy consumption. This has a potentially significant implication for the design and engineering process, a matter that will be returned to later in this Chapter.

Limitations: Whilst the work of occupancy analytics was designed to model occupancy presence, and indeed to provide a statistically modelled correlation with the 'real world' occupancy presence, the simulation cannot be considered absolute. It can only predict within a range of probabilities. As with any simulation it can only be as good as the quality of the input data, the model logic and the limitations of the software. The analysis of the data with the Oncology department (Stage 1 of the case study) illustrates this point.

Neither does the analysis set out to suggest that at a certain hour of the day, there will be specific occupancy density within a specific room. The author did not set out to achieve this, because common sense would suggest that there could be a myriad of variables that would be unknown to the simulation team, on any day, let alone at any hour of the day. Yet the need is to understand the probability of diversity of use of space, and thus by restricting the analysis to sub-zone level, the author could reasonably create an analysis of the probability of distribution in the like spaces that comprise each sub-zone.

Unique contribution: All of the Occupancy Analytics work in this thesis is the work of the author, with the exception of the work carried out by Professor Augenbroe and his team as identified below:

1. The implementation of the technical implementations of the author's specifications. The author's role was specify, direct and then lead the validation of the work to achieve the design objectives of the study.
2. Design the Health Activity Model database. The author's role was as a collaborator in this work. Professor Augenbroe led the design and original instantiation of this model. The work was also informed by the work of the data analyst at Brighton & Sussex University Hospitals NHS Trust, and a consultant database developer.
3. Develop and maintain a library of departmental simulation models.
4. Operate and directly configure the Discreet Event Simulation software.

The relationship between the author's unique contribution and that of Professor Augenbroe and his team is illustrated in Figure 90. The output of the simulation as raw data files, and the subsequent post-processing of those files was carried out by Professor Augenbroe and his team. All the areas coloured orange are the author's unique contribution.

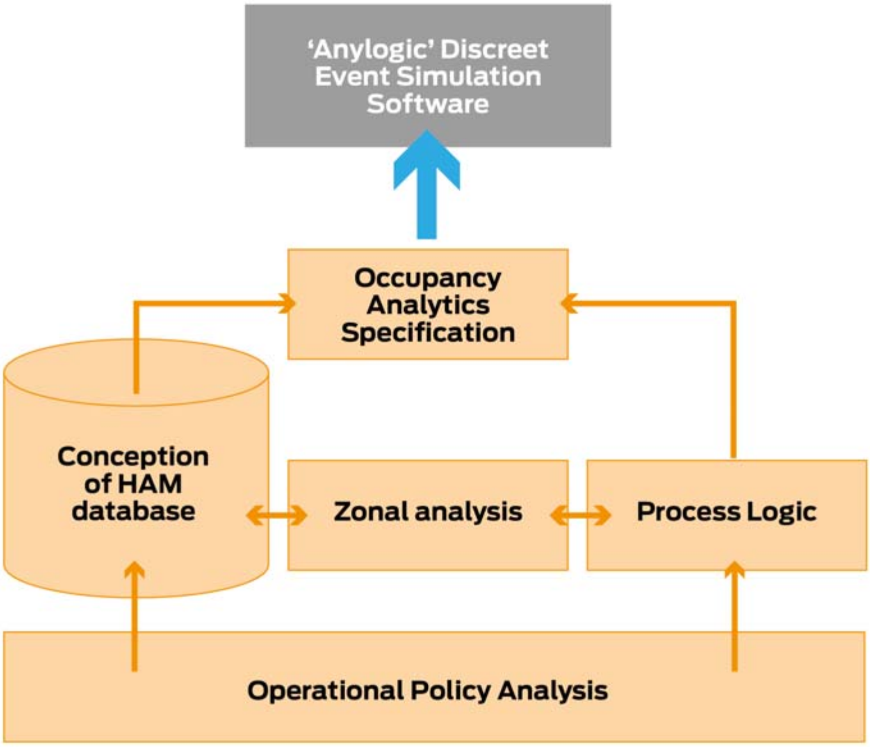

Figure 90 - The distinction between the author's unique contribution and that of the work of Professor Augenbroe

9.2.3 – Whole Facility Energy Modelling: Summary of main conclusions and unique contribution

Summary: In considering the proposition, the research objectives, and the current body of knowledge the second of the two methods developed by the author is one that he refers to as 'Whole Facility Energy Modelling'. Unlike the author's invention of Occupancy Analytics the concept of Whole Facility Energy Modelling is not new. It is to achieve what the name implies: a whole building perspective of energy consumption. The departure from current research is in the development of the content of the Whole facility Energy Model. The unique contribution that the author argues that he has made concerns the method that the author has developed which uses occupancy analytics data as the basis of an analysis of energy consumption and associated carbon emissions. The author argues (and this will be discussed later in this section) that whilst all of the components of whole facility energy modelling probably exist (unlike that for occupancy analytics) it is the means by which they have been brought together in the authors Whole Facility Energy Model that is the author's invention and unique contribution. For example, even the most recent investigations into Whole Facility Energy Modelling still approximate In-use schedules, operational intent and energy consumption demands of users. The following summarises the conclusions from Stage 2 of the case study in Chapter 7:

- That it is possible to forecast the energy and carbon impacts of In-use, through the processing of validated occupancy presence schedules into the Whole Facility Energy Model and to produce energy consumption forecasts based on occupancy presence in each zone type, for every hour of a 24 hour period. In this regard the first part of the proposition is proven.
- With this knowledge, it follows that the clinical leadership of a department could make a substantial impact on reducing energy consumption through organisational and service redesign. The author demonstrated that this is possible, by using the organisational redesign studies (from Occupancy Analytics) to study the energy and carbon impacts/ benefits of such redesign. The development of this method has conclusively achieved Research Objective 2. [**Claim for unique contribution]**
- User intervention in control could deliver substantial energy improvements should the control systems be configured to facilitate such an intervention. The author demonstrated that it is possible to study the impact of different controls profiles in the Whole Facility Energy Model.
- The potential for the new knowledge of forecasting the probability of occupancy presence to be used as the basis for a new measurement norm of kWh/per patient type/ per patient episode. With a patent centric focus the energy consumption could be more relevant for users than norms based on the building area or volume. The author demonstrated how the probability of this could be forecast the probability of consumption for one patient type. **[Claim for unique contribution].** The further contribution of the author to utilise the patient centric norm to create a departmental energy budget: a means by which continuous improvement

in energy performance could be facilitated during In-use. The author argues that this is essential if the NHS is to make sustained and absolute reduction in carbon emissions brought about by significant reduction in energy consumption.

- The potential for understanding where and how significant reductions in energy consumption UK acute hospitals could be achieved using these two methods. A forecast performance for the 3Ts project of 280kWh/m^2 approximates to the best performing Scandinavian hospitals. With an engineering strategy supporting the diversity of occupancy this has the potential to reduce by consumption to 260kWk/m^2 for the whole hospital. With an aggressive user intervention, where users make some sacrifice to thermal comfort then 200 kWh/m^2 is potentially possible, although perhaps unlikely, because hospital occupant types are diverse. The forecast energy reductions were calculated by independent consultants to lead to a 22% reduction in carbon emissions when compared to the engineering designers scheme, based on a CAV system.
- An analysis of small power loads in support accommodation validates the findings of Dunn and Cook (Op Cit, 2005) that current standards could be reduced by at least 50%, therefore impacting efficient engineering design.

Discussion: In recent years there have been a number of concerted attempts to model whole building energy performance. The most recent studies are: (Leach et al., 2012) and an earlier one, (Brown et al., 2010). In the latter investigation the author's discuss the major assumption that are typically made in such models: a) '*Operating assumptions*' and b) '*Equipment not customized to the buildings*'. The author's also emphasise the great difficulty in being able to model the '*intended for as-operated conditions*'. In the same way that Brown et al. emphasise the difficulty of modelling such operating conditions without the available data, so do Leach et al. Further evidence of this need was cited by Menezes et al. (2011)

> "*With Building Regulations relying heavily on predictive indicators of performance**, it is vital that we understand the limitations of the current compliance modelling and aim to***

predict realistic energy consumption levels by using detailed DSM73s that account for realistic occupancy and management behaviours."

This is the unique contribution of the author: to provide that operational data in a form that can be processed into a dynamic simulation model such that there is a direct correlation between the working practices of the clinical user and the energy and carbon impacts of that use – what Menezes refers to as '*realistic occupancy and management behaviours*'. The author achieved this through the analysis of operational policies, and the granularity of the CIS data using the Occupancy Analytics methodology.

The two key elements in both methods have been to model occupancy and energy consumption at each hour of the day using a zone type specification. The author specified a simulation model method that would forecast the probability of energy consumption for each patient type based on each physical patient pathway though the acute hospital. This is another unique contribution. This method contrasts with the sometimes used, simplistic assessment of energy consumption per patient, by dividing the annual energy consumption by the recorded patient throughput. Such a method fails to inform the clinical user how they might change '*consumption practices*', which the EEA (Op Cit, 2012) find embedded in many organisations. This is because a norm based on such a generalisation would obscure the impacts that different patient types have on energy consumption and thus provide no proper empirical basis on which to seek improvement in consumption centred on each patient type.

This work leads to the logical creation of departmental energy budgets, such as was discussed by Leach et al. (Op Cit). However, unlike their work that had no operational rationale (as asserted by Brown et al. cited above), the author investigated how such budgets could be created from an understanding of consumption practices focused on each patient type, patient episode and patient pathway. The author reasoned that such budgets could be an important means by which clinical users understand the energy and carbon impacts of their working practices.

[73] Dynamic Simulation Models

It was with this knowledge that the author sought to understand how organisational redesign through peak load smoothing could impact forecast energy consumption. The clinicians were very supportive of this work because it also addressed well understood inter-departmental conflicts, through a lack of ‘joined-up’ operational policies. This is the ‘win-win’ that the explained in Stage 2 of the case study.

The analysis carried out in the case study clearly demonstrated the limitations of current practice in being able to accurately forecast energy performance. The work of Menezes (Op Cit, 2011) is just one of a number of studies that highlight why these simulations fail. The author’s investigations have sought to rectify this, and as such he argues that the proposed methods are his contribution to new knowledge.

Implications: The author cited the work of Raftery earlier in this thesis:

> *“There is a clear need for a complete, coherent and effective measurement framework so that it is possible to measure real operational performance of buildings.”*

The author accepts that his contribution is one component to be accommodated in a measurement framework, and thus the need remains for such a framework to be developed and tested.

The literature review identified a number of potential applications of the Whole Facility Energy Model, ranging from early stage target setting through to optimisation of the building In-use. The author’s analysis was predicated on the Whole Facility Model supporting the analysis of the acute hospital In-use, such as the Peak Load Smoothing study, but then utilising that data to inform the RIBA Stage C/D forecast energy targets. Others have also suggested how the model should shadow the whole process through to In-use. This was the original proposal of the author for the 3Ts project in 2010. This concept supports the original theory proposed by Kagioglou et al. (Op Cit) where a legacy database was conceived. So far as the author is aware this remains to be realised in practice.

Limitations: The limitations of this investigation are predicated on assumptions made in the analysis. The most significant assumptions made in the Whole Facility Energy Model were:

a. The mean probability of occupancy presence was chosen. The RIUSKA software was unable to process multiple occupancy profiles reflecting the upper and low percentiles of occupancy presence.

b. The imaging equipment energy consumption profiles were generalised from manufacturers equipment and records of metered energy use for specific types of imaging equipment.

c. The algorithms used in RIUSKA were not evaluated against fundamental principles, and consequently the assumptions made in the software were not evaluated either.

d. Whilst the author created scenarios (use cases) of energy use of the clinicians and managerial occupants, there was no scientific evaluation of these, and it could be considered that there were flaws in the method used. The author defends this, by arguing that the methods chosen was to provide an example of what could be possible to be achieved.

Unique contribution: All of the Whole Facility Energy Modelling in this thesis was carried out by the author with the exception of the work identified below which was carried out by Granlund OY who were under contract to the authors business:

- Configuration of the proprietary software (RIUSKA) for the analysis and dynamic simulation.
- Data entry and the operation of the simulation. However the author specified how occupancy and associated data was to be used in the model.
- Production of the energy forecast reports, which the author specified. However the author led the production and development, but the content was created by Granlund OY.
- The energy analysis of patient pathways. The author conceived the concept and developed the specification for this work. It was implemented through an investigation coordinated by the author, but implemented by Granlund OY and Professor Godfried Augenbroe.

As with the Occupancy Analytics investigation the author created the specifications and guided the team as to his specific requirements, which they responded to.

9.2.4 – The Energy Efficient Brief: Summary of main conclusions and unique contribution

Summary: The concept of the Energy Efficient Brief is not new. The need for it is documented in CIBSE Guide F. Whilst the need was identified some years ago, the author's research indicates that the concept appears never to have been developed. Indeed it is very difficult to identify it from searches within the established body of literature and of the Internet. The Subject Matter Experts were familiar with the concept but in their experience were not aware that it had been implemented in recent years. Subject Matter Expert Bordass said that in his experience the use of it was more common 15-20 years ago.

The author has reasoned that such a brief is needed because it provides explicit focus to documenting a strategy for the achievement of low energy – low carbon performance. The evidence of such a need is also found in the lack of recognition of the need to harvest data from In-use; to then analyse it and then finally to use this knowledge to inform new design. The emphasis on In-use is as much concerned with the actuality of building performance (which is widely recognised) as it is with the operational performance as found in occupancy analytics. It is this distinction which the author believes would transform our understanding of how to substantially reduce In-use consumption – that which is largely in control of the users. Neither the RIBA Green Overlay to the earlier Plan of Work, or the later RIBA Plan of Work 2013, mention any need for such a brief, and yet the subsequent reflections of the PROBE investigations of Bordass et al. (Op Cit) express the 'great divide' that exists between design and In-use. It was for these reasons and the need to translate In-use requirements into 'appropriate values' for the engineering designers that the author argues establishes the imperative for the Energy Efficient Brief to be given renewed focus.

The author's approach to understanding the scope and potential content of this brief was to assimilate the requirements from the body of knowledge that exists as well as the results of the investigations into the two stages of the case study.

Throughout this thesis the author made explicit what he refers to as ‘Key Issues’ – issues that need to be reconciled in the Energy Efficient Brief. It is this ‘bottom-up’ approach to the investigation that the author then contrasted with existing work in this area, which whilst not explicitly expressed in terms of an Energy Efficient Brief, does point to essential requirements for large buildings that would be expected to lead to the achievement low energy –low carbon outcomes.

The following summarises the conclusions from Chapter 8:

- The Energy Efficient Brief would provide the focus for translation of In-use requirements into ‘appropriate data’, as evidenced by Occupancy Schedules (Stage 1 of the case study). However the functionality of this has not been tested on an engineering design project. The concept remains to be proven.
- A low – energy – low carbon overlay to the RIBA Plan of Work could compliment the Green Overlay, which might focus in future on the ‘soft’ issues of sustainability (sustainable materials specification, local impacts studies and waste management and so forth), whereas the proposed overlay would focus on the ‘hard’ issues of building performance, the management of data from In-use and the establishment of energy performance metrics informed by In-use. The utility of such an overlay remains unproven, until it has been thoroughly tested in application on projects.
- Occupancy Analytics and Whole Facility Energy Modelling could provide the empirical basis for energy and carbon target setting and composite benchmarks of departmental performance. Operational Polices would provide the contextual information for those targets. Through the results of the analysis in the Whole facility Energy Model, as discussed earlier, the empirical basis for energy targets and patient centric benchmarks was established. However until those targets have been proven in practice, this concept remains unproven.

Discussion: The aspiration of an Energy Efficient Brief remains an aspiration because it is unproven. The cessation of the 3Ts project whilst awaiting Department of Health and Treasury approval prevented the planned implementation of it. Had this been possible, the author would have had the opportunity to develop the work into a case study. Potentially the closest representation of the approach advocated by the author is ‘Soft Landings’, and in particular the recently published “*Government Soft Landings’ (Cabinet_Office, 2013)*, however investigation of it clearly indicates that the focus is concerned with the identification of requirements for Facility Management services and less concerned with the development/ management of In-use requirements though feedback and analysis. Indeed in the post-occupancy evaluation requirements, the evaluation is concerned solely with the effectiveness of the FM service.

Despite the fact that the author is unable to prove the utility of the Energy Efficient Brief, the author argues that he was able to achieve the third and final research objective:

> *The research objective is to make a new contribution to the briefing process, called ‘The Energy Efficient Brief’, such that this brief would provide the data required for the engineering teams at an early stage of the project process.*

The author argues that this is the case because he has demonstrated that is possible to translate In-use requirements into ‘appropriate data’ for engineering design, because this was proven in the implementation of the Whole Facility Energy Model.

In Chapter 7, the issue of how and when these requirements should be used to inform the engineering design process was discussed. The author proposed a low energy –low carbon overlay to the RIBA Plan of Work 2013. Whilst this provides an explanation as to the potential interventions at each stage, it does not fully address the process requirements for the implementation of building engineering physics.

Implications: From the consideration of the implications for future research in Chapter 8, the author concluded that there is a gap between Stage 7 (In-use) and Stage 0 (Strategic Briefing). That an essential aspect of the analysis of In-use should be data driven is not in question. The author argues that he has examined In-use sufficiently to understand what data needs to be available to the engineering briefing and design process, but not *when* it needs to inform it. The author partially answers this question in the proposed overlay to the RIBA Plan of Work 2013.

The answer cannot be prescriptive, because the answer will depend on what level of certainty the client requires of any forecast of energy and carbon performance. The trend of legislation from the EU, suggests that dynamic simulation modelling will become more of a necessity and less of a choice for the client. Research is required to understand where in the process an appropriate level of detail is required. To use a concept identified in the literature review: does 'black-box' formulaic design still have a place in low energy – low carbon performance, and to what extent should design move closer to implementation of building engineering physics based in fundamental principles referred to as 'white-box' design? The middle ground would be 'grey-box' design, but how much uncertainty would remain as a consequence of this? What benefit would design based in fundamental principles be realised for the client?

Limitations: In Chapter 8, the author proposed a novel approach to future benchmarking through the creation of composite benchmarks of departmental performance. The author proposed that these would be informed from the proactive management of departmental energy budgets, a concept also discussed in Chapter 7. The author argues that composite benchmarks such as proposed by the author could transform the briefing process by enabling the creation of energy targets informed by In-use strategies aimed at low-energy –low carbon outcomes from operational policies. Would this indeed be the case? Is it conceivable that benchmarks informed by such an approach would be realistic to be achieved? Could they compliment existing approaches such as CIBSE TM22 and TM46 for example?

Unique contribution: All of the work into the investigation of the Energy Efficient Brief is the author's own work.

9.3 Is author's proposition valid?

The author has argued that the first and second parts of the proposition have been demonstrated to be valid. The evidence for this confidence is set out in the conclusions in the foregoing section. As to the last part of the proposition, the investigation in Chapter 8 explains the mechanisms by which the alignment anticipated in the proposition could be achieved.

…Through a process of negotiation, engineering design strategies and In-Use working practices could become closely aligned,

where such alignment would be documented in the Energy Efficient Brief. The expected result would be improved forecasting and substantially improved In-Use energy performance and carbon emissions.

The author argues that first part of the third section of the proposition is valid, but whether these methods would deliver the expected substantial improvements sought in the proposition remains unclear and points to the need for further research.

9.4 Further research needs.

The following is a summary of the identified research needs from Chapters 6-8.

1. Occupancy Analytics provides a logical means to analyse occupancy presence where there are explicit organisational processes operating in the facility and large flux of occupants arises. Could it be applied in other building types? Educational facilities are possibly the most obvious building type that could be investigated because large occupant flux is caused by curriculum schedules. School's too have been highly criticised for the same reason as hospital facilities in that the forecast energy consumption is rarely achieved in practice Demanuele et al. (Op Cit). Just as in acute hospitals, occupancy presence and related use was seen as the most significant factor as to why school facilities failed to achieve forecast energy performance.

- Through the analysis of In-use the author has recognised the potential of clinical process improvement strategies to provide the data required for the HAM. Stage 1 of the case study presented experiments in process improvement measures that would then impact occupancy flux and in so doing impact space utilisation and the associated energy consumption. However, further research could identify other significant opportunities to reduce energy consumption and still improve the quality of service delivery. The research would require the identification of occupancy data such as that identified for the HAM and then to investigate how this data would impact the requirements documented in the Energy Efficient Brief.

- The use of the Whole Facility Energy Model in the support of In-use energy management alongside the Building management System. The prescient vision of Selkowitz et al. (Op Cit) was an early statement of intent in this regard. The research need would be to document a framework and the full dataset as envisioned by Raftery (Op Cit) and Kishk et al. (Op Cit).
- The investigation into the engineering process impacts of Occupancy Analytics and Whole Facility Energy Modelling warrants further research. The author's proposed overlay of the RIBA Plan of Work 2013 illustrates the potential to integrate low energy – low carbon In-use operations into the Plan of Work through an enhanced understanding of In-use (Stage 7). The need is to analyse the full dataset envisioned above, and develop guidance as to the integration needs with respect to the engineering design process.

- There appears to be a paucity of research concerning small power loads in acute hospitals in terms of how measured data could inform new standards. The work of Dunn and Knight (Op Cit, 2005) provides an insight into this potential. The author's user intervention in control strategy could be developed into further research, particularly in terms of users willingness to actively manage energy consumption within the spaces that they occupy.
- There appears to be a paucity of research concerning large power loads from imaging equipment in acute hospitals. The author's work with a Manufacturers Reference Group on the 3Ts project provides an insight to this potential. However, in order to model this occupancy demand profiles for each service would be required.
- There is a clear need for a measurement framework. The author's work on patient centric performance measures, and departmental energy budgets provide a focus for such needs. Raftery (Op Cit) explains the need in these terms:

> *“There is a clear need for a complete, coherent and effective measurement framework so that it is possible to measure real operational performance of buildings.”*

- Substantial work in lean healthcare and other efficiency initiatives would offer a rich resource for analysis in both occupancy presence impacts as well as the consequences on energy consumption and the associated carbon emissions. This potential needs to be investigated further.
- The author has provided an insight into the potential of a new norm for energy benchmarking based on a patient centric measure. The measure offers the intriguing possibility of measurement of intensity of use. Furthermore because the measure is derived from operational policy it offers the potential for clinicians to understand how to control the energy and carbon impacts of each patient pathway. Further research is required here.
- The study into departmental energy budgets was curtailed by the project being halted awaiting the Department of Health and Treasury approval. The research need is to understand how to develop such budgets constructed from the patient centric measures. Studies into incentivisation and management of user behaviour in managing these budgets could be another are worthy of investigation. Connection to the Applied Behavioural Analysis community may provide a new dimension to the research.
- The author believes that there is a significant issue for the UK in terms of its adherence through the HTM’s to ventilation standards based on air change rates rather than being based on volume/rate per person, as is adopted in much of Europe. The initial investigations by the author showed that there is potential to achieve necessary indoor air quality commensurate with the need to reduce energy consumption associated with moving large volumes of air in an acute hospital. As Beggs et al (Op Cit, 2008) have commented: “…*there is too little knowledge in this area of research*’. More recent research has attempted to reconcile the competing factors of indoor thermal quality with the risk of spread of infection such as that by Khan et al. (Op Cit). However, the focus of this

latter work was not to understand the energy impacts of such strategies, which is the concern of the author.

9.5 Final remarks

> *"…Science is part of the reality of living; it is the what, the how and the why of everything in our experience."*[74]

With a particular emphasis on the 'how' and the 'why' the author set out in this thesis to understand the challenges of designing low energy – low carbon performance for acute hospitals in the UK. The challenges are daunting, not least because it requires the willingness of people to cross the 'Great Divide' - that which exists between engineering design and In-use. This thesis has attempted to demonstrate how this could be achieved. Yet, will the proposed methods of the author be sufficient? The author raises this question because part of the '*reality of living'* is that people are invariably reluctant to change – to work outside of the familiar. For construction professionals, fear of failure, albeit because of impact on reputation or professional indemnity insurance means that 'stepping outside' of what is euphemistically known as 'best practice', is perhaps too big a 'step' to make. For clinical leaderships teams it means believing that low energy – low carbon performance is not their responsibility, regardless of the environmental impacts of their operational policies or working practices. A litigious construction industry still seemingly focused on lowest capital cost, and fee structures that all too often do little to support investment in research and development; clients and contractors all too often unwilling to share the risks of innovation – all of these factors serve to inhibit the '*fundamental change in process'* advocated by the Innovation and Growth team and others. Succinctly put, society appears to reward the safe haven of 'best practice' at the cost to our environment. Yet as Einstein was quoted to have said:

> *"Insanity is expecting a different result from doing the same thing over and again."*

Yet '*different results'* are what the Carbon Reduction Commitment of the UK Government and Near To Zero Buildings objectives of the EU requires. '*Not*

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[74] Rachel Carson. A US fish and wildlife naturalist, and inspirational writer. Quote from Carson's National Book Award acceptance speech, 1952.

doing the same thing over and again', as has been demonstrated on the 3Ts redevelopment project, is to attempt to break the deadlock of underperforming acute hospitals in the UK. It means that to achieve much improved predictability of performance, engineering design must traverse the 'Great Divide' and be properly informed by In-use. Equally, it means that clinical users must come to understand that their role in this regard is to develop operational policies and working practices that also seek to minimise energy consumption and the associated carbon emissions, whilst still optimising health outcomes. It means that In-use, the management of building performance data becomes the norm and not the exception, so that the proper application of building engineering physics is no longer constrained by a lack of 'appropriate data'. As Dr Frank Duffy wrote and cited in the opening quotation of this thesis:

> *"To me the magic of design is real, important and undoubtedly the province of architecture, but nonetheless capable of being enhanced by scientific understanding of user requirements."*

It is to this objective, that this thesis is dedicated…

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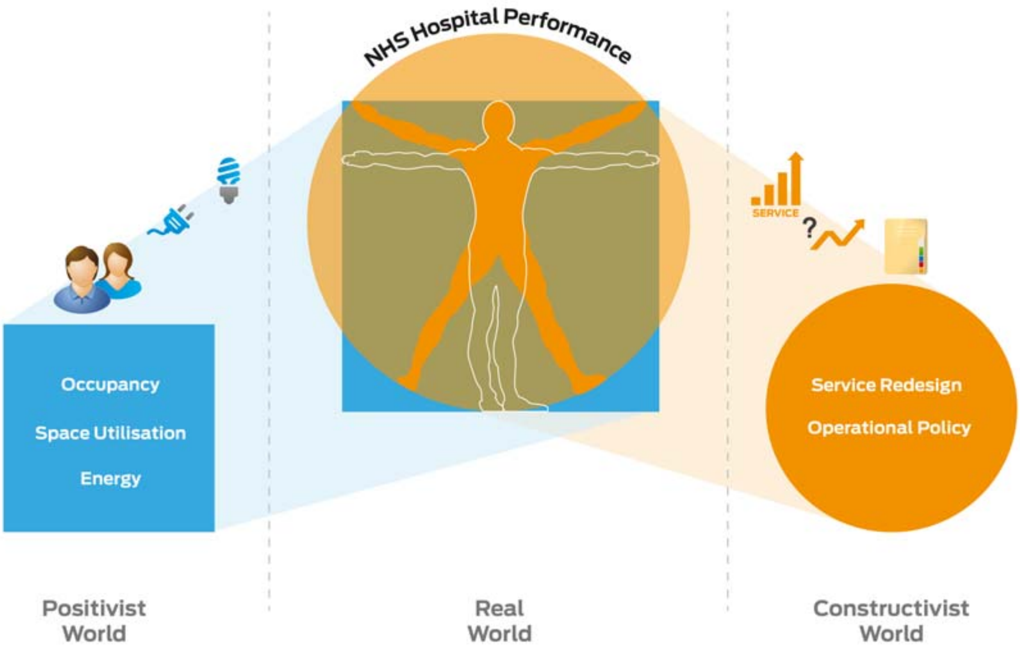
Low energy – low carbon acute hospital engineering design and operation in the UK: Analysis of the impact of In-use



Matthew Bacon

School of Built Environment

University of Salford, Salford, UK

VOLUME 2 of 2 (Appendix)

Degree of Doctor of Philosophy

2014

VOLUME 2:

LOW ENERGY – LOW CARBON ACUTE HOSPITAL ENGINEERING DESIGN AND OPERATION IN THE UK: ANALYSIS OF THE IMPACT OF IN-USE **1**

APPENDIX 1 : TRANSCRIPTS OF INTERVIEW WITH SUBJECT MATTER EXPERTS **3**

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Appendix 1 : Transcripts of interview with Subject Matter Experts

A1.1 Background

The need for expert opinion from what the author refers to as Subject Matter Experts was set out in the Introduction to this thesis. The author's approach to the interviews with them was that the key findings that emerged from the Chapter 3 - Literature Review, and specifically the summation of the Gaps In Knowledge (Section 3.4) needed to be subjected to expert opinion. The reader will recall that the author argues that codified knowledge in the construction industry is poor. It can only be speculated why this might be the case, perhaps it is that commercial organisations regard acquired knowledge as a commercial differentiator, and as such are reluctant to share it? The author regards this issue as significant in the literature review because what is codified through standards and guidance may not reflect what is leading best practice in the industry. As action research is fundamentally concerned with linking practice and theory (McKay and Marshall, Op Cit) then the author reasoned that in seeking such opinion, a new understanding of the implementation of building physics into practice might emerge and be one that could inform the authors research.

A1.1.1 Overview of methodology

The author has explained earlier in this thesis how the Subject Matter Experts were identified. Each was approached through a telephone conversation explaining the purpose of the investigation. A follow up email was then sent to confirm what was discussed. In that email an early draft of the author's abstract for this thesis was included. Having established a time and location for the interview, the Subject Matter Expert was then sent an Ethical Approval document along with a document that summarised the findings of the literature review and the statements of Gaps in Knowledge. It was this document that was to be used as the framework for the interviews, and where the specific statements made by the author were discussed.

The interviews were recorded and then a transcript was produced. Interviewees were then sent a copy of the transcript for their written approval. Corrections were then made and a revised copy sent for final approval. All Subject Matter Experts agreed to the publishing of the transcript of their interview.

A1.2 Commentary on the interviews

Returning to the primary themes of this thesis namely what has more recently (from the time when the initial research questions were conceived) been described as the 'performance gap' and secondly the poor absolute energy performance of acute hospitals in the UK, the interviews provide illuminating insights into engineering design practice. These could be characterised as:

1. The role of the client in seeking low energy – low carbon performance. Bellew observed that if the client perceives little value in energy modelling, then it is usual for it not to get done – apart from that required for compliance purposes. Despite this, could the results of dynamic energy modelling be assured to provide the client with improved expectations of performance anyway? TM54 (Op Cit) offers some guidance as to why it is difficult to provide such assurance. However this thesis identifies that it is the lack of In-use data, and indeed a void in the understanding of In-use, that requires substantial assumptions to be made in the engineering design process. This is a point made by Bordass, and where he also eloquently described this in his paper: *'Flying Blind: Everything you wanted to know about energy in commercial buildings but were afraid to ask.'* (Op Cit). Runicles explained that a major consequence of poor briefing is that engineering designers will work to a perceived worst-case scenarios. This means that large factors of safety tend to be built into the engineering design process. These large factors of safety compromise the ability to achieve optimised engineering design for low energy – low carbon performance.
2. Why do the engineering designers need to make such assumptions? Both Runicles and Bellew concur that the briefing process is very much lacking. Indeed without an informed client or a client representative, too little information or data is available from them to inform the design process. Of course Bordass would argue that Soft Landings (Op Cit) should meet this need, but with little evidence of effective implementation and an industry reluctant to share

knowledge should the industry be surprised that there is a paucity of validated data?

3. But what of the latest regulation, such as Part L2A of the UK Building Regulations? Isn't this meant to ensure that In-use requirements become an essential part of the engineering design strategy? With the requirement of 'near to zero' for all new public buildings by 2018 doesn't this mean that public sector clients, at least, are obliged to provide much better informed briefs? All those interviewed suggested that engineers are insufficiently experienced in producing information for such compliance. Bordass adds that energy simulation models can be made to show what some clients wish them to show. Runicles suggests that to ask two or more modellers to model the same building and forecast the energy performance for it, they will all arrive at different results. SBEM (Op Cit) is an attempt to avoid such modelling inconsistencies, but in doing so it creates an overtly simplified model to demonstrate the potential of the design against normalised criteria and was never intended to be used for a forecast of actual performance.

4. In the health care sector the Department of Health has produced technical guidance for engineering design teams, and whilst the data for energy targets is very generalised, of greater concern is that the energy performance targets that it promotes are far in excess of those required for near to zero energy performance. It should not be of any surprise that the absolute energy performance acute hospitals today, for the greater part, perform no better than those built during the 1990's. The evidence is also clear that the technical requirements of the Depart of Health have not kept up to date with the changes in the Building Regulations. As the technical guidance has been largely mandated in contemporary hospital design (mainly through PFI contracts) then it should not be surprising that carbon emissions from hospital buildings continue to rise.

5. Bellew, Runicles and Bordass all concurred that detailed data concerning In-use is a necessity for optimised low – energy – low

carbon building design. Current guidance is poor. Concerning CIBSE guidance for example, such as Guide A – Environmental Design (Op Cit) there is no data concerning In-use energy in hospitals. Occupancy analysis within academic research highlights this void, where the majority of research is focused on commercial office buildings. Bellew is perhaps one of a few consultants that pro-actively seek to establish an understanding of In-use to inform the engineering design process. Why should this be the exception and not the norm? In analysing the CIBSE publication KS8 (Op Cit) in the literature review, it clearly identified what is required of a comprehensive briefing process. Bellew believes that clients need to be prepared to fund a briefing process that will elicit these requirements. Manning (Op Cit, 2010) suggested that it is in the briefing process where engineering design should be providing greatest value and advocated that new skills would need to be developed for this to happen. Bellew also suggests, that the client needs to be prepared to share in the risk of optimised design, because analysis of In-use is essentially predicated on the client assuring that the facility will be operated as stated. He cites his work at the WWF headquarters in the UK and more recent work in Singapore to demonstrate the value of such analysis to low energy – low carbon performance. His experience on projects such as these is that the engineering systems will inevitably much smaller (typically 30% smaller) than systems calculated by conventional means. He observes however that it requires an enlightened client to support such a strategy. Of public sector clients Bordass is concerned about the loss of expertise during the years of austerity, and this has effectively deskilled the briefing process for new health care facilities as much as other public building types.

6. This dialogue raises the obvious question: what can be done about arresting this situation? All Subject Matter Experts agreed that it is in the briefing process that the greatest change has to take place. It must be informed by better data that connects building performance with

In-use operational practices, and not simply the anecdotal evidence that arises from initiatives such as Soft Landings. The research community is also significantly compromised by lack of validated In-use data. This suggests that In-use analytics (what is sometimes referred to as 'post-occupancy analysis') is a competency that requires development. CIBSE TM 22 (Op Cit) as a methodology goes someway to achieving this, but nevertheless there remains a paucity of health care analytics.

A1.3 Transcript of interview with Mr. Patrick Bellew RDI [1]

Matthew Bacon (MB)	Patrick I really appreciate the opportunity for this interview – thank you.	
Patrick Bellew (PB)	It is a pleasure – I enjoyed reading your abstract and it reminds me of current challenges, where we see over-sizing of plant as endemic for exactly the reasons that you suggest.	
MB	Yes over-sizing is one potential impact…Of course you can use formulaic- risk adverse briefing and design strategies that push up plant sizing…	
PB	From a low energy – low carbon perspective perhaps over-sizing is not such an issue – yes the plant will not be operating as efficiently, but as long as we can control the systems to deliver only what is required, then that is where we will achieve the efficiencies…	Risk of Plant over-sizing.
MB	…yet the impact of over-sizing is larger CAPEX, perhaps compromising investment in energy reduction measures	

[1] For CV please see: http://en.wikipedia.org/wiki/Patrick_Bellew

	(The RAE report refers to this).	
PB	No engineer was ever sued for over-sizing the plant! The problem is that clients are reluctant to invest in energy modeling – others simply do not understand why it is important and the consequences of not investing in such studies. For example: Entire buildings are being designed on more or less throw-away remarks by property agents – an example: who say “we have some wealthy clients who want to have to have all these features” and the briefs then require us to design all these features that the development agents ask for…just in case clients come in who want these features – just what happened on a luxury development in London. The fact that these clients only enter the building once or twice a year does not seem to be an issue for them. I’m not sure if that is relevant to hospitals?	Cross ref

MB	Well it is similar – many assumptions are made and these assumptions push plant sizing up the top end of the spectrum. What I argue for is that we need an evidence base for 'right-sizing' that provides the minimal perspective to contrast with that at the top end of the spectrum of plant sizing. So we say that "if you were to operate the hospital like this, then this is the minimum that this system could be designed for." So we then say: "what risks do we need to 'take on board', that would cause us to move from the minimal perspective towards the top end of the spectrum?" We ask how to quantify those risks and the benefits to the client in designing to mitigate those risks? The client is then required to consider which of these risks are likely to materialise, and what options do they have in managing them. I argue that the client must have visibility of all of these factors so that they understand what risks they need to manage.	
PB	Yes I agree with you.	
MB	I feel that the value of the evidence-based philosophy is that it provides a basis for the client to 'come back' from the maximum perspective to a level of right –sizing appropriate to the risks that they wish to manage.	
PB	What you have described is exactly the same in many areas – whether you are working in hospitals, offices or residential, the problem with our industry is that there is little enough data to provide information on basic statistics such as annual energy consumption, never mind for demand modeling.	Lack of appropriate data.
MB	OK – with that background – can we come to my questions? I have extracted a series of statements from	

	the thesis that I wish to put to you to get your reaction. In doing so I am not seeking to ask your affirmation – but more to seek your opinion and alternative views…	
PB	Yes I understand what you are after…	
MB	Did the abstract help you to understand my position?	
PB	Yes very much so…you want to provoke a response to your statements?	
MB	I have been studying the theory and the practice and seeking to bring both fields together in amore explicit way. So whilst you may agree with the analysis – I am quite expecting those that I interview to disagree with the solution!...that's fine, because it will simply reflect the diversity of opinion based on the perspectives of those that I choose to interview.	

Statement 1: *In the wider construction industry, Bordass characterised the poor relationship between design and operation as the 'Great Divide'. Whilst he was writing in terms of another process, the sentiment provides a very helpful insight into the wider disconnect that was evidenced in the PROBE studies (Bordass et al., 1997). A key reflection of the author has been that because of the 'Great Divide' assumptions become an inevitable part of the whole process. If designers either do not have access to adequate briefing data or information they will make assumptions in the design. If users do not understand the impact of design decisions on their working practices they too will make assumptions concerning those working practices.*

Question: What is your experience of the inadequacies of briefing data…

- How do you manage assumptions concerning In-Use?

PB	Well let's do the first one first. Our experience is pretty mixed – for the most part it is left open to us to imagine	

	what the operational characteristics of the building will be and we have access to data for ‘conventional’ building types such as offices and apartments for things like occupancy and demand requirements. We work on a variety of building types and as I mentioned to you before – not particularly hospitals. However, I can imagine that the same rules apply. When we get a particularly knowledgeable client and that will usually be in the university sector for example, where you get a group of people that regularly commission buildings and routinely understand how they get put together and what the operational requirements are the we will often get a very thorough brief. But even then we will find that it is either the facilities guys or the Estates Department that will commission the building – they will have usually done end user briefing work but they will not necessarily have come up with a clear understanding of how the building will operate.	
MB	Can I come in at this point?	
PB	Yes please do	
MB	I have this theory – if you recall I wrote the design management guidelines at BAA and there was this focus on briefing and my reflection on briefing as we understood it then, was that so much of our focus in briefing was on the ‘what’ of the requirements and much less on ‘how’ the facility would be operated. Is that something you would recognise?	
PB	Oh definitely. For the most part briefs (once the spatial requirements have been established) usually in terms of floor areas and floor – to ceiling heights…and more recently would incorporate a requirement for an	Briefing silent as to how the facility would be used.

	environmental benchmark –BREAM , LEED or whatever. It rarely goes beyond that in terms of quality. I will occasionally get clients who will say: “Daylight is very important”, or “Indoor air quality is very important”. Some clients really keen on the healthy living. ..so we get practical guidance, but it is not operational – it is static.	
MB	Do you regard that as sufficient for briefing – have you reflected on it?	
PB	Do you know? No we do not – we generally accept it, and we try to project onto it what our own version would be at that time of the briefing.	
MB	So there will be some big assumptions?	
PB	Very big, yes…and that is because most clients are unwilling to articulate beyond the basic requirements, but I would say that after 25 years of doing it – we tend not to ask those questions. We often know what they want. A good example of where we worked a lot harder on the briefing question was on the Garden by the Bay development in Singapore – these giant glass houses, where the end users were the end us was essentially plants from all around the world. We had to create comfortable environments for all of them, which involved shifting temperatures from day to night, seasonal temperatures to mimic the global environmental differences.	Cross ref: Big assumptions.
MB	So the second question: How do manage assumptions concerning In-use?	
PB	We generally do it through our reporting in a very general way. We would write these in our Stage D and E reports, but to be brutally honest I doubt if most clients would ever read them in detail.	Cross ref: Assumptions not challenged.

MB	I discussed the issue of assumptions with Professor Duane Passman, the Director for the 3Ts redevelopment when I originally made my pitch to him concerning the challenges of making informed decisions on complex projects. I suggested that when one was unaware of the assumptions that had been made by the design team concerning design recommendations, the decision maker is often unaware of all of those assumptions. In particular the decision maker maybe unaware of the energy and carbon impacts of those decisions. He very much empathised with these me on this reflection – and observed that it can be sometime later – often when it is too late to change a decision that these assumptions become apparent. I explained to him that we need to provide what I refer to as the enhanced brief, which is designed to expose these assumptions and achieve a joined up strategy between design and operation.	
PB	For the most part there would be two ways to deal with the management of assumptions. One way is though presentation at Stage D – Operational aspects of building – but we also do a lot by engineering stealth. The main variable that we are dealing with is occupancy. The tools that we now have (within the last 5 years) is to use occupancy sensors. We set the building up so that it will adjust automatically according to occupancy. So the plant is operating at optimum efficiency for different occupancies. That said – we make our own assumptions concerning diversity of use. The client would never be able to articulate those numbers.	Cross ref: Potential to mitigate errors in assumptions through building control systems
MB	This is exactly my point – this is what Occupancy Analytics is about. It examines the breadth of factors that impact diversity of use. At Brighton the engineering team	

	had no understanding that there would be the diversity of use that we modelled. The design strategy was built around a CAV system. It was then determined that a CAV system strategy was inappropriate to manage the forecast diversity of occupancy. So the investigation turned to a VAV and heavy modulation. But they then argued that CAPEX goes up because of the substantial overhead of modulated control.	
PB	No it does not follow that the VAV would be more expensive because you should be able to downsize the kit, because the terminal loads would be so much smaller.	
MB	Yes this has been a contentious debate with the contractor and the designer. Nevertheless from a systems perspective we have a system much better aligned to the forecast usage of the building. Our occupancy studies highlighted massive differences between the formulaic approach to occupancy assessment and our science-based approach.	
PB	Yes – it would do I can see that.	
MB	Comparing the engineering design occupancy basis of 6400 with our analysis of 2300 demonstrates the significance of the issues that we are dealing with.	
PB	Yes I can see that.	
MB	We studied the assumptions concerning how Imaging equipment would be used. I set up a manufacturers reference group to analyse the forecast energy demand based on different equipment profiles. The difference between our analysis and that of the engineers' assumptions was 1/5th of that forecast by the engineers.	
PB	This is exactly my experience at these luxury apartments –	

you have to plan for 18 people in a living room for a party, so you have a fan-coil unit with fresh air designed for that load and a fan-coil unit in the kitchen designed for an 8kW cooker load. Now think that is ridiculous – but now multiply that 450 times for all the apartments results in a 3MW electrical load – when In-Use it is only 300kW! The probability that all 450 apartments have full parties in the living rooms on the hottest day of the year – all bedrooms full – is obviously very low. I think that our (the M&E industry) calculation methods are flawed.

Another example of briefing issues concerned a training academy, where there was a briefing requirement for teaching class room facilities grouped together separately from the outdoor practice facilities (firing ranges and such like). This would lead to an efficient building design with low energy potential. Well into the design process someone realised that the classroom spaces could become contaminated with explosive or gunpowder residues from the outdoor activities and that this would fundamentally compromise the class room based activities with cross-contamination. It was then determined that a decontamination area would be required between the outdoor facilities and the classroom – otherwise it would not be possible for the operational requirements (concerning training schedules) to be achieved. This was missing from the original brief.

So a major change to the brief was required which caused all classrooms to be moved out into the landscape to ensure no cross-contamination. A very good example of operational briefing needs.

The consequence of the new requirements was that buildings and engineering plant got larger, and many of the

	efficiencies of grouped facilities were lost.	
MB	So we see massive assumptions rarely challenged until it comes to the operational phase when it is too late to do anything about them.	
PB	Absolutely right.	

Statement 2: *With a focus on In-Use and a subject area concerning low energy – low carbon building performance, the question would then arise as to what aspects of In-Use should be investigated? In reading the RAE report (Op Cit) the clear need is in the development of building engineering physics:*

> *"We are at the start of a period when the application of building engineering physics will become one of the principal drivers in the construction of new buildings. In the 21st Century buildings and their construction must evolve rapidly to meet emerging challenges."*

PB	I would argue that in larger sectors of engineering design much of this has been practiced, but there are large parts of the profession that do not practice building engineering physics – they are mechanical, or aeronautical engineers…I have to be careful because building engineering physics has been our passion for the last 20 years. There are a few practices like ours. I would guess that a major part of our profession has low understanding of building physics and just add up numbers.	Poor implementation building engineering physics.

An implication of this statement could be that building engineering physics has not served the construction industry well if building energy performance has not measurably improved over the last two decades at least. Is this the only reason, or could it be that there are other factors that may have lead to this situation ***? For example, might it be the failure to adequately apply building engineering physics in the engineering for low energy – low carbon buildings, or to adequately inform the physics with appropriate data?*** *As discussed earlier, the issue here could be the one of assumptions being made at any of the key stages of the process and which could result in poor quality input data* ***. No matter how good the physics, the result will be misinformed if the input data is inaccurate.***

Question: What is your view of the statements in bold?

- How much of engineering design is based on formulaic principles, and how much of it based on the thorough application of building engineering physics?
- How much of building engineering physics is compromised because lack of In-Use data and/ or knowledge?

PB	Building on what I do know (which is not much about hospitals), the usual issues in these things are ones of cost and budget. The willingness of people to make investment in low carbon technologies. Hospitals tend to have a very long design and construction phase, so I always think that anyone completing a hospital now – probably completed the design of it 10 years ago. So the data relates to a much longer time cycle than other types of buildings where I think we have seen energy consumption reducing. So investment in CHP and demand control ventilation, have not necessarily happened in hospitals – at the speed at which one might have hoped that it would. The technology exists to build much better buildings.	
MB	If we can move away from the technology and think about the application of building engineering physics generally. So given your comments concerning poor understanding of building engineering physics in the profession – this could be one reason for the poor application of the science?	
PB	You said it earlier on – if there is nothing in the brief that the client is prepared to share the risk of either over or with the design team, are you ever going to create an environment where an engineer would make anything smaller?	Cross ref: Client's unwilling/ unable to share the risk of under-sizing.

MB	In my recent visit to Singapore – one of my findings was that Singaporians are risk adverse in this area – it is a matter of pride – should they ever be proved wrong. From there point of view there is no client driver to 'right-size' plant. However the second part of the question was concerned with lack of 'appropriate data'. We discussed earlier the need for occupancy data. We have often not been able to calibrate our designs so how do we know what data that we need to collect – it is a vicious circle.	
PB	I think that the difficulty is that even when you do have occupancy data a lot of the CIBSE guidance, say for hot water demand in hospitals – they do have data for this – although it maybe very inaccurate. So yes we do lack this – even on occupancy data for houses – we have none of this. Data concerning right sizing of cooling plant for residential dwellings simply is not available. It is crazy. No one that we know has done it. The counter point to that as an engineer would be if you want to build some thing that is flexible for future adaption there will always be a risk that if you hone the design to much you run the risk of the building not being adaptable.	Cross ref: Lack of In-use data
MB	Absolutely – I fully agree with that. So I say – design for today using an evidence based analysis, but then take on the risk issues for future flexibility transparently such that the client can be engaged in the decision-making process. However, our approach is to study the probability of use, based in the stochastic nature of hospital occupancy.	

PB	I looked that up this morning! I need to remind myself of what the science is.	
MB	So our studies of probability enable us to make statements such as "9 out of 10 days the occupancy could be this, but in 1 out of 10 days it could be this".	
PB	Where do you get that information from?	
MB	It comes out of the simulation. We model the variability of the process. We produce an occupancy dataset that can then be used in building engineering physics.	
PB	Right – I could not agree with you more. It reminds me of a very successful university building in the USA that we worked on. It was initially using far greater plug loads than had been forecast. It was because the space that we had built was so wonderful that students wanted to work there and stay there much longer. It was packed the whole time it was open during the day. We had a DCV system that was running flat out because the building was so popular. You can then have the counter-point of a very successful building that exceeds all expectations and results in much higher energy usage. However that did not last, and the use has now stabilised.	
MB	The work on Brighton has involved a dialogue with the users to explore how they could intervene in the control of the building – not just automated systems. As sensors cannot forecast – then could we not optimise the facility over time through a better understanding of use? The idea in my mind is that we would have a user group working alongside a facilities group. By this means users could say: "this is how we wish to use the facility" and the facility team would say: "if you wish to use it	

	like that- this is how the systems need to be configured to achieve that need, and these are the energy and carbon impacts of that requirement.	
PB	This would require a huge amount of understanding of the facilities team as well as the users…	
MB	We have agreed a protocol with the users that they have signed up to. We have been discussing peak load smoothing with them – and one study has been to consider how departments could share space in periods of low occupancy.	

PB	Of course there have been heating systems around since the 70's to enable optimised control – able to predict what systems need to be running based on outside temperature parameters. Yet this is only a very small area of our work where we can get that kind of predictive tool.	

Statement 3: *The author reasons that if it were possible to understand how users need to work in the building and to use that understanding to inform the building engineering physics, then through the brief it might be possible to use ensure a close fit between design and use – the very issues that Bordass was alluding to in the 'Great Divide'.*

Question: What is your view of this reasoning?

a) In those buildings designed for a client-user, how well do you believe that you understand forecast use?

PB	I agree with this reasoning, but with one caveat. We have enough challenges in getting control systems designed to meet the needs of the users. There comes a point where the technology becomes so complicated that it is beyond the wit of most users. Then managing and changing it becomes even more of a problem.	
MB	Absolutely agree. I went to see Crown House Technologies to discuss the briefing of the control systems. I explained that our intent was to provide them with a user brief that explained how they wished to manage their facilities. They explained that they had never had any thing like this before – the best that they get is a brief from the engineering designer.	

	The other part of this briefing with the users was to understand how we could get the users to intervene in the control of the building – so that we could reduce the control complexity. So we asked users what compromises they would be prepared to make in the internal air quality for the sake of driving down energy and carbon emissions? The studies indicated that we could reduce the consumption by around 30% with user intervening in control.	
PB	A floating set point control systems is one means – but the 'pain' is shared around the system. It is not difficult to see a future where the ability to target control is possible. I love a quote from Mike Davies predicting the future of buildings (written in the 1970's) –it was his vision for responsive building envelopes: *"Look up at a spectrum-washed envelope whose surface is a map of its instantaneous performance, stealing energy from the air with an iridescent shrug, rippling its photogrids as a cloud runs across the sun, a wall which, as the night chill falls, fluffs up its feathers and turning white on its north face and blue on the south, closes its eyes but not without remembering to pump a little glow down to the night porter, clear a view-patch for the lovers on the southside of level 22 and turn 12 per cent silver just before dawn."* There is now the possibility for system controls to manage peak loads such that the tumble drier in the house cannot be switched on until there is capacity in the system. Siemens and others are putting together city-wide	

	systems. A company called Living Planet have developed an operating system that enables this kind of functionality.	

MB	So to come to the Green Building Council quote. I guess you are familiar with their work?	
PB	I am – I was a founder and I am a Trustee…	
MB	Apologies for my ignorance!	

Statement 4: The UK Green Building Council (Op Cit) report stated:

> *The most significant development in building science over the last thirty years has been the development of computer models to assess the energy and environmental performance of buildings. These models are now regularly used to assess the potential impact of energy efficient technologies in the design and refurbishment of buildings.* ***However, when buildings are refurbished or new buildings built, they can use up to twice the theoretical energy performance. This is a serious problem, which can significantly impact on the potential for the world to achieve carbon reduction targets.***

The report then goes on to state:

> As things stand, the building industry is unlikely to achieve model-based targets in reality and this problem needs to be addressed at a national level. **The causes of the discrepancy between model predictions and actual building energy use must first be understood, then incorporated into model structure, input data requirements and the ways models are used. These methodological improvements need to be based**

on sufficient empirical data rather than further modelling. The tools used in design consultancies need to be able to predict real building energy use, and national policy needs to enable the design process to do that and mandate that it does.

Question: Why do you think that these discrepancies exist?

b) Do you agree that it is empirical data that is missing?

MB	So we have the models - but we do not have sufficient data.	
PB	So there are a few issues – be careful concerning notional standards, and calculation methods with real building performance. Mainly because the notional calculation method only requires us to model regulated loads, and not unregulated loads. So there will always be a big disconnect between what is modelled and what is measured. Second point – our experience in trying to un-pick why a building is performing badly beyond the blindingly obvious – like all the lights are left on all the time or whatever, shows that the reasons are far from obvious. At Yale we designed two buildings and carried out post-occupancy reviews on both. We found that neither building was performing as modelled. We went back and we had good sub-metering in both so that we could see where all of the energy was being used. Unless you can find out where it is going it is really hard to find the reasons for poor performance beyond the obvious. What we then did was to do comparative modeling to understand where the problems were. We were then able to fault find. In all cases it was incorrect	

	programming and sequencing of programming of the controls system software, that was the contributing factor poor energy use. Generally control systems run sequences – so when an event takes place another event in the system is triggered – it is a sequential process. A particular example was in one building were seeing excessive electrical loads on the mechanical plant. It turned out that the failure was with the operation of the ground source heat pump. There was an auxiliary electrical heater that was supposed to be used in really cold weather to output some extra heat into the tank should the ground source be insufficient. They were programmed the wrong way round. So the electrical heater was running all the time and the ground source never came on. We would never have found this had we not done a post-occupancy survey. Now it performs as required. To do this deep drilling of issues – someone has to pay for it.	
MB	This raises the issue of calibration of systems in the commissioning stage. Recent research has shown how difficult it is to calibrate with limitations in software design, as much as limitations in access to sufficient data. So at hand-over why was the building configuration not calibrated so that this issue could have been exposed?	
PB	We had a commissioning engineering working on this. They were independent people working on it for the entire life of the project – even they missed this. Even with the most careful processes things can still go wrong.	Commissioning

MB	OK returning to your two points – the EPC for Building Regulations. Yes, I understand the issue concerning regulated and un-regulated consumption. But for the client all they see (wrongly) that they will be receiving a high performing – but the reality is often so different.	
PB	When we compete on fees for a project – most often the only thing we are required to do is to achieve compliance with the building regulations. Bear in mind that legislation only requires us to carry out full energy modeling for the last four years (since 2010). Prior to that there was no obligation to do so. You had to do peak heating and peak cooling loads. Only where we were working on buildings going for BREAM or LEED were we required to energy model. So energy modeling is a relatively new requirement in the UK. There is almost no money in client budgets for doing it. It can be expensive because it takes a lot of time to do occupancy programming. It is also very difficult to keep staff on for more than a few years doing it, because it is tedious. Trying to put occupancy schedules in for an office building or a hotel, particularly when you are trying to optimise the design is very time consuming. My point is that it is quite a new science, and we do not know as much about it as you think that we do. I can guarantee that when we were working on Heathrow Terminal 3 (for *which the author was Project Architect*) for example, there was no energy modeling done. Peak heating and Peak cooling was all that one did. Energy modeling is a new discipline.	A new science, which is in its infancy.
MB	This brings me to the concept of the Whole Facility	

	Energy model that I describe in the Thesis. We have a data exchange between the occupancy model and the energy model.	
PB	But your energy software will not necessarily be compliant with DOE for example...	
MB	We use RIUSKA, which is DOE compliant. It was for the reasons that you have outlined that I conceived the need to model the energy and carbon impacts of the occupancy analysis. My business is soon to start on a new hospital in Sweden where the engineers would like to work with us to develop the work on this new hospital.	
PB	Sweden is a country that always has been interested in optimisation. The first time that I did this – the ‘nerve jangling’ downsizing of equipment was on a Swedish based project – a Termodeck building in Winchester. It is a 30-40k sq ft building and the modeling showed that I needed about 40kW of heating whereas a conventional Hevacomp model would have put in 400kW. In the end we put in 100kW as a consequence of a risk assessment. I was very nervous at the start – but it works fine. I did this through discussion with the client. I explained that we would be putting in a much smaller boiler, and he replied: “why would you want to do anything else?” If you had performed the calculation conventionally, you would have assumed that the building would be empty, and you would make the boiler big enough to heat the cold building from empty.	‘Right-sizing’
MB	Getting back to the issue of regulated and un-regulated – the reality is that operational consumption leads to an operational performance rating that is far worse than the	

	code compliance rating.	
PB	Agreed. Whenever we carry out a LEEDS assessment we do model both regulated and un-regulated energy. However, the commercial lobby says that we cannot model the building unless we know who the occupants are. In an industrial unit you will not know if it is storing furniture or will be a sandwich making facility!	
MB	In the Whole Facility Energy Model, the objective is to model the whole of the consumption such as you would do for LEED compliance.	
PB	With the WWF (World-Wildlife Fund) they optimised building operation by carefully considering who would use space at different times of the day and seek to only service that space that was required for the operational needs. In doing so they managed to reduce the size of the building by nearly 30% simply through optimisation of workflows. In the other project that I mentioned –Training Centre, the workplace consultant faced a lot of resistance in getting people to share space – apparent confidentiality issues and such like.	

MB	Can we now discuss the research questions?

Consequently there are two research questions that are central to this thesis:

1. *Why hasn't energy consumption in acute hospitals improved during a period where legislation has sought to improve building energy consumption and the associated carbon emissions?*

PB	Is that true?	
MB	We can see from the research that historically the asset performance was quite poor, but the use was much lower than that of today.	
PB	Of course we have much greater use of technology today…	
MB	Nowadays the asset performance is so much better than 20 years ago, but the operational performance is so much more intensive. Today the CIBSE guide puts hospital benchmark performance circa 400-500 kWh/m2, which is what it was in the 1990’s. So I reason why do we spend so much effort on optimised asset specification, when this work so easily be undermined by what is in effect uncontrolled In-Use consumption? So working with users to help them understand how to control use, through operational policies is where I argue that we need to focus our efforts. We work with them to re-engineer the operational policies so that they understand how working practices can achieve energy reduction.	
PB	In schools we can see the same pattern emerging as within hospitals – space-heating loads have reduced considerably – but electrical loads have completely reversed over 20 years, such that these loads are now the dominant factor in consumption.	
MB	So I think that you are agreeing that the major need is to control In-Use consumption – because this is the dominant factor of rising consumption and which undermines the improvements in asset performance?	
PB	Yes I am.	Focus: In-Use consumption.

2. *Why is there such a significant disparity between the design aspiration and the actual performance?*

MB	I show you the CIBSE TM46 data for Health Care facilities. As you can see they illustrate a substantial divergence between designers aspiration of performance and the achieved performance In-Use. This is not concerned with the regulated – unregulated debate – but much more concerned with accurate forecasting.	
PB	I would also suggest that it is probably also a consequence of inadequate system commissioning. When the 'wheels fall off' these are generally the reasons for this.	Commissioning

In seeking to understand current knowledge the author suggests that there are two obvious perspectives:

- *Engineering practice relation to the analysis and the forecasting of In-Use hospital energy performance.*
- *Theory relating to the analysis and the forecasting of In-Use hospital energy performance.*

Concerning the former, the engineering practice perspective would seek to understand building engineering physics and the implementation of it through best practice, design guidance, and standards. *The latter, from a theoretical perspective would seek to understand current theory, testing of theory, and research into new knowledge.*

Question: How would you answer these questions?

PB	How can you factor in inertia – the fact that a hospital is such a big beast how do you go back and retro-fit it? It is so incredibly expensive. Lets us say that with lighting you can reduce this down from 15 W/m2 down to 3W/m2 for the lighting electrical load. But to do this the light fittings are very expensive and it becomes a very expensive job. I guess that hospitals under construction today will have been specified some years ago when the opportunity to use low energy fittings did not exist. So one could foresee that these new hospitals would not perform as well as they could.	
MB	Surely this is where life cycle cost analysis enables the CAPEX/ OPEX equation to be understood?	
PB	As with energy modeling clients have to be convinced of the need for it.	
MB	Agreed. Can we move onto the issue of the Energy Efficient Brief?	

Statement 4: *It is pertinent to note that whilst the CIBSE Design Framework references a briefing process, there is no reference to it in the CIBSE Guide F (Op Cit). This is surprising because of the emphasis that KS8 places on engineering designers to ensure a proper foundation for the design process through comprehensive analysis of the brief.*

A detailed analysis of this document is contained in Section 3.2.6. From that analysis the following evidence is pertinent to the engineering design process. There is a clear requirement for engineering designers to:

a) *Gather design information, such as occupancy hours, activity and density of occupancy (p10).*
b) *Document a design brief: "which can include occupancy" (p15)*

c) *Analyse the impacts of occupancy and activity in order to assess internal heat gains (p32)*
d) *Analyse internal design conditions for the assessment of intermittent operation, internal loads comprising small power and lighting (p19)*
e) *Perform a load diversity analysis to establish peak demand (p30)*
f) *Understand the impacts of oversizing heating systems (p36)*

MB	In the practice guide – CIBSE Guide F and the Knowledge Base Series – both refer to the Energy Efficient Brief. (MB the reads out to PB the Energy Efficient Brief requirements from KS8)	
PB	Not to my knowledge do we use these guides – but we do write energy efficient briefs for our projects. In some projects such as WWF they come out as a specific project requirement. But generally these come out in the Stage D brief.	
PB	Concerning occupancy analysis as listed - No we do not do that.	
MB	It seems to me with the new occupancy data we create the opportunity to design the systems from first principles – or we could use the 'black-box' approach where we use formulaic principles to calculate the loads. Alternatively I could use a mixture of both formulaic and data, which is a kind of 'grey box' approach.	
PB	But remember buildings have always been designed assuming an empty building as explained earlier – icy cold with no heating in it. I would guess that in most hospitals you go to the heating plant will be over-sized by a factor of three or four times, because it is just the way that the Institute recommends that you size heating	Formulaic – 'rules of thumb' guidance.

	systems. It is mad – but that is how it is done. When we come up against other consultants – we find that our way of doing it is very unusual.	
MB	My challenge is that on the Brighton project we showed a massive difference for the basis of design. Yet there view was the impact on the sizing of the engineering systems was not going to be significant. In terms of cooling loads they said that from our experience the hospital cooling load will be about 70kW/m2. I argued that if we wished to optimise the design how can we do so with such a 'top-down analysis', with such a formulaic approach. Surely what we should be doing is coming at the design from a 'bottom-up analysis?' Surely we should optimise each department – manage concurrent peak demand and size the systems accordingly? Does this make sense to you?	
PB	Sure – of course it does! In a current project the other engineers wish to size cooling load on 150kW/m2 and we believe it should be around 55kW/m2 – I ask them where this figure comes from? It comes from an 'accountants' approach to engineering – which comes from adding all the numbers up and see what they come to – versus an engineering method. What you are advocating is logical – it is clearly the right way to do the engineering. The problem is that many engineers are totally risk averse…they take the absolute worst – case and size the systems accordingly. So if the client goes way at Christmas and turns the heating off – when they return to work and switch on the boiler it has to be big enough to cope with that demand – that is clearly ridiculous – but it is the way that many engineers	Example of the benefit of using building engineering physics compared to an 'accountants approach' to engineering.

	think.	
MB	Can we move onto my analysis concerning gaps in our knowledge? How strongly would you agree or disagree with the following statements?	

Gap in our knowledge - 1: Lack of comprehensive In-Use data, means that engineering designers have poor empirical evidence on which to base engineering decisions. **Specifically the gap in our knowledge concerns the potentially critical importance that building occupancy datasets have on building engineering physics and in particular the impact of building occupancy on accurate energy performance and the forecast analysis of In-use**.

PB	I would strongly agree with that. The corollary to this though is that engineering design standards take precedent over an occupancy driven design analysis. There are standard ways of designing without having to analyse occupancy.	Cross ref-13
MB	I accept this point, and what arises are the big assumptions concerning occupancy and In-use.	
PB	Agreed.	

Gap in our knowledge - 2: Models of engineering analysis can be considered to be imperfect. Models are rarely tested with In-Use data (most often because it is not systematically collected), and consequently the science fails to mature. The lack of testing against reality means that model errors are likely to be repeated from one project to the next. **Specifically a gap in our knowledge concerns lack of knowledge concerning what data could be available from In-Use such that it could be used to inform engineering model design and to validate forecasts of energy use**.

PB	Yes it is an appreciable gap. There are two other issues that go with this. Firstly, that clients are usually unwilling to pay for post-occupancy review. Secondly, a liability one – people often do not wish to know that the building is not performing because it raises question of liability – who is at fault for the under-performance? Then you start to get a ‘witch-hunt’ as top why? This is what BREAM outstanding requires – a back-check of your design.	

Gap in our knowledge - 3: The CIBSE Energy Efficient Brief fails to communicate the importance of In-Use. Specifically it fails to translate In-Use requirements in to building engineering physics in terms of ‘*appropriate values’ for mathematical model based on fundamental principles*’. **Specifically a gap in our knowledge concerns lack of knowledge as to the content of an informed Energy Efficient Brief and specifically the means by which In-Use requirements need to be analysed to inform that brief.**

PB	Yes agreed - the WWF brief may point to some of this – but I am not sure as to how much occupancy featured in that brief, because I am not sure that we prioritised the briefing in the way that you might have done.	Cross ref: Agreed Gap in Knowledge -3

MB	It seems to me that the Energy Efficient Brief is the way that we could bring all of this together.	
PB	Yes sure, this makes sense.	

Statement: *Returning to the theory of building science as it relates to energy use in buildings it is clearly sophisticated.* ***Yet the theory is inconsistently applied, and much of the implementation is based on poor quality data, poor assumptions, and poor validation In-use.***

PB	Yes we are definitely agreed on this.	Cross ref: Agreed Inconsistent application of theory – poor quality data.

The factors that drive performance, and indeed which are critical to that performance, are becoming increasingly understood. Yet post-occupancy studies (the author prefers to use then Term: In-Use) clearly demonstrate the failings in the planning, design and engineering process for buildings to achieve anything like the aspiration of energy performance that client and the project team would hope to aspire to.

PB	Yes we are agreed on this. There is also a lack of expertise in the client and people are reluctant to step up to take responsibility. There can also be changes in the client organisation over the period of the project and new members can also be reluctant to take responsibility during a period of such change.	Cross ref: Agreed concerning factors impacting poor performance. Cross ref: Barrier to improvement: clients not willing take responsibility for energy efficient briefing.

Statement: *From the literature review it is also clear that a common issue that impacts both practice and research in the field of forecasting and designing for optimised energy In-use, is the lack of In-Use data in the public domain. To characterise the response in practice to this would be that it relies substantially on standard guidance (such as CIBSE design guides) and formulaic principles. Some of these principles are even enshrined in the recent standard: EN1521, designed to support the Energy Performance in Buildings Directive (Op Cit). Nevertheless this clearly positions what can be considered 'best practice' despite the obvious deficiencies. It appears to be common in practice to make numerous assumptions concerning the factors that drive engineering design and consequential energy consumption. The need is clear: an effective form of communication of In-Use requirements aligned with engineering design strategy.*

PB	Yes – the main danger in a big hospital – There is a reluctance in industry to 'hang ourselves' on what the software tells us…so there needs to be a sense check on 'what my gut tells me.' If your only sanity check is to go back and look at CIBSE 'rules of thumb', you cannot because you will be finding that your results will be telling you a 1/3 or a ¼ of what the 'rules of thumb' were telling you. The industry still does not trust the software enough – would engineering designers, control specialists risk their careers on a piece of software? I met one of Germany's leading green design specialists – he has been really frustrated by the control engineers who are incapable of designing the control system to respond to their reductive design strategies…it was not that the analysis was wrong – but that the controls were not doing what they were supposed to do. So the client goes back to the designer and accuses them of incorrect design. It then took six months of un-paid work to prove	Cross ref: Risk of reliance on software. Cross ref: Danger of inadequate commissioning.

	that it was the control design that was wrong and not the basis of the design.	
MB	It is partially why I feel that having users take responsibility for control would help to remove some of the complexity of the control system design.	
PB	Yes this makes sense – but I go back to my earlier point – if I have designed around standard guidance then if the design is wrong I am less likely to be sued. If I work outside the guidance, then I am more likely to be sued if something goes wrong. This is the real fear in the industry, which holds us back from improving. So if your occupancy studies are to be the basis of design, and the client would prefer to use these rather than basing the design on standard 'rules of thumb' – then Professor Bacon will you take responsibility for the results?	Cross ref: Risk of working outside standard industry guidance.
MB	Patrick thank you so much for your time and insights – really appreciated.	

A1.4 Transcript of interview with Mr. Stephen Runicles[2]

Matthew Bacon (MB)	Steve I really appreciate the opportunity for this interview – thank you.	
Stephen Runicles (SR)	It is a pleasure to help.	
MB	As explained in my email, I have extracted a number of statements from my Thesis and I would like to obtain your views on each statement. I am not necessarily expecting you to agree with them, because it your views that are most important to me. So the first statement:	

Statement 1: *In the wider construction industry, Bordass characterised the poor relationship between design and operation as the 'Great Divide'. Whilst he was writing in terms of another process, the sentiment provides a very helpful insight into the wider disconnect that was evidenced in the PROBE studies (Bordass et al., 1997). A key reflection of the author has been that because of the 'Great Divide' assumptions become an inevitable part of the whole process. If designers either do not have access to adequate briefing data or information they will make assumptions in the design. If users do not understand the impact of design decisions on their working practices they too will make assumptions concerning the impact of them*.

Question: What is your experience of the inadequacies of briefing data…

- How do you manage assumptions concerning In-Use?

SR	Most briefing processes focus on performance – it tends	

[2] For CV please see: http://www.bdp.com/People/Directors-A-Z/P---S/Steve-Runicles/

	to be the peak performance that is required. So if you were to purchase a car you would say: "I want this size of car – this size of engine". In a building it tends to be I need x amount of power, this is the temperature – this is the humidity that I want. So there tends to be specific numbers. They are all about designing capacity. One of the big issues is how to you decide what are appropriate diversities? Working out the peak is very simple. So how does this all come back to the architecture of the system. If you added all of the parts together, then it will be two or three times bigger than the 'animal' needs to be. So the skill, the judgement might be trying to understand as much as possible from the client what the diversity profile is. This is the biggest challenge that I see. I agree with Bill Bordass concerning the divide between design and In-Use. Designers require the expertise of those that operate the building. If that is not available within a briefing team, and often it is not, you are left with trying to elicit historical knowledge from that user.	
MB	My experience is that a lot of briefing tends to focus on 'what is required' and too little on 'how' the facility is to be used. I believe that you will try to infer these aspects of use from the architectural brief – and make assumptions where you need to, if the brief is unable to provide the information that you require.	
SR	Yes	
MB	In the 'how' of use, I was pleased to find that from the CIBSE guides much about the need to understand about the 'how' of In-Use. Yet in all of my experience on major projects, I have never had that dialogue with the engineer. What is you attitude as a practice towards this need? Do	

	you have a briefing process, that attempts to elicit the 'how' of use?	
SR	It varies like all things, on different teams and different projects. You are having to make a judgment as to when these things are required. You have to know what is required. As a practice we use modeling a lot. We try to establish a model profile of use and have discussions with the user and try to get some understanding. We find that the client is more interested in building form and size. One is always pushed away from going into too much detail and this brings more assumptions at the early stage of the process. One of the things that I have noticed in the industry – it does not happen so much in our practice, is that design like anything is an iteration, during the design there is an evolution. It is important to check those early assumptions and revisit them.	
MB	Is that a formal process in your practice?	
SR	Yes it is. We do not just refer back to the brief – we consider if the next level of modeling has affected the plant sizes. If when I have done the initial design and I have estimated plant sizes using my experience, and that does not change when the team has done some detailed design work – that is my first question to the team. I cannot possibly have reached perfection on 1% of information.	Process-1
MB	So how do you make all of these assumptions visible? Perhaps you are making assumptions with even consciously thinking about them? How do you understand the sensitivity of these assumptions?	
SR	It is very difficult – we use design stage reports and depending on the type of project – such as hospitals where	

	we have are having conversations with trained engineers, or trained Facilities managers – so we can therefore alter a document that meets their understanding – but sometimes we need to go beyond there understanding. That does pose and issue – we try to play back the key information to them…and information that his driven out information and assumptions.	
MB	Do you think that they really understand the consequences of the assumptions that you have documented in your design report? Do you ever attempt to document the potential impact of those assumptions on the final outcome?	
SR	We attempt to do so – but whether they are properly understood and so understands the impact of those – I doubt if they do...so they see what they wish to see – not perhaps the importance of an impact of a decision.	
MB	From my experience of major projects, my impression is that the client is often not aware of the assumptions made by the design team – and whilst some may be visible – may are not…	
SR	…and many appendices that contain them too…	
MB	…yes true – when they are documented they are buried in reports and perhaps not made as visible as they could be. So the client is being asked to make decisions with incomplete understanding. So it follows that later in the process that the impact of the assumption becomes more obvious, and the design team response – 'oh it is the Stage C report!'	
SR	True…	
MB	Then the lament comes – it is too late to change	

	now…this is what I have been wrestling with in this Thesis – you said earlier that in each project one needs to reset the assumptions…is there in your view, even a theoretical place where you could consider improve the process by having a more formalised approach to the management of assumptions?	
SR	It does not often happen. I try to take clients along with the designs we do. The stage reports are a punctuation to that. However, there is a formal process gateway that we have to go through. We have to satisfy our own quality checks. Clearly there are a lot of assumptions in any design.	
MB	We can return to this later, I would like now to go to the next question.	

Statement 2: *With a focus on In-Use and a subject area concerning low energy – low carbon building performance, the question would then arise as to what aspects of In-Use should be investigated? In reading the RAE report (Op Cit) the clear need is in the development of building engineering physics:*

> *"We are at the start of a period when the application of building engineering physics will become one of the principal drivers in the construction of new buildings. In the 21st Century buildings and their construction must evolve rapidly to meet emerging challenges."*

An implication of this statement could be that building engineering physics has not served the construction industry well if building energy performance has not measurably improved over the last two decades at least.

SR	Yes I have seen the data concerning this.	

Is this the only reason, or could it be that there are other factors that may have lead *to this situation**? For example, might it be the failure to adequately apply building engineering physics in the engineering for low energy – low carbon buildings, or to adequately inform the physics with appropriate data?*** *As discussed earlier, the issue here could be the one of assumptions being made at any of the key stages of the process and which could result in poor quality input data**. No matter how good the physics, the result will be misinformed if the input data is inaccurate.***

Question: What is your view of the statements in bold?

- How much of engineering design is based on formulaic principles, and how much of it based on the thorough application of building engineering physics?
- How much of building engineering physics is compromised because lack of In-Use data and/ or knowledge?

SR	I think that we understand the physics very well, both as engineers and architects. My reflection is that buildings are becoming much more airtight and thus less permeable. They naturally breathe less. What is odd with the data for improved energy performance of buildings is that you would think that item alone would have a notable difference in terms of energy performance over the last 20 years – certainly since the 1976/1995 Building Regulations. But they are not. Now perhaps if you have a building that is very airtight – but it is poorly used – leaving doors and windows open, you will use much more energy. So there are a lot of factors linking – design assumptions that you make as part of the process – part of the interpretation – then bringing that together in applying the physics and science. It is also a fact that the building might be used in a way that was not intended. Personally I find it difficult to separate the two.	
MB	You have clearly identified the issue – an assumption by	

	engineering designers about how the building should be used (to optimise the physics), compared to how the users understand how it can be used – where they have little or no congnisance of the impacts of their use and the design intent. Let me show you this diagram (**Error! Reference source not found.**)…CIBSE benchmark data suggests that 400kWh/m2 should be typical hospital energy performance – comprising regulated and unregulated consumption. Going back to the 1980's – 1990's we see poor asset performance relative today's asset performance (driven for example by air tightness) – but today our In-Use of healthcare facilities is completely different. So what I have theorised in this diagram is that reason why it has not improved is because we have been very poor at managing In-use.	
SR	I think that you are right. But I also think that over the 30 year period of your illustration – are we actually using our assets more? Perhaps the kWh/m2 or m3 may not be the appropriate metric anymore? Maybe it is not on metric – but the number of patients that it serves? How do you relate this to health?	
MB	Yes I can see that expansion of use could be a significant factor. But in the conversation that we have had on 3T' another part concerns the impact of standards that we are obliged to use in the UK – around the HTM's and quantum of air-changes per hour. Now in the early stages of the project (one of the reasons why we were asked the question concerning comparative standards across Europe) – we carried out a comparison with Finnish standards. If you take the single bed room, the Finns do not use liters of air per person, and the corresponding air changes per hour is about 2.5-3 air changes per hour.	

SR	You might suggest that this is based on air-quality for whatever purpose that might be. Personally I think that technology is one thing that will help us with this, so that we can reliably measure air-quality issues, and this is about spaces being more responsive to how they are being used rather than having affixed condition.	
MB	Yes – this is how I see it and was a key principle of the controls strategy for 3Ts.	
SR	Yes – there are certain parameters that are somewhat fixed, such as not re-circulating air. Perhaps it is like treating water more than once – and we do. Sometimes we are treating air that we do not need to condition and put energy into delivering. But I think in terms of air change rates, I think originally a lot of these requirements were translated from empirical standards in terms of opening window areas. My recollection 30 years ago was that we use to talk about 2.5% floor area for ventilation in buildings - somehow, I do not know where that became equated to six air changes per hour. There is more science in what these should be, but many of the standards tend to be worst case. It is said that the air flow rate gives you a positive air flow regime which is better for staff and patients – I do not think that is true.	
MB	So there we are – we have this formulaic that I write about…	
SR	Yes I fully agree…	
MB	Which engineers are used to providing because it effectively leads to over-capacity. A number of engineers have said to me we need future flexibility. Even if we are over-designing that extra capacity will cover us in the future. But my counter argument to this is that the client is	

	unaware of this situation – it is indeed a major assumption on the part of the engineering team…what is an assumption behind an air-change rate? You know that I have argued on 3Ts that we need to understand the actual need for future flexibility - can we quantify that risk?	
SR	I think that is definitely an area of design – design is a bit strange – it should be more joined up and it should run alongside…in the same way that we should reset our assumptions during the design – during the use of the building we need to be doing the same thing – just as you have described for 3Ts. We need to return to the assumptions in the design during the In-Use phase and retune the systems accordingly. On 3Ts there is comprehensive documentation that considers in details every system and the diversity considerations for each. I do have some criticisms of it, and some praise for it – because it was very detailed and discussed in detail with the client. It rarely says 'we will just go for the highest'. It tends to be that all future flexibility are additions to the systems. But you can argue as you have done that future flexibility can also involve reduction or more use.	
MB	Yes my arguments exactly – and as you know I expressed concern in the report that future flexibility is not just about growth – it is too simplistic to consider just one factor like this. There is much evidence in the health sector that facilities should get smaller – examples such as decentralisation. I am working on a project in Leeds at present where the objective is to move services out into the community from the larger acute facilities.	

SR	Personally I do not like future flexibility – it comes a problem in 'series'…I have focused on what they require at present…but I also have to consider future diversity not across the whole system but to each part of it? I have to consider how to you apply future needs of diversity to each system.	
MB	Part of this however is concerned with how you approach system design – either in terms of 'top-down' engineering based on experience and formulaic guidance. A kind of 'black-box' approach to systems design? How much is pure engineering from first principles, a kind of 'white box' approach? What I am thinking is that if we set aside anything concerned with professional concerns of failure and conceive a purist world, where we say that we wish to drive for low energy – low carbon performance – would we not be tackling all the basis of our assumptions – i.e. reset all of those assumptions? Would we not be saying: now we know what we know – would we not be tacking all of those assumptions and testing against our knowledge of building engineering physics? So from this consideration we would be able to say: 'what more do we know about building engineering physics that could produce better – fine tuned engineering design?'…	
SR	Hmmm bravery probably! I think I need to play back on a couple of issues there – firstly the engineer cannot solve it all, and the engineers are converting something that has been given to them. You only need as much engineering as the space or volume that needs to be treated. If we are going to reduce our consumption of resources whatever those might be, in whatever form they go back to…energy, money, water –or whatever. So our buildings	

	should be smaller – not bigger. So if you look at your comparative data from the 1990's to present day, you will find that treatment spaces have got bigger. Now if you have a bigger space – all of those spaces needing treatment, then if you take ventilation as an example, the bigger the volume the more that it needs. If you have prescriptive standards, unlike the Finnish standards where you have six air changes for a ward or Single Bed, it is six air changes multiplied by the volume. If that volume has morphed into something of the acute hospitals of today we are inevitably going to consume more. By making them bigger we are neutralsing the benefit of improved asset specifications.	
MB	That maybe one way of explaining it – but of we look at the NHS SDU carbon emissions graph showing performance against the CRC we find that in absolute terms carbon emissions are rising, not falling. So I argue that to move towards the CRC we have to reduce absolute emissions, even though we are growing the capacity. My argument is that we will not achieve this through asset specification – we have to achieve it through a fundamentally new approach to In-Use…because energy In-Use can be factor of between 3-5 times the asset demand.	
SR	In carbon foot-printing – some people say at least 10 times…	
MB	Whatever it is – it is a lot…	
SR	Agreed – it is a lot…	
MB	This I why I believe that we need to focus on In-use…	
SR	The economic approach to this was we both know if Whole Life Costing…but it seems to me that decisions	

	would be better made if we were to test and run our simulations based on a 10 – 20 year life. Ultimately that is where we need to be. But the challenges and difficulties such as you have in developer lead projects is that it has a shelf life of a period which far less than the building life and that is until he sells it. If we as a society wished to do one thing to reduce energy consumption (not carbon) that would be to replace the existing building stock…but not replace with buildings that are substantially larger. We did a study for a university to consider the benefit of new build replacement to their existing building stock compared to refurbishing. The study showed that over a 20 year period it was better to keep the asset until it had reached the end of its useful life. Perhaps our models of care should adapt to the facilities that are there – not to adapt the stock to the new model of care…	
MB	This is part of the decentralisation debate. In Leeds they have done just this by moving services into existing community buildings. But returning to the question…!	

- How much of building engineering physics is compromised because lack of In-Use data and/ or knowledge?

MB	Think of the analogy of a white box – grey box – black box – your intuition as an engineer is to work in the grey box – but would prefer to work in the white box – but you have insufficient data…	
SR	I think it is unlikely to ever enter the white box because of a lack of information there is obviously a higher uncertainty, and as soon as there is uncertainty – whatever we do - we compensate.	
MB	Yes – so this is where these assumptions come in?	
SR	Absolutely. It might not be about just over-sizing, but the capability to just add something. Obviously if you have a spare space for a generator – there always seems to be a need for them, even though we rarely have power failures. The fact is that you have built a volume of space to enclose it – but perhaps the future is that you could add a module – but not actually building and having to illuminate and ventilate the space. Space and volume as I have said is the biggest issue.	
MB	Let me cut to the chase…I argue that Occupancy Analytics is an addition to building engineering physics…it is a key component of understanding In-use, where assumptions are made about how and why people use space. So this is a big unknown – what we have seen as Brighton is a massive opportunity to reduce space and therefore volume and this could make a major impact on forecast energy consumption.	
SR	If you are able to demonstrate the benefits of that work, and it is brought into the briefing process, that is the bit of In-use that rarely gets articulated in the brief. I love the analogy where you showed that there were 20 consultant	Process-2

	rooms – and yet less half of the consultants would ever be on those spaces at the same time – otherwise the department's out in the hospital are not functioning. So your study show that this is the kind of smart building that we need to understand. It is smart building that can adapt to that.	
MB	Let us move on…	

Statement 3: *The author reasons that if it were possible to understand how users need to work in the building and to use that understanding to inform the building engineering physics then the design process through the brief, then it might be possible to use ensure a close fit between design and use – the very issues that Bordass was alluding to in the 'Great Divide'.*

Question: What is your view of this reasoning?

c) In those buildings designed for a client-user, how well do you believe that you understand forecast use?

MB	I see the potential in this kind of dialogue of not just a better fit between design and use – but the design of an engineering system able to be optimised for use because users would understand the impact of their working practices (operational policies) on the energy and carbon	

	performance of the hospital.	
SR	Yes – a very interesting thing to try to achieve. Because in my experience users behaviour does change if they are given appropriate information. I think of times when I worked in London before train information systems were provided. Waiting for delayed trains was very frustrating and we used to behave badly because of that – but as soon as we were provided with this information we behaved differently – a lot more considered. I think that we have to discover what information changes behaviour and engage people with the information.	
MB	This is what I have been pursuing on 3Ts – developing a dialogue with the users to establish what information – how that information should be provided to them. This is part of the monitoring and controls strategy.	
SR	Yes there has to be a fundamental change at hand-over. But I also think that there is an issue around Soft-Landings where the user will not get the best out of the system without the support of the engineers. But users need to be incentivised to use the facility better – incentives can be a very powerful means of bringing about change.	
MB	Yes – this is very much part of my thinking too – how we get to change users attitudes. I am reminded of the post-occupancy studies of the Scottish Parliament building where the engineers were quoted as saying: we did not understand that (in relation to the MP's offices) they were going to be used like that. The users response was that we did not understand that they were designed to be used like that…all the issues of the 'Great Divide'. So windows were being left open and opened when they should not	

	have been, and consequently the system became unbalanced. So we see an EPC value…	
SR	..a capability rating…	
MB	…yes understood, but so different from the DEC rating. I know they are different…	
SR	Yes – perhaps to address the 'Great Divide' we need to work on how closely the DEC could be managed according to the design and visa versa.	
MB	Taking that point, I have the TM46 data. It shows just how big an issue this is. It is shocking how different the design meridians are compared to benchmark performance In-use.	
SR	This arises because notional design is this 'black-box' where you feed a certain amount of information into it and out comes the information. The software does what it is designed to do and it does not reflect In-Use.	
MB	Yes I do understand that. My point is that the client see the capability of a high-performing building, but that performance can never be achieved.	
SR	I was not defending it, because I have seen engineers assuring the client that is how his building can be expected to perform – so you are exactly right that the client is often mislead. I would like to add that the client does not sufficiently understand or that the advisor has not sufficiently explained the context of this capability. But going back to the users needing to understand something of the engineering (I think it is more than that), but I do think that there are many users who are not interested in either a detailed or even an influential understanding – because their attitude is that someone	

	else can deal with that. If we make the lowest energy option the easiest to use, then the majority of users will use it. But I think we (our profession) does a lot in design because of convenience.	
MB	My research shows that there is a big gulf between the actuality of use and the impacts of use…in practice it is predicated in assumption, and in theory the attempt to reconcile the two has been though modeling of uncertainty. So on 3Ts when we had this big debate about CAV (Constant Air Volume) and VAV (Variable Air Volume) – arising from our analysis of the diversity of use. Collectively we agreed that a design strategy based on CAV was inappropriate and that a VAV design strategy should be considered.	
SR	Yes a demand based system…but we do have technology to help us achieve this – I do not think that this necessarily means greater complexity. Many in the industry would say: 'you cannot run the risk of putting modulation in hospitals', but I would argue that we need modulation because without it hospitals can become unaffordable to run. What is the biggest danger? Modulation however is complex and users need to understand the impacts of running a modulated system – users must have the capability of using them. I know from experience that modulated systems require higher levels of maintenance and attention and so it shifts the economics. There are capital issues but they are expensive to maintain over the life-time of the facility. However, it should always pay back, but in hospitals it is imperative that the system is properly funded through its life-cycle.	

MB	A few engineers have I talked to say that it should end up with a much smaller system – I also consider how spaces would be used – not so much from a quantitative position such as how many occupants but their attitude to the use of space – users respond by saying: "we have no proper understanding of the impacts of use on space, save for switching off lights and monitors". I suggested that users could have responsible control – even so far as compromising on indoor air-quality, because we all can have such varying physiological responses to our environment. These considerations too can lead to less demand on the ventilation system for example.	
SR	Ventilation systems tend to do pretty much what they need to do, but the control is not necessarily visible to the users – perhaps it is through a help desk and re-tuning takes place through a central system. However, I recognise too that there is a level of control that is required by the user, because it is convenient.	
MB	Agreed, but to expand on this I am suggesting there needs to be a dialogue with users as to where on the spectrum of control they are willing to intervene?	
SR	Yes agreed – so that would then impact the system design in terms of either a smaller or a larger input change. We do have systems that will also constrain control through configured parameters such as +/- 20%, as long as they did not step outside any health care/ health and safety criteria.	
MB	On 3Ts we considered an alternative position where we allow temperature to float by up to +/-2 deg C in certain spaces.	
SR	Like Florence Nightingale wards…go back to having	

	capes!	
MB	Recognising our different capacities to tolerate different levels of Indoor Air Quality. So I reason that if control is a key aspect of driving down energy consumption, then we need to engage the users because they can push for reduction in demand much more than could be achieved from an automated system. In discussion with user representatives they were willing to consider the possibility of moving outside the norms of established parameters in control within office type functions. This would means that ventilation rates, lighting and power would be subjected to user intervention in control.	
SR	Yes this make sense.	

Statement 4: The UK Green Building Council (Op Cit) report stated:

> *The most significant development in building science over the last thirty years has been the development of computer models to assess the energy and environmental performance of buildings. These models are now regularly used to assess the potential impact of energy efficient technologies in the design and refurbishment of buildings.* ***However, when buildings are refurbished or new buildings built, they can use up to twice the theoretical energy performance. This is a serious problem, which can significantly impact on the potential for the world to achieve carbon reduction targets.***

The report then goes on to state:

> As things stand, the building industry is unlikely to achieve model-based targets in reality and this problem needs to be addressed at a national level. **The causes of the discrepancy between model predictions and actual building energy use**

must first be understood, then incorporated into model structure, input data requirements and the ways models are used. These methodological improvements need to be based on sufficient empirical data rather than further modelling. The tools used in design consultancies need to be able to predict real building energy use, and national policy needs to enable the design process to do that and mandate that it does.

Question: Why do you think that these discrepancies exist?

d) Do you agree that it is empirical data that is missing?

SR	Models need to be validated. If you build a simulation model – validation against actual consumption is essential. In the mid 90's CIBSE carried out a comparative study of a thermal modeling programme and found that not one programme gave the same answer because of differences in the way that modellers used the software and made assumptions.	Cross ref: In-use data_5
MB	I think that a key part of the problem is that we because we have a poor understanding of use, we have a poor correlation between energy forecasting and forecast of use through statements of intent defined in operational policies. Surely it stands to reason that if modellers do not understand use, then the models will be inaccurate?	
SR	I agree. The more detail that we can get from the user then perhaps the better our forecasts will be…but on 3Ts the assumptions that we made were early on in the projects. Our thermal model was nothing like as detailed as your Whole Facility Energy Model, and it just goes to show that if you have the appropriate input data it was quite significant. So the more information that you have got (and it has to be the right information) …in hospitals	

	it can take between 5-10 years before the building gets switched on. By the time that the hospital does get used, then the users should review how they plan to use it. So by the time that is constructed it could be at least 5 years old. The time delay from initial briefing to use can involve a substantial difference in energy consumption.	
MB	The proposition that I put to the 3Ts leadership was that the planning for In-Use does not stop, and In-Use there needs to be an on-going review and re-configuration based on new practices and operational policies. Consequently the scenario that you describe is not 'freeze framed', but is part of an on-going process. I envision that we hook up our simulations to the BMS though an In-Use database. A change management team works with the facilities engineers to optimise use and thus facility configuration over its life.	
SR	Maybe a design engineer would be part of the team… I agree …I can get very excited about this concept! It is not dissimilar to my car, where it flags up when something is on the way (an amber light) to needing a service. So what is happening is that all the millions of pieces of data are being checked against various parameters. In the same way we can do that with a BMS. I agree that the simulation programme should be running alongside the BMS during the life of the building.	
MB	I think that we are in complete agreement as to what we need to achieve! I think you are endorsing the philosophy – where we have to have a close dialogue with the users.	
SR	Yes I am – totally. The best thing for me is that the client does not get to the end of their first year of operation and finds that the energy costs are completely wrong.	

MB	With this alignment the question then arises how do we get this understanding into the briefing process? How do we go about gathering this information? So I go to CIBSE guides and I look for the evidence of a briefing process that will enable us to get an understanding of In-Use. Further investigation reveals a large disparity between what is required in CIBSE Guide F – the Energy Efficient Brief, and the Knowledge Base Series. Guide F is completely silent on occupancy briefing, but the KBS6 goes into great detail about it. Have you ever used the Energy Efficient Brief guidance?	
SR	Not specifically, but we have carried out a study on quite a small building. It had a limited number of spaces…but with 12 rooms we understood exactly how they would be used. But rarely do we develop such a brief.	
MB	In one of my interviews for this Thesis the interviewee said that they rarely got the opportunity with the client to produce an Energy Efficient Brief. The conclusion was that it requires an enlightened client.	
SR	I think that you have to guide the users through the process…you have to know what aspects of the brief are material to the design.	
MB	Yes this is so true…hence my study of the science to understand what is critical to it that determines the outcome. In my experience at BAA, I found that engineers would typically respond to a brief as though it is a static requirement. It occurred to me that if users were to understand the potential impact of their brief on the outcome energy performance, then they might question this and say: “do we really need to brief that”…so if they were to understand the impact we could then do	

	something about it…change the brief …modify operational policy. This then leads to the concept of Peak Load Smoothing, so that we could manage required capacity through this process.	
SR	I think in engaging the right users is the way forward – but part of it is about briefing …but it is more than this…	
MB	Yes I think that there is a part of briefing that is a dynamic process…	
SR	Yes this is so true… that is what I was trying to say. I think that the difficulty of the briefing process – but there is a difficulty finding people in the briefing process that are either interested – prepared to take the responsibility. Maybe they do not have the time…yet if I were to refer in brief to an Association of Consulting Engineers (ACE) requirement or a CIBSE requirement – people will be satisfied…that is enough!	
MB	My belief is that in order to optimise forecast performance we need to see the dynamic elements of the brief as an iterative process with the client…if you have the right users in the process. I see the need is to translate the Operational Policy (the language of the user) into an Energy Efficient Brief (the language of the engineering designer). So this is how I envisage that we need to 'Cross the Great Divide'…does this make sense?	
SR	Yes it does, and I see something in the work that you have been doing that you go into these consultations with a model already built. So when the client says I want 'X' – you can show them what this actually means.	
MB	Exactly what we have been doing…	
SR	Yes I know – this is what I find quite fresh…something	

	that we have the ambition for, but maybe not the time.	
MB	The users respond very well to it. We took them through a process where they were able to challenge the input data – the model logic and the results. The workshop process was organised into two stages, so that in the first stage they were given the opportunity to challenge the input data, and if there was new data, then we would re-run the model before the second workshop, so that they could come to this, knowing what the consequences were. We found one department where space had been significantly over-estimated, and through consultation with the 3Ts leadership team the view was that we had provided an empirical basis on which to challenge the space allocation in the brief.	
SR	Yes I can see you have consultations with specialists who are experts in their field…a fantastic opportunity. It can provide a great basis for challenging standards, although there are occasions where the clinician is adamant that a space will be serviced according to a specific standard. Yet standards take years to evolve and when do they become 'time expired'? So how reliable are the standards for what we are attempting to achieve? Tricky.	
MB	Another 'tricky' issue concerns your process on 3Ts and what we have been doing alongside you. My reflection of the process …and I want you to challenge this…is that given the stage of the process that you were designing in, you naturally took a 'top-down' perspective of the engineering requirements. You made statements such as 'our experience of hospitals is that there would be a cooling load of 'x'…is this a fair reflection of the process?	

SR	Yes, they are based on some calculation, but I must also say that some detail applied badly is more dangerous than formulaic ‘top down’ applied well. One of the key early milestones in any hospital is the physical sizes/ space for transporting fluids and gasses around the facility – even before any detailed data is available from full briefing. On 3Ts if I was to put in request for detailed room data for every engineering element that would be considered a poor approach. So the top down approach needs to take place in the context of an iterative process. So there is an equal criticism if we are asking for too much space – because it could destroy the viability of the scheme.	
MB	There is an interesting dichotomy here…	
SR	Yes there is…	
MB	So informed judgments need to be made in the early stages based on limited information?	
SR	The earlier stages are broader iterations narrowing to a point that gives you some confidence that you have got the right size, in terms of the physicality of it, but also the budget. You will never take a job beyond Stage D if it is over budget. Also nowadays Planning is taking place between State C and Stage D. But this means the less robust - less accurate that the design is at that stage.	
MB	What I was thinking here is that you could use of work in a ‘bottom-up’ approach to use the data as a ‘sanity’ check where you compare with your ‘top-down’ assessment. So I reason that we now have better quality information to give the client a better understanding of what they are going to get, and so narrow the variability that concerns you.	

SR	Well the study that you did on 3Ts is a replica if you like, a parallel study in a different level of detail. It is relatively easy to splice parts of that study that either reinforce or challenge the more robust assumptions that have been made. If you were applying this to the wider industry – other projects – all we need is more data to validate those types of models.	
MB	Many would say that M&E budgets are too inflated. In one discussion an engineer explained to me that when we have the opportunity to develop the design from 'bottom-up' (AKA first principles), we can typically reduce system sizes by at least 1/3rd. So when a client says to us: "you are not going to do any modeling – you are going to rely on your experience as engineers", you end up with one solution. If you are able to engineer bottom up we will end up with a much smaller system.	
SR	I alluded to this when we were discussing these issues on 3Ts. I may not have been completely obvious about it. But there are three key components in what I said, in terms of sizing systems. We have an allowance in there for design development, because of the stage that the design is at. You could say it is 10%. You have then got a brief for flexibility (an assumption) of another 10-15%. Then what you are talking about is another level of detail, which allows you to reduce the broadness of some of those assumptions, and fine tune it. Then I can completely agree you – if you take these factors out and model for defined capacity – you have intelligent management of use (such as what you talk about as peak lopping) it is actually about shifting use. If you get too busy in a day you have to spread things out. Hospitals cannot afford to staff all the areas and do three times the volume of	

	patients – because spaces get bigger – they need more staff – it becomes unaffordable.	
MB	So I reflect on this work and ask: “what is the impact on the design process?” One could say that now we have this better quality of empirical data (as advocated by the Green Building Council) let’s compare the results with the ‘top-down’ study and the ‘re-set’ the assumptions that you talked about earlier. So if you took 75kW/m2 cooling load or whatever it is (based on your experience) – but the data is actually showing 50kW/m2.	
SR	But even if it is only 72 – is it 72 that should go forward…or less. But I do completely agree with that. I think that the most important aspect of your work is to get actual information that reinforces and validates – if you have proven information. This industry does not have enough current and detailed information – because it has to be detailed – you have to understand the assumptions. The forecast if the Churchill Hospital of 38GJ/100m3 – there will be a lot of assumptions built into that figure. Does it include the ground source heat pumps – does it not? Does it include unregulated and regulated or not? So many different figures. We need more data – but we need to share it. Anything that can validate the models – will provide you with that re-set.	
MB	I think that this issue (what you refer to as validation) I think of as calibration – we have two forms: Firstly what some refer to as ‘post-occupancy’ – A form of engineers that I have been taking to in New Zealand say that after the first year of operation we measure performance and expect to be within 10% of our forecast. Yet they had also informed me of the substantial assumptions that they have to make at an early stage of the design process. So I	

	argues that I could not understand how a forecast can be accurate within 10% if you do not know anything about how this building is going to be used. So how is it calibrated? Is it independently calibrated?	
SR	Agreed that is how calibration must be performed. What if a user has a bright idea – let's take lighting – a space with say 500 Lux – actually the staff do not need that – they have a little dial on the wall that allows them to turn it down. If my eyesight is getting poorer – then I require more light. Others do not. I went to the Royal Berkshire Hospital at the weekend - it was the first hospital that I have walked into in the last 10 years at least that was not over-heated. I would have guess that the temperature was around 18-19 deg C. – It was 7 deg C outside. How many hospitals do we walk into that are operated at 25 deg C? So I do like this idea of going back to the user control – but we have to incentivise it.	
MB	Agreed - users need to understand the impact of control both good and bad. I would now like to turn our attention to the Gaps in our Knowledge, and I would like to know whether you strongly agree or disagree – (or anywhere between) with each statement.	

Gap in our knowledge - 1: Lack of comprehensive In-Use data, means that engineering designers have poor empirical evidence on which to base engineering decisions. **Specifically the gap in our knowledge concerns the potentially critical importance that building occupancy datasets have on building engineering physics and in particular the impact of building occupancy on accurate energy performance and the forecast analysis of In-use**.

SR	I would say ‘insufficient’ as well as ‘poor’ because it is out of date – a lot of it is out of date. I think that occupancy is a key component – but not the only component – lots of other things such as the way in which space is used.	Cross ref: In-Use data
MB	OK I need to clarify that I am talking here of not just the quantification of occupancy but the impact of use of the occupants.	
SR	It is the way that energy works and particularly large scale systems – you cannot get an instant response from a system that travels 4-5km. So you expend a certain amount of energy having it available. So that is where I would say that occupancy In-Use has the largest impact. But there is a big energy bill associated with readiness.	
MB	Isn’t ‘readiness’ a user decision? This would be part of operational policy surely?	
SR	Yes ‘readiness’ is calling for a demand. It is a bit like hotelling – where the room is not brought up to condition until the user has arrived – but what if the users turns up much later – or not at all. An automated system cannot do this for you. This is where the user can significantly impact consumption as you mentioned earlier.	

Gap in our knowledge - 2: Models of engineering analysis can be considered to be imperfect. Models are rarely tested with In-Use data (most often because it is not systematically collected), and consequently the science fails to mature. The lack of testing against reality means that model errors are likely to be repeated from one project to the next. **Specifically a gap in our knowledge concerns lack of knowledge concerning what data could be available from In-Use such that it could be used to inform engineering model design and to validate forecasts of energy use**.

SR	Absolutely, if you do not understand how those assumptions are fed – you cannot inform the design. If you are unable to get the granularity you cannot understand what cause is having an effect. You make different decisions based on the level of information that is available to you. But perhaps the first port of call is not the building engineering. The building physics – the building science that you talk about I think is something that is the right size that provides the right level of functionality. You could also say for example (you probably have!) that through your peak load smoothing – your staff profile could be 20% smaller. So there is a chain reaction…not just on the staff bill – do you avoid running shifts at night when you need extra lighting? Do you need less toilets? Less capacity.	
MB	So what is the leanest that you could run this hospital at? This comes round nicely to the third point.	

Gap in our knowledge - 3: The CIBSE Energy Efficient Brief fails to communicate the importance of In-Use. Specifically it fails to translate In-Use requirements in to building engineering physics in terms of '*appropriate values' for mathematical model based on fundamental principles*'. **Specifically a gap in our knowledge concerns lack of knowledge as to the content of an informed Energy Efficient Brief and specifically the means by which In-Use requirements need to be analysed to inform that brief.**

MB	Just to explain this – I read around the subject of building modeling and the data sets that the modellers use. I studied thermodynamics to understand the scope of calculations used by engineers. So often the observation was made that "we do not have the appropriate data".	
SR	This work has reinforced to me that probably the most critical consideration in assessing the capacity of the system is its diversity. It is an aspect that I have seen the least guidance on. Because there isn't the data – it is not sufficiently detailed to enable the engineer to understand if it is applicable. I recall that when I started in the industry questioning the difference between a VAV with diversity and a Constant Volume System? The engineers in that company would say in the order of 60-70% of a CAV system. So they check with the FM team and in the first year of operation they find that the AHU's have indeed been running at 60% of capacity. I assume 70% I have my capacity set up. So If I was asked this question now – that is where I would start – but we need better data.	

MB	I reason that a key addition to the process of delivering low energy – low carbon hospitals is the Energy Efficient Brief. If we have better quality data to make better informed strategic decisions – space and volume as you state…	
SR	Yes there is a hierarchy – a major impact is building volume – the function of space. How may functions you build in and the size of it – in ventilation terms this is the most significant influencing factor in the size of systems. That chain reaction of how much air do I put in, affects the electrical consumption – affects the heating system sizing – it affects the cooling – affects the plant roof space – the riser sizing – just such a dramatic impact. If you halved your ventilation you could reduce your risers by 25%. Your building envelope shrinks. There is no doubt that smaller is less energy. From the engineering perspective the most critical issues is to get the briefing for the functionality correct and of course get the scale right. This also related to the work that you did – not just on the population but the flux. 'Right-sizing' is of fundamental importance to the Energy Efficient Brief. I sometimes feel that I have inherited a scheme that is 'greedier' than it need be.	
MB	We talk about this chain reaction – what would then follow in the Brief?	
SR	One issue is concerned with capacity and one is concerned with annual energy consumption. They are inter-linked. So I think that there are performance standards and criteria. So the standards which you must achieve is crucial. The speed of response is an issue. I think we have a bit if a hang up on responsiveness – so using your example of hot water delivered to the outlet in	

	3 seconds – this requires systems to be over-sized. For example if we were all to have Combi boilers in our houses and thus instantaneous water heating – could our gas network cope? Our instantaneous draw on resources means that we need bigger pipes everywhere. This is your scenario isn't it – get the users to understand the impact of their working practices?	
MB	What I am trying to get out of the Energy Efficient Brief is to tease out what the key components should be. As we work through the design stages – what should be drop into this brief?	
SR	What is the performance and when is it required? We need hourly profiles of use. Profiles reliable for that type of department. Profiles ideally calibrated by real data. How much and when. Imagine that if you were to have 100 spaces the diversity of profiles could be quite different.	
MB	Yes this is very much how I have envisioned this – hence the discussions with each department to discuss their preferred use of the space and the tolerance for use in terms of what compromises they would be prepared to make under different operating conditions. If you recall we carried out a study to consider the energy impacts of an aggressive profile of use in order to determine the potential impact of that profile on overall consumption of Outpatients. It seems to me that it would be very complex to configure an automated profile that has so many 'variables in it that it would become overtly complex to run and maintain.	
SR	Maybe sometimes the size of the simulation is too big. Perhaps where you have modelled and identified larger	

	consuming departments – you model those specifically? You do not want the over results being diluted by other ‘low performing spaces’.	
MB	Some departments were very receptive to the vision for low energy use, but some were less so. However after some discussion, all departments agreed to support the In-Use strategy.	
SR	If they were allowed say 10% of their budget to control – I would think that they would be delighted!	
MB	Or you could earn so many points for certain levels of performance…a staff training day, or attendance at professional development seminars would be worth so many points…	
SR	The challenge for incentives in large organization is that they can too easily become the sole focus for everyone’s attention and thus detract from the actual performance of delivering effective care…when I started working on 3Ts and Brighton with its Green led agenda – I was looking at carbon credits – how increase cycling and make it a destination!	
MB	It was for this reason that we developed ‘soft-energy’ budgets so that it would not become the sole focus of attention that you suggest it could…then we work with users to understand how best to measure and incentivise – to learn what encourages changes and learn from the users how they might leverage the benefits. I would now wish to turn to three statements – please tell me how strongly you agree/ disagree with them?	

Statement: *Returning to the theory of building science as it relates to energy use in buildings it is clearly sophisticated.* ***Yet the theory is inconsistently applied, and***

much of the implementation is based on poor quality data, poor assumptions, and poor validation In-use. *The factors that drive performance, and indeed which are critical to that performance, are becoming increasingly understood. Yet post-occupancy studies (the author prefers to use then Term: In-Use) clearly demonstrate the failings in the planning, design and engineering process for buildings to achieve anything like the aspiration of energy performance that client and the project team would hope to aspire to.*

SR	Yes agreed.	

Statement: The literature review identifies the need for a close integration of the needs of In-Use with the planning and design strategy. ***Without this coupling, design strategies will be compromised,*** and a lack of knowledge will persist concerning the impacts of In-Use on those strategies. Where this happens, the evidence is clear: inefficient energy use, poor energy performance and compromise system performance.

SR	Yes agreed. There is much higher risk of them either being inaccurate or inappropriate.	

Statement: From the literature review it is also clear that a common issue that impacts both practice and research in the field of forecasting and designing for optimised energy In-use, is the lack of In-Use data in the public domain. To characterise the response in practice to this would be that it relies substantially on standard guidance (such as CIBSE design guides) and formulaic principles. Some of these principles are even enshrined in the recent standard: EN1521, designed to support the Energy Performance in Buildings Directive (Op Cit). Nevertheless this clearly positions what can be considered 'best practice' despite the obvious deficiencies. It appears to be common in practice to make numerous assumptions concerning the factors that drive engineering design and consequential energy consumption. The need is clear: an effective form of communication of In-Use requirements aligned with engineering design strategy.

SR	Yes agreed…there is a disconnect – there needs to be bridging across the gap – we will never close the gap – I guess we need some form of briefing addressing it, or if there is not expertise from the client – we could have models a/b or c and the impacts of these are...so that there are some levels of guidance for them. In terms of briefing 'I want a load of performance criteria' – but I would also wish to know what the clients tolerance is – it would help to inform diversity – rather than just use 'set-point' conditions you could lower the capacity – you can manage the system to adapt somewhat deliver the performance through management of tolerances. I have done with before where we have either had too much power or too little. In terms of a boiler – you shift the mean water temperature, which in turn shifts the capacity of the system. So you can effect change through the management of tolerances.	Cross ref
MB	Much of what we have discussed concerning the brief has been concerned with the tolerance of the client to work within parameters rather than prescriptive absolute values. The Energy Efficient Brief should test users for their propensity towards these tolerances and acceptance of compromised conditions.	
SR	If you have a single room and it is prescribed as requiring 23 deg C and 50% humidity, +/- a control band - that is what I have to achieve. But when you add all of those requirements into a system all the way down the line –	

	you apply diversity against that prescriptive fixed point – if you were able to apply that diversity against an acceptable tolerance – key word being acceptable, especially on a large facility what is the likelihood that you are going to need everything at that same point?	
MB	Exactly my point – we study each department and their individual needs, we study the impacts of concurrent use based on negotiated operational policy – build up your peak profile…this is what I mean as a bottom up approach – we get systems tuned to the needs of the department rather than a ‘top-down’ approach and apportion system capacity across departments. It seems to me that the one-size fits all strategy leads to over-capacity.	
SR	It would do…over-sizing is influenced by users tolerance… tolerance to system performance is very low. We also expect too much so our life styles lead to excessive use, and intolerance of compromise. We need more systems that just go to off, rather than to a set point.	
MB	So all that you have talked about is how users interact with the facility...it is people that cause energy consumption though their behaviour and we need to find the means to influence that and help them understand the impact of their decisions.	
SR	I think that we do – but I also think particularly in hospitals the equipment is a big issues – I have seen chef’s in kitchens leaving gas flames burning because the fuel bill had nothing to do with him. However, I think that people are more connected now with energy consumption – but in non domestic buildings we still detach ourselves from this that pay the bill.	

MB	Yes so true – so we need to address users needs and education in the impacts of their working practices on energy – we need to target 250-300 kWh/m2 and not to be complacent with accepting 450kWh/m2.	
SR	But we must address the multiplier too – if we can meet the need with 70kWh/m2 and not 100kWh/m2 this will make the biggest impact on consumption.	
MB	Steve – I have found this a very stimulating discussion – thank you!	
SR	I have enjoyed it immensely too!	

A1.5 Transcript of interview with Dr. Bill Bordass[3]

Matthew Bacon (MB)	Bill I really appreciate the opportunity for this interview – thank you. I am going to read out some statements and I am seeking your opinion about them. I do not necessarily expect you to agree with them! However, the first one is quoting from you!	
Bill Bordass (BB)	It is a pleasure to help.	

Statement 1: *In the wider construction industry, Bordass characterised the poor relationship between design and operation as the 'Great Divide'. Whilst he was writing in terms of another process, the sentiment provides a very helpful insight into the wider disconnect that was evidenced in the PROBE studies (Bordass et al., 1997). A key reflection of the author has been that because of the 'Great Divide' assumptions become an inevitable part of the whole process. If designers either do not have access to adequate briefing data or information they will make assumptions in the design. If users do not understand the impact of design decisions on their working practices they too will make assumptions concerning these working practices.*

Question: What is your experience of the inadequacies of briefing data…

- How do you manage assumptions concerning In-Use?

MB	So if designers have made assumptions as how the building will be used, and have based their engineering strategy on these assumptions – do the users really understand the potential impacts of such decisions on their working practices? How do you see these	

[3] For CV please see: http://www.bdonline.co.uk/bill-bordass/16782.bio

	inadequacies?	
BB	Hmmm, I think that the inadequacies are widespread. I think it has been getting worse over the years, because less attention has been given to a briefing dialogue – it has got more mechanical. The situation that you were just describing for the health service – you do not get any dialogue with the users at all! In PFI for example, you have this massive brief, if you have got three competitive teams you cannot possibly have a dialogue with one team, let alone three. It is endemic.	
MB	Have you seen any good examples of how assumptions are managed? In your work around post-occupancy have you seen the impact – the consequences of poor or even goo assumptions?	
BB	I have seen many examples of poor assumptions. For example I was involved in a study of one university – where they were evaluating the performance of four recent laboratory buildings. For all, the design assumption had been that it was a 24 hour building, but when surveys were done they found they only had two or three people in at 3:00am. But they still used an awful lot of energy because the engineers had not designed in any demand responsiveness..	
MB	This is a great example of an engineer designing a system without understanding the impacts of a design decision. Perhaps the users do not understand 'how to drive the car properly'…	
BB	Well it is not about understanding how to drive it – there are often no pedals and the steering wheel is in the boot! In terms of the good ones – the short answer is very rarely. This is because most of the good ones are one-offs.	

	They do not tend to be replicated, even in the same organisation. The reason it seems to me – is that to get a good one is hard work. It needs somebody who is really committed and they tend not to be liked in larger organizations– because they bend the rules – they do so to get good results. So I have seen time and again the consequences of this.	
MB	It is what I used to say in BAA – the good projects usually had 'heroes' in the process.	
BB	Yes, you will always find good results arising from one or two people in the project. Ideally it is a team – with the client – designer – contractor. If you do not have these you end up replacing them with piles of process – which become impossible to manage.	
MB	Yes – so you end up with massive of documentation – pulling their last job of the shelf because it is easy to do and they do not think about the consequences…	
BB	Exactly. This is also the thing – I have said this for ages in terms of briefing – it tends to tell you the what and not the 'why' the 'how' and the 'who'!	
MB	Absolutely – this is what I feel too – we will come to this later. All of the work that I have been doing around Operational Policy is all about the 'how'. It is about understanding working practices. For example I discuss how an MRI might be used and we discuss matters such as how the machine is set up. In these discussions we find that some ways of using the machine are more energy efficient than others – but the clinical outcomes is still the same.	
BB	Yes so true. I remember when I was working at a university and the electricity consumption has gone up in	

	the Biology lab and the client was convinced it was a new animal house cage washer having been installed. We looked at it and found they had started to use a row of plant growing cubicles with triple banks of lights inside – each cubicle used about 4kW, including the air conditioning to take the heat out again! So we proposed replacing the bank with about ¼ the number with energy efficient reflectors. The researchers were very much against this – but agreed we could do one as an experiment. They came back and said: “This is brilliant – we don’t get all of this heat from the lights anymore – we do not need the air conditioning messing things up for us!” So it was a win-win all around – much reduced power load on lighting – substantial reduction on the cooling load and better science.	
MB	Let is move on…and think about the kind of data that we need to understand the ‘how’…	

Statement 2: *With a focus on In-Use and a subject area concerning low energy – low carbon building performance, the question would then arise as to what aspects of In-Use should be investigated? In reading the RAE report (Op Cit) the clear need is in the development of building engineering physics:*

> *“We are at the start of a period when the application of building engineering physics will become one of the principal drivers in the construction of new buildings. In the 21st Century buildings and their construction must evolve rapidly to meet emerging challenges.”*

BB	There are two issues here – one is building operational science. In hospitals for example, the building physics becomes less important – it is important at a simple level	

	– but so much is operationally related. The second is a market problem. It is actually easier to sell kit than do your science properly, so not enough value is placed on professionals working on the fundamentals.	

An implication of this statement could be that building engineering physics has not served the construction industry well if building energy performance has not measurably improved over the last two decades at least.

MB	You will know this of course but in health care CIBSE TM46 still positions benchmark performance of hospitals at 400kWh/m2 – we were benchmarking this value in the 1990's.	
BB	There has been no proper investment in benchmarking since the 1980s & 1990s. Since the Energy Efficiency Best practice programme was handed over to the Carbon Trust in 2001, it has largely been neglected. I was co-author of the scoping study for TM46. We reviewed the existing benchmarks and found them inconsistent and out of date. We proposed a new, more consistent approach, with crude starter benchmarks to get things going in the absence of better data. Once DECs were in play, we had expected the government to invest in getting better data. But they didn't, so we are still stuck with the starters.	So
MB	Regardless of the absolute values in TM46 is the absolute gulf between predicted performance and the actuality of In-Use performance.	
BB	Well, the whole purpose of Display Energy Certificates was to draw attention to that gulf. We already knew this	

	from Case Studies, we were told they were anecdotal!	
MB	Ok let us return to the question…	

*Is this the only reason, or could it be that there are other factors that may have lead to this situation****? For example, might it be the failure to adequately apply building engineering physics in the engineering for low energy – low carbon buildings, or to adequately inform the physics with appropriate data?***

BB	It is actually three things: The physics is often fine, the data is often questionable, and the context is often wrongly defined. So for assumptions, let us consider wall construction. There are some recent examples insitu U-value measurement of two walls: a wall in a traditional building that had a calculated U Value of 2. The other is a tolerably well- insulated wall – with a calculated U value of 0.3. Test measurements showed that both had a actual U value of about 1. The issue for the old building was that essentially it was assumed that the wall was solid brick. In reality the wall contained a lot of insulating lime plaster and a lot of lime mortar. The modern building was filled up with 'fluff', in which there were air convection currents, and had massive cold bridging through the timber frame. Essentially because of the lack of investment in the knowledge domain over many years and the absence of good feedback, we have been perpetuating all sorts of errors where the physics in theory has driven the construction further from construction and operational practice. So the physics is often fine, but the context is not properly captured. If you consider the cavity wall by-	Cross ref_10

	pass it was not discovered in monitoring until about 2007. They found that modern, insulated terraced houses lost more heat than detached houses. Why? Because cavities in party walls that had been added for acoustic isolation were open at the top and all the warm air went up into the roof space. An infra-red photograph clearly shows this. Solution: close the top of the wall cavity. Again and gain we have a situation over the past decade or two where the practice has departed enormously from the theory. PROBE showed clearly how greater complexity was the enemy of good performance.	
MB	OK – but don't you think we know too little about In-Use?	
BB	We do not know as much as we should. However, the industry and government has chosen not to tune into what is known. It seems to me they are hostile to a lot of this knowledge. They want to bury that bad news and do not want things to be too challenging. This is why building performance has to be developed as a public interest knowledge domain in its own right and not left to the construction industry.	

As discussed earlier, the issue here could be the one of assumptions being made at any of the key stages of the process and which could result in poor quality input data. ***No matter how good the physics, the result will be misinformed if the input data is inaccurate.***

Question: What is your view of the statements in bold?

- How much of engineering design is based on formulaic principles, and how much of it based on the thorough application of building engineering physics?
- How much of building engineering physics is compromised because lack of In-Use data and/ or knowledge?

MB	Let is move on…and think about the kind of data that we need to understand the ‘how’ of building use…	

Statement 4: The UK Green Building Council (Op Cit) report stated:

> *The most significant development in building science over the last thirty years has been the development of computer models to assess the energy and environmental performance of buildings. These models are now regularly used to assess the potential impact of energy efficient technologies in the design and refurbishment of buildings.* ***However, when buildings are refurbished or new buildings built, they can use up to twice the theoretical energy performance. This is a serious problem, which can significantly impact on the potential for the world to achieve carbon reduction targets.***

The report then goes on to state:

> As things stand, the building industry is unlikely to achieve model-based targets in reality and this problem needs to be addressed at a national level. **The causes of the discrepancy between model predictions and actual building energy use must first be understood, then incorporated into model structure, input data requirements and the ways models are used. These methodological improvements need to be based on sufficient empirical data rather than further modelling.** The tools used in design consultancies need to be able to predict

real building energy use, and national policy needs to enable the design process to do that and mandate that it does.

Question: Why do you think that these discrepancies exist?

e) Do you agree that it is empirical data that is missing?

MB	It seems to me that this report, is not so much discussing the gulf of performance that exists between the EPC and the DEC – it is saying that even when forecasts are produced of both unregulated and regulated energy consumption there is a substantial discrepancy between forecast and reality.	
BB	This is definitely so and this one of the reasons why we put this on DECs to bring this to the public attention. There is an enormous issue about this need for more data when quite a lot of evidence is 'under your nose'…you do not need more data on a cavity wall – once you know that there is a ventilation stack between buildings. It seems to me that more data is used as an excuse for inaction, rather than people proceeding on existing data to move forward.	
MB	Let me challenge that please. I talked earlier about the work we carried out at Brighton and how by really understanding use we suddenly expose substantial assumptions made by the engineers – assumptions they argue that they have to make because of insufficient data – it is not 'under their nose' in this instance…	
BB	OK…if we go back to the models – I have just been speaking to some well known engineers about this very matter…they say that what is happening is that the regulatory model is used for the design model – which	Cross ref

	it should never be…and we know about the tweaks that we can do to all models. Consequently if somebody wants a particular design solution, they can find a model which shows that it meets the regulations. So you get these all glass buildings – despite all of the regulations. What tends to happen – and this is one of the horrible unintended results of the model, is that the models tend to say that by adding more complication you get a better result. In practice we are seldom able to deliver and manage the implications of that increased complexity. So you actually end up travelling backwards if you are not careful. Again and again I find that in terms of energy stuff – not enough money is used on the right areas of the design – it is wasted on the wrong things.	
MB	Just to pick up on your argument: “for more data read more complexity”…what drives plant sizing…and ultimately efficiency and consumption? A key part of this must be the size of the building – the volume and the type of spaces to be conditioned. This, we know drives the size of the plant infrastructure…and from this we can then consider the diversity of occupation and so design the system to respond to that need. Referring to the Lab buildings that you mentioned earlier…had an occupancy and diversity analysis been carried out, then the issue of very low occupancy outside of normal working hours would have been identified – would it not? At Brighton a similar debate caused a review of the system strategy which was predicated on a Constant Air Volume system (CAV) …but once the team understood how the buildings were going to be used, then a	

	Variable Air Volume (VAV) system would seem to be more appropriate. This is an example of where new data can challenge conventional design. You say it ‘under their nose’, but much of what we have discovered is that Use is ‘under their nose’ but it is not translated in terms that engineers are able to use.	
BB	Yes it makes sense up to a point…a lot of things go to much by the book these days…so if it not in the book it does not exist. The professionals should be ‘running ahead of the book’…as well as ‘writing the book’.	
MB	So when you talk about ‘writing the book’ the euphemism is the ‘formulaic’ the ‘rule of thumb’?	
BB	Yes absolutely.	
MB	So this is my argument that there is too much reliance on the ‘book’ so to speak and not enough engineering using applied building engineering physics. Because we have insufficient understanding of what happens In-Use those rules of thumb etc., which were conceived decades ago – can be irrelevant to the modern day use of buildings – let alone hospitals. Cold and Hot water standards of consumption are positively archaic – founded in the Victorian era!	
BB	The Technology Strategy Board has been considering some of this. Another problem is that many organisations not in the public sector regard any knowledge that they do have on in-use performance as a market advantage, and do not share the information within the industry. This is another reason for having a separate but connected knowledge domain.	

MB	I hear what you say about the possibility that new knowledge and new data may increase complexity – but if you were given the opportunity for a PROBE 2 today – what would you be seeking to understand – now you know what you know?	
BB	We probably would not do anything very different. The problem with PROBE was that the government thought that it was 'job done', whereas what we needed was a constant 'drip feed'. We did bid with BRE to make links between BREEAM (input) with PROBE (output). But it was not possible to secure government funds for this form of triangulation. The other problem was that the government was dismantling what used to be the Department of the Environment. One casualty was that building research was called construction research, and moved it to the Department of Trade & Industry. Fairly soon the Partners in Innovation programme, that had funded PROBE was closed down. Government wanted to get performance 'right first time' in response to the Egan agenda. But without feedback, how do you know what 'right' really is? If a drip feed had been maintained, it would have been incredibly useful. What you need to do is essentially three things. First, something about the 'hard' side: energy is quite good, in addition to the technical side, it unwraps a whole load of other things, e.g. what is the commissioning like; what is the maintenance like; what is management like. You can also wave instruments about, occupants ask what you are doing, and then tell you about their	

	experiences, information you would never get – or be allowed to ask -directly. Secondly the 'soft' side - do an occupant survey and combine the insights with the technical work. Third, take the results back and get people to talk about it. This is the basic technique to 'lever the thing open'.	
MB	OK – so that is the technique that you use…but what is the empirical data that you think is hurting the industry?	
BB	OK – let's us look at heat pumps and CHP – we looked at them in energy demonstration projects the 1980s. Many were performing poorly. But demonstration projects were supposed to be about good news, so often the information did not get out. In early 2000 engineers and policymakers started to think that CHP and Heat Pumps were a good idea. Now they are getting results back which shows that the CoPs of many operating systems are nothing like what the manufacturers claimed. Instead of being a CoPs of 5 , you may get 3, but quite often they are only 2. We knew all of that in the 1980s – the issue was that a technology may be good in theory but needs to be in the appropriate context and receive a high attention to detail for it to do what is expected.	
MB	Building off that point – is not the problem that we do not calibrate the buildings sufficiently against the design? I feel that what we should be arguing for (and I would like your perspective on this) – we know what we need to do to achieve low energy – low carbon performance – we have all this technology to supposedly deliver this. Yet the buildings are being used is not actually delivering that.	

	What is the empirical evidence of this? Do we ever calibrate our buildings to prove this beyond reasonable doubt?	
BB	The short answer is no. The other perspective is that there are inputs, outputs and outcomes. Historically we have been talking about inputs. Now certain things get to outputs – pressure testing – commissioning and such like. But there has been very little investigation into outcomes. So what you often find is that you do the inputs based on flawed models and flawed assumptions (as you state), but until recently the outputs have seldom been verified and the outcomes are hardly ever looked at. So there is a whole situation, I wrote in that 2001 paper: 'Flying Blind', where the people who are getting this stuff done have little understanding of the impact on outcomes.	Cross ref: In-use_4
MB	In 'Flying Blind' you argue that we do not have the data.	
BB	Yes – but it is more than this – we do not have the institutional mechanics for capturing and using that data…	Cross ref: Appropriate data -2
MB	My sentiment exactly – surely this is all about assimilation of that data and harvesting knowledge from it…	
BB	Yes it is – but not just harvesting knowledge from the data – but harvesting knowledge with the data.	
MB	This leads to my vision for an In-Use database, where data is streamed from the Building Management System. I envision that we store in this In-Use database all of the contextual data about the buildings(s) and its	

	environment- the nature of its use and so on.	
BB	The stories are the most powerful thing. You need the data to back up the stories, but the data alone does not necessarily give you the story. The important messages may be ‘watch out for that’, or ‘what data do I need to ensure that this will be appropriate?’ Again this relates to professional roles and practices. It seems to me that to get from detection in the field to inclusion the ‘rule book’ often takes a decade or two. Whereas we need to get to this within months! This is where informed professionals can advance the science even where it based on weak signals – data from the field can give important insights into what happens in practice and where the pitfalls may be.	
MB	Yes this is my argument about occupancy analytics – new data to advance the science.	
BB	Yes, but sometimes it is more of a matter of approach. Take building air-tightness as an example; if you want a building to be airtight, think of it like a swimming pool. Decide where the air-tightness layer is going to be and follow it around, being rigorous about design and practice and allowing for maintenance (to get at it and fix it in areas that may be weak). This will get you a long way to improving performance in practice before you get to the numbers.	
MB	Yes we found this in our Energy Reduction Measure studies for Brighton. For a relatively low investment the life cycle benefits were substantial because of the impact on reduction in energy consumption.	
BB	You are likely to get comfort and control benefits too where things are better considered.	

MB	Perhaps we can move on to my two research questions…	

Consequently there are two research questions that are central to this thesis:

1. *Why hasn't energy consumption in acute hospitals improved during a period where legislation has sought to improve building energy consumption and the associated carbon emissions?*

MB	The reports from the NHS SDU tend to show building carbon performance running counter to the needs of the Carbon Reduction Commitment (CRC).	
BB	Yes I have seen this.	
MB	Why is this…?	
BB	More kit and un-manageable complications! Lack of closure of the feedback loop. Stupid policy – which mandates complication – which runs counter to the findings of studies into in-use building performance.	

2. *Why is there such a significant disparity between the design aspiration and the actual performance?*

BB	Because the feedback loop is missing. This is also a societal problem – government and clients telling contractors to put up the building as cheaply as possible and walk away. Also the reliance on markets, which tend to be better at selling kit rather than selling performance. Some years ago we looked at computer room air-	

	conditioning. A number of systems had free cooling and/or heat recovery…and nearly all of them used more energy than the basic system. The reason was that the most effective way of cooling a computer room was an efficient piece of refrigerating equipment was big evaporators, big condensers, big slow fans, small pressure differences, and well controlled expansion valves. But what made good marketing was add-on modules. So what you had was basically an undersized system in terms of small heat exchangers and small fans with big motor. Then you added the go faster-stripes to it, which increased parasitic losses in the system. So take a 30kW cooling unit which uses 4kW of fan energy to circulate the air. Bung a run-around free cooling module on top, which adds resistance, increasing the fan energy to say 6kW of fan energy to circulate the air. Extra fan and pump power will also be needed when the free cooling is operating. But say the free cooling module saves energy for 2000 hours per year, but for the other 6760 hours in the year you still need the extra fan power to force the air through the free cooling module. On the face of it, things looked good but the "improvement" could actually haemorrhage energy. I am looking at a server room at the moment where the operational load requirement is 16kW, but for future expansion capability and contingency etc. it has a 60kW chiller on the back of it. The packaged chiller includes a "free" cooling circuit to chill water without refrigeration when it is cold. The IT consultant advising me on In-Use performance	Plant over-sizing -4

	says the data processing could have been done for 3-4kW, and would have required two simple split system air conditioning units to cool the room and provide standby. Instead we have a highly specified which would have been efficient at 60kW, but at 16kW this free cooling stuff does not pay back as variable speed chiller runs efficiently at low loads, while the free cooling introduces parasitic losses from the fan and the pump. And the whole system is complex to maintain and has gone wrong much more often than a simpler system would have been likely to. The problem so often is that it is 'toys for boys'…so you often you find unnecessarily big kit that 'ticks all of the boxes'… not designers using their influence to ask awkward questions to avoid expensive and wasteful over-specification and over-sizing.	
MB	Yes I recognise all of this…an inherent reluctance in engineers to realistically size – forget about right-sizing – in my terms 'right-sizing' means designing for the use – but then visibly expose the margin to manage the agreed risks with the client.	
BB	Yes – some of the margins are simply contingency planning	
MB	Yes – ruled by fear…so the engineers would say 'no one was ever 'sacked because the purchased IBM equipment' so speak…no one would ever be criticized for over-sizing…a whole Professional Indemnity issue is at stake here too – because the industry norm is to fall back to common practice which as we know is based upon contingencies…	
BB	Yes the client is sometimes prepared to take a calculated risk…but often they do not know what the risks are, and	

	neither does the professional team.	
MB	Yes agreed – so let us know consider the issues of use as they may impact the right-sizing of plant infrastructure…	

Statement 5: *It is pertinent to note that whilst the CIBSE Design Framework references a briefing process, there is no reference to it in the CIBSE Guide F (Op Cit). This is surprising because of the emphasis that KS8 places on engineering designers to ensure a proper foundation for the design process through comprehensive analysis of the brief.*

A detailed analysis of this document is contained in Section 3.2.6. From that analysis the following evidence is pertinent to the engineering design process. There is a clear requirement for engineering designers to:

- *Gather design information, such as occupancy hours, activity and density of occupancy (p10).*
- *Document a design brief: "which can include occupancy" (p15)*
- *Analyse the impacts of occupancy and activity in order to assess internal heat gains (p32)*
- *Analyse internal design conditions for the assessment of intermittent operation, internal loads comprising small power and lighting (p19)*
- *Perform a load diversity analysis to establish peak demand (p30)*
- *Understand the impacts of oversizing heating systems (p36)*

Question: Referring to the requirements set out above, from your experience how rigorously do you consider that these requirements are pursued in practice?

- Referencing each requirement, from your experience where do you consider that 'rules of thumb' and 'formulaic' approaches are used in preference to mathematical models that embody fundamental principles?
    - Are any of these aligned to specific stages of the engineering

design process?

- Why are these used in preference to mathematical models that embody fundamental principles?

MB	So you get very little from Guide F – in terms of the ‘how’ of use, which seems to me to be a critical omission.	
BB	I had thought that a developing body of knowledge existed within our institutions, and that as this evolved publications were revised or added. However, what usually seems to happen is that the information sits there until somebody suggests we need this or that. An expert group is set up in order to produce it. They ‘flash off – here there and everywhere’, producing things that often do not join up in the middle (much as you have said)….it is really exasperating.	
MB	I feel that there appears to be somewhat more joined up thinking emerging from the US in this area…	
BB	Yes, I think they have better mechanisms for doing this. In the UK, we have not understood with the roll back of the State the role professional institutions should play and how to put sufficient horse-power into creating and revising standards and Guides. The US does understand that you need a national technical infrastructure, so they have four National Laboratories dealing with buildings and energy; while we privatized BRE and expect the market to provide what we need. In the US, ASHRAE standards are responsive to market needs and the suggestions of policymakers and researchers. They are revised on a five yearly cycle and	Cross ref

	ASHRAE keeps them to programme. The predictability allows the community to rally behind the development, for example you can out a PhD and industrial research behind it because you know there will be an output and when. We do not do this but we need to.	
MB	Yes my own research has troubled me – that professional institutions in the UK seems to be ineffective as guardians of knowledge, but no doubt they would disagree!	
BB	Yes I see within professional institutions a lack of joined up thinking…	
MB	KS8 – Occupancy analysis seems much better focused…	
BB	Yes it is all there, but I agree with you that it does not join up!	
MB	In discussing this with various engineers, their view is that rarely is there anyone in the briefing team that understands the importance of the issues that I have listed in my statement from KS8…it seems to me that the whole briefing processes has tended to focus on the 'what' and too little about the 'how'… So I ask the engineers how you challenge the client for this information? Yet if you do not have the data – the knowledge – only anecdotal information (the '*stor*ies' as you put it) how do you bring about an improvement? They then say to me – well isn't that what your new evidence is providing? Have you ever seen any real attempt to understand the 'how'?	
BB	No. That is the culture…	
MB	So let us move to the Gaps in our Knowledge…	

Gap in our knowledge - 1: Lack of comprehensive In-Use data, means that engineering designers have poor empirical evidence on which to base engineering decisions. **Specifically the gap in our knowledge concerns the potentially critical importance that building occupancy datasets have on building engineering physics and in particular the impact of building occupancy on accurate energy performance and the forecast analysis of In-use**.

BB	Yes definitely... never seen that!!	

Gap in our knowledge - 2: Models of engineering analysis can be considered to be imperfect. Models are rarely tested with In-Use data (most often because it is not systematically collected), and consequently the science fails to mature. The lack of testing against reality means that model errors are likely to be repeated from one project to the next. **Specifically a gap in our knowledge concerns lack of knowledge concerning what data could be available from In-Use such that it could be used to inform engineering model design and to validate forecasts of energy use**.

BB	Yes definitely...	

Gap in our knowledge - 3: The CIBSE Energy Efficient Brief fails to communicate the importance of In-Use. Specifically it fails to translate In-Use requirements in to building engineering physics in terms of '*appropriate values' for mathematical model based on fundamental principles*'. **Specifically a gap in our knowledge concerns lack of knowledge as to the content of an informed Energy Efficient Brief and specifically the means by which In-Use requirements need to be analysed to inform that brief.**

BB	Yes definitely...I used to write energy briefs 25 or 30 years ago!	
MB	So I believe that this is what is required to achieve alignment between the ways in which the building is to be used, with the engineering of it. The brief should attempt to couple these…	
BB	Yes I agree - a communication spine is required. But I think you may have missed one perspective –we have discussed the design model versus the regulatory model – but all too often the regulatory model is used as the design model, which it should not be… Yes we need transparency – what you described as your Whole Facility Energy Model. But for the most part the modelling - subject to the contextual issues of material and construction properties - are fine in terms of the physics – the problem is the construction was not designed and built quite like the model had assumed. Secondly, usually the modelling does not get deeply into plant control. Instead it models the loads and applies factors to the loads to determine the energy used by the plant. Too often this is hopelessly optimistic in relation to the way installed plant and systems really work.	Assumptions
MB	Yes agreed – I say that a key part of the understanding is how the building should be controlled.	
BB	Indeed	
MB	So I argue that we need to get users engaged in control.	
BB	I suggested that the CIBSE Log Book could be the	

	foundation of this – helping to establish a narrative about how the building will be work, what occupants and management need to do, and where the energy will go. In my view you should start writing this log book at Day One – you then refine the operational requirements of the building as you go along.	
MB	I agree that the analysis is agreed between us – let is consider this – a model that shadows the whole process and is a repository of modelling and briefing data – procurement decisions, actual construction data and of course control and commissioning configurations. It is the equivalent of your Log book - but a digital model of it…then we can then hook the simulation to the BMS, where we can stream the data into the In-Use database. Through discussions with the users we consider how they might be prepared to use the facility – how tolerant they wish to be – whether or not they would be prepared to intervene in control. Or alternatively whether they would not wish to be responsible and to allow for automated systems to control for them…but in doing so loose the opportunity to aggressively reduce energy consumption. How do you respond to that?	
BB	In principle very well. We did useful work 20 years ago on user and automated control: some things are best given to the user, others best automated and so on. In terms of users there is interesting recent feedback from schools with three different types of CO2 control in the classrooms. 1). Automated window opening systems. Teachers did not like them springing into life	

	and suddenly introducing noise and draughts: 2). mechanical ventilation systems: these were often poorly designed – all the assumptions that you talk about - and often there was overheating in summer. 3). A traffic light indicator that prompted the teacher. They tended to be the most accepted: the teacher could then make adjustments as and when they chose. So simpler was better for the user.	
MB	Much like my proposed control system at Brighton…	
BB	Yes – you use the manual for the 'on condition' and automation for the 'off' or 'turn-down'…	
MB	The Maggie Centres also showed the benefits of user intervention in control…	
BB	We found this out 20 years ago too! The issue is that when there is a one to one relationship it works very well – but in larger spaces it is much more difficult. Two reasons – the biggest bully – or there tends to be a poor relationship between what is experience locally and where the cause is. For example, in a small room it is easily to adjust blinds for glare-free daylight; in a big space it is much more difficult – any window may be the offender, and they may be a long distance away. So blinds down – lights on becomes common. We are so used to having to work with 'blanket engineering standards' and yet they are inappropriate for so many specific conditions…	
MB	Exactly my point – we have to challenge the formulaic – (The Rule Book as you put it earlier)… so 500 Lux is a standard that is batted around – but we also know that we can work in much lower level of lighting.	

BB	In an office, you can get complaints if you go too much above 500 Lux in an office - too bright and glary. Those with visual impairment may need more, but local supplementation is normally preferable. for them too…	
MB	So our tolerance as individuals varies so much – so how can we expect automated systems to address the wide range of needs? It seems to me that we have not only to get the 'Basis of Design' right – we also need to get the 'Basis of Operation' right.	
BB	Yes agreed…	
MB	It seems to me that we need to get users to understand the impact of their working practices on energy and carbon –this requires a dialogue and it probably needs users to be incentivised to act responsibly… So through this work we could negotiate with users concerning alternative practices that could lead to lower energy consumption…space sharing during times of low use - and control intervention – tolerance to systems responsiveness– practices concerning equipment use and so on…to bring this thinking to the fore	In-use
BB	Yes this sounds very good…	
MB	I am now going to read some statements and I would like you to tell me how strongly you agree or disagree with them…	

Statement: *Returning to the theory of building science as it relates to energy use in buildings it is clearly sophisticated.* ***Yet the theory is inconsistently applied, and much of the implementation is based on poor quality data, poor assumptions, and poor validation In-use.*** *The factors that drive performance, and indeed which are* *critical to that performance, are becoming increasingly understood. Yet post-occupancy studies (the author prefers to use then Term: In-Use) clearly demonstrate the failings in the planning, design and engineering process for buildings to achieve anything like the aspiration of energy performance that client and the project team would hope to aspire to.*

BB	Yes agreed. In the majority of cases yes for sure. Although there are exceptions.	

Statement: The literature review identifies the need for a close integration of the needs of In-Use with the planning and design strategy. ***Without this coupling, design strategies will be compromised,*** and a lack of knowledge will persist concerning the impacts of In-Use on those strategies. Where this happens, the evidence is clear: inefficient energy use, poor energy performance and compromised system performance.

BB	Yes – 'Bridge the Great Divide' with two-way flow!	

Statement: From the literature review it is also clear that a common issue that impacts both practice and research in the field of forecasting and designing for optimised energy In-use, is the lack of In-Use data in the public domain. To characterise the response in practice to this would be that it relies substantially on standard guidance (such as CIBSE design guides) and formulaic principles. Some of these principles are even enshrined in the recent standard: EN1521, designed to support the Energy Performance in Buildings Directive (Op Cit).

BB	Yes, its terrible you get all this received wisdom. I know people have challenged these…such as where did the 8litres/sec/person come from? I think someone said it was reached out of the air by somebody in New York in 1926, and on it goes…	

…Nevertheless this clearly positions what can be considered 'best practice' despite the obvious deficiencies. It appears to be common in practice to make numerous assumptions concerning the factors that drive engineering design and consequential energy consumption. The need is clear: an effective form of communication of In-Use requirements aligned with engineering design strategy.

BB	Yes – the communication spine – connecting the technical side (for the experts) and the reporting side (for more people to be able to understand). It seems to me that your software idea is great, but if you also have a communications convention that can receive data from many sources, then whatever gets fed into it can be compared.	
MB	The software is the enabler. However, I envision the need for a Change Management Process where users accountable for their soft energy budgets and the facility engineers responsible for hard building performance – such that a dialogue between the two – a 'Bridge Across the Great Divide' if you like, can be established. I envision that such a dialogue between them can be reached – a consensus – joined up thinking which as you would say is so often missing… Using this knowledge we then have the means to reconfigure the BMS to optimise the systems responses to the emerging needs of the users. It seems to me that we then have the basis for detailed calibration…so we have the model design data and the In-use data that we could analyse to study the delta between the two…	
BB	I hear what you are saying…but we need to work towards that vision with simple steps. The vision also seems to be	

	most suitable for an intensively managed building. We find that two types of building can work well: those that need intensive management and get it; and those that can manage themselves for the most part. Anything in between seems to be 'all dressed up and nowhere to go'!	
MB	I think it is important to engage with the clinicians…the response that I have had are comments such as: "We now understand something of the impact of our work on energy consumption."	
BB	I think that is really important – if they feel that their actions are insignificant then of course they are likely to give up. However, if they see a virtuous circle emerging, they can exceed your expectations. This is a real problem…as you say in terms of information management. Too often in the way the building control systems are configured does not match well the way that they are used and managed. If people are asked to turn off their computers but are unable to switch off the lights, it is terribly demotivating.	
MB	Bill we must end it there – it has been a fascinating discussion and I thought that the anecdotes that you have provided have been so helpful – thank you very much for your time, I really appreciate it.	

A1.6 Transcript of interview with Mr. Dale Sinclair[4]

Matthew Bacon (MB)	Dale, thank you taking the time to read what I have sent you and to participate in this interview. I understand that you led the process of updating the RIBA Plan of Work (PoW) to create the latest version. You will be aware from what I sent to you that I have proposed an enhancement to the Plan of work where I argue that Stage 7 (In-use) should be connected to Stage 0 (Strategic Definition). I envisage a dialogue required with the users in order to understand In-use needs as they impact the requirements for new / refurbished facilities. Before we discuss this and specifically the questions that I have posed, could you please explain the background to the new Plan of Work?	
Dale Sinclair (DS)	I was Chair of the Large Practice Group at the RIBA and it was agreed that this group would act as the best interface with the Construction Industry Council collaborative process initiative. This was a significant initiative that RIBA felt it could contribute to. Prior to this, Bill Gething had developed the 'green overlay' to the Plan of Work (PoW). Using this approach the RIBA practice team felt that we could produce a BIM overlay. As BIM had a large practice focus I agreed to Chair this initiative. The overlay work got us thinking how we could improve the current PoW and dovetailed with my involvement on the CIC BIM Forum and the CIC PoW Groups. For various reasons the CIC PoW Group made slow progress, so we decided to put our effort into	

[4] Chair of Large Practice Group at the RIBA

	the new RIBA PoW. We took the agreed CIC stages, developed an initial plan and engaged with large and small practitioners with the newly formed task group. The backbone of this work was the 8 stages of the CIC PoW. The Stage 0 was not initially part of the process. One of the features of the CIC work was that it was developed as schedules of deliverables (information) at each stage of the process, and not as a Plan of Work.	
MB	Yes I understand, the CIC plan is conceived around information or ‘drop points’.	
DS	Exactly, and these are a just sub-set of the PoW. We developed a consultation process within the RIBA and once the new plan was bedding in the RIBA commissioned an ‘Overview document’. RIBA Enterprises then commissioned the detailed PoW publications.	

MB:	Am I correct in my understanding that from a sustainability perspective, one of the 'Drop Point's would be the sustainability targets?	
DS	Yes this is correct. However a key feature of the PoW is the 'Task Bars': we were keen to put additional layers in into the PoW. We set out to create a Plan of Work that is very flexible and can be tailored to a specific project.	
MB	Could it be correct to say that the process of design for a project is not well understood, and that there is reluctance to bespoke it to specific projects?	
DS	Yes exactly – this is our view too. Yet we did design it as an 'evolution' of practice – not a 'revolution'. In terms of Stage 7 (in-use) I am sure students in the future will be perplexed as to why there was not an In-use stage to the old Plan of Work.	
MB	My recollection is that In-use was originally in the PoW of but then removed.	
MB	Did you study any other process models from industry, when you were contemplating how you would update the Plan of Work?	
DS	No we did not. Our focus was to address the areas where the old plan was no longer working. However we were also in 'catch-up mode' with the UK Government, which had been developing PAS 1192 – the standard on information sharing at each process stage. Consequently we could not afford to take on new concepts in this 'evolutionary' piece of work.	
MB	Thank you Dale – this is all very good context. Perhaps we could now turn to my interview document? Having	

	read the document you will be aware that I have developed the concept of the Energy Efficient Brief. Perhaps it addresses part of what Bill Gething has promoted as the 'Green Overlay'?	
MB	First question. The PoW explains the need for sustainability targets. Does the need for forecasting use to provide a basis for these targets in the Brief make sense to you?	

Question: Do you agree that the process for forecasting In-use would be helpful to the briefing process?

DS	Absolutely. Yes of course – if we are able to forecast use then a much better quality of Brief should emerge. One of the attractions to me of this thinking is the bridging between Stage 7 and the return to Stage 0 – a means of taking knowledge from one project to the next.	
MB	My Thesis explores these issues and specifically how we can develop an understanding from In-use data to inform the Brief.	
DS	This approach resonates strongly with my experience in the design of university facilities, where we have seen In-use consumption balloon in response to the electronic curriculum. We recognised that we needed to understand the factors of In-use that impact such consumption.	
MB	This is an example of understanding Use. I think you strongly agree that analysis of In-use would be very helpful to the Briefing process?	

I believe that the briefing process from this perspective needs to be enhanced because there are complex issues that need to be considered as part of the brief at this stage.

MB	I argue that we need an 'Enhanced Brief' – in other words an analysis of forecast In-use designed to produce the data	

	required to accurately engineer the facility. So the issue is how we capture these requirements and communicate them to the engineering team?	
DS	Yes – the issue about Preparation and Brief Stage 1 – we have been very specific to advocate that the Feasibility studies are not the start of the design process. They are a means for testing the Brief. Our experience in the major projects group was that we were receiving briefs that had been created by project managers. Consequently the rigor of feasibility studies was not taking place. I believe that what you are proposing would fit very well into the Stage 1 part of the Plan of Work.	
MB	Yes – this is exactly what I have envisaged. I see that as another layer to the Brief focused on occupancy data and the impact of working practices and policies.	
DS	Yes I can see this. It is not dissimilar to the situation when we work in Further Education projects and we receive the Feasibility design with an analysis of the demand of people on each space, produced by an FE specialist.	
MB	How do they calculate this?	
DS	They use the timetables to predict the need for different types of teaching space..	
MB	OK – well we use forecast data of occupancy demand and then model that with the clinical process. We have found that it is the variability in factors impacting use, that is a major determining factor in the diversity of use of space and thus the forecast utilisation of it. So we work with the users to understand how they plan to use the facility. It is that understanding that will provide the logic for the simulation. It is in this analysis that we consider the potential impact of new service delivery strategies on	

	space planning and on engineering plat infrastructure design. So I advocate what is in effect a data driven brief.	
MB	Next question…	

What is your view of a brief that is informed by operational data?

DS	We have not really been exposed to this. However, we have been speaking with the British Institute of Facilities Management to try to get them involved and to capture this 'In-use data'. However, they are still trying to come to terms with the concept themselves. My opinion is that the focus in FM tends to be on the asset use, and not so much on the people that use/ operate out of the facility – which is what you are advocating. I can see that there will be an increasing focus on project performance outcomes – for this to work the industry will need the kind of data that you can produce. Some of these outcomes will also become contractual – especially the government ones.	
MB	The opportunity to impact projects with analysis of In-use seems so much dependent on the procurement process. In PFI hospitals for example, the common observation is that there is a very limited dialogue with the users and this means that the opportunity to develop a better correlation between outcomes and use is limited.	
DS	By focusing the brief on outcomes it means that the emphasis on how the outcomes will be achieved is shifted onto the project team.	

MB	Hmmm…this is potentially dangerous because it the project team has such a limited understanding of operational policies – how could they establish the rationale for use, devoid of input from the clinicians?	
DS	Accepted – so we need to involve the users, but hospitals are very collegiate and so if a clinician insists that this is what they require then, in my experience it is very difficult to challenge this.	
MB	Yes I agree and that is the rationale for Occupancy Analytics – it is an evidence based means for the challenging process, where we are not obliged to rely upon anecdotal evidence to sustain an argument. Our work enables clinicians to understand the impact of their working practices on space utilisation, plant infrastructure, imaging equipment utilisation for example. Clearly the larger the facility the more energy it will consume.	
DS	Of course in an acute hospital circulation space is a major factor too.	
MB	Yes this is so true – the occupancy diversity issues will have a direct impact on the space required for circulation.	
DS	Absolutely.	
MB	So do you agree then that the operational data informing the 'right-sizing' of the facility would be a valuable contribution to the sustainability brief (the Green Overlay)?	
DS	Yes I do. The same parallel exists in the education sector – because if we do not collect feedback on the utilisation of space we simply replicate the over-sizing from one	

	project to the next.	
MB	But the complex questions then concern the impact of In-use on energy and carbon emissions. Understanding how the spaces are used provides the rationale for the design of the engineering design and the controls systems. I argue that without this information the engineers will make assumptions.	
DS	Yes this is true, and I can think of a number of examples where assumptions were made by the engineers that did not happen in practice. So yes I do agree with you on this matter. So if these assumptions can be tested against operational policy I can envisage huge energy savings.	

MB	I argue that a robust brief in Stage 1 should be tested by simulation so that users understand the impact of their requirements on the outcomes that they are seeking – such as sustainability targets as envisaged by the Green Overlay. It seems logical to me that one needs a good understanding of forecast use, in order to provide a robust rationale for those targets. This is what I mean by a Brief informed by Operational data. What is your opinion of this logic?	
DS	It makes perfect sense. We envisage in Stage 2 that the design is underpinned by many strategies, and I can see how this work could inform the sustainability strategy for example.	
MB	Yes – I envisioned for Stage 2 that there would be a coupling of the design and In-use strategy. I discuss the need for this at length in my Thesis.	
DS	Yes this makes perfect sense – exactly.	

Do you agree that it would be helpful for users to investigate the issues of In-use as part of a briefing process?

DS	Yes most certainly.	
MB	My reasoning has been that we need a 'Whole Facility Energy Model' and that this models the energy and carbon impacts of In-use.	
DS	Coming back to you what you were saying – as we get better sensors we can obtain better data that we can use in the briefing process.	
MB	This would be the case if we know how to store/ manage the data.	

DS	I agree and this is where we need to reference that data in the BIM.	

What is your opinion of using an energy model to simulate briefing requirements, so that users have a better understanding of their briefing requirements?

DS	The Plan of Work has so many new feeds that are required – and what you are advocating would fit very well with these feeds. We have thirteen groups looking into the detail of these issues – but we need a common language to ensure that these feeds have a common message.	
MB	So the energy simulation / analysis would be one of these feeds?	
DS	During the Stage 2 we see the need for much analysis – but taking a hospital for example, just getting the planning with all of the adjacencies resolved is a huge challenge in its own right – let alone addressing the analysis. There can be a contradiction where some parts of the team wish to fix detailed policies, but the design concept is still evolving. This means we need to get the right information at the right time. This raises the question as to what information is a must for Stage 2 and what could be deferred to Stage 3 when the concept is starting to be fine tuned?	
MB	Surely this would be determined by the decision points in the process and these will be influenced by the overall project strategy? Does this also not mean that we need to fix certain parts of the brief at Stage 2, but can only do this if we have reliable briefing information and data?	

DS	Yes – so a Fire Strategy needs to be fixed at Stage 2 but an acoustics strategy could be deferred to Stage 3?	
MB	In all of your conversation with the 13 authors for the detail of the PoW have you witnessed any of the kind of thinking that I have been promoting – particularly with the emphasis on coupling In-use and design strategies?	
DS	We are looking at ways of connecting stage 7 and stage 0 but not in the manner you have described. What you are presenting is a different means of getting to a robust project brief or even a strategic brief. However, I would like to understand how you address Stage 0 in your analysis.	
MB	Yes you are correct in this. Of course at Stage 0 the client will be posing the question: do I need a building? So through the simulation I propose that we analyse the perceived needs and establish the operational parameters that would determine the threshold requirements for a new facility.	
DS	Yes that it is exactly – and given that most acute hospitals are part of a campus then maybe an extension or remodeling might achieve the same outcome.	
MB	So the need to join Stage 7 and Stage 0 together become self-evident.	
DS	Absolutely.	

Can you envisage a more detailed process where the team is engaged in operational iterations and study of different model of service delivery for example?

DS	Certainly, and on reflection my own experience at the new Birmingham acute facility was that when we	

	investigated some of the In-use issues we were finding that we were being briefed by clinicians that could not see beyond the constraints of their existing facility.	
MB	Yes this is how I envisage the operational iterations between designers and clinician.	
DS	I think also that operational outcomes must be part of the analysis, so that we are quite clear what it is that we trying to achieve.	
MB	This thinking thus moves us from what has traditionally been a focus on the ‘what’ of requirements briefing – spatial requirements – functional requirements and such like, to a focus on the ‘how’ of requirements briefing – How will this facility be used? – How will operational practices impact the demand for space? – How will clinicians help to drive for low energy – low carbon use?	
DS	Agreed – but I emphasise that we need to focus on outcomes so that the iterations have an objective to them.	

Template for the Energy efficient brief. What is your opinion of this template?

MB	Did you get a chance to study the proposed template? Was there anything that ‘jarred’ with you?	
DS	Yes I did but was not able to study it completely – but nothing comes to mind that I felt the need to challenge. I have to agree that a brief just based on clinical areas is never going to result in a successful project. Anything that helps to bind operational policies into the design process has got to be a good thing.	

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MB	Yes I agree and that is the rationale for Occupancy Analytics – it is an evidence based means for the challenging process, where we are not obliged to rely upon anecdotal evidence to sustain an argument. Our work enables clinicians to understand the impact of their working practices on space utilisation, plant infrastructure, imaging equipment utilisation for example. Clearly the larger the facility the more energy it will consume.	
DS	Of course in an acute hospital circulation space is a major factor too.	
MB	Yes this is so true – the occupancy diversity issues will have a direct impact on the space required for circulation.	
DS	Absolutely.	
MB	So do you agree then that the operational data informing the ‘right-sizing’ of the facility would be a valuable contribution to the sustainability brief (the Green Overlay)?	

DS	Yes I do. The same parallel exists in the education sector – because if we do not collect feedback on the utilisation of space we simply replicate the over-sizing from one project to the next.	
MB	But the complex questions then concern the impact of In-use on energy and carbon emissions. Understanding how the spaces are used provides the rationale for the design of the engineering design and the controls systems. I argue that without this information the engineers will make assumptions.	

DS	Yes this is true, and I can think of a number of examples where assumptions were made by the engineers that did not happen in practice. So yes I do agree with you on this matter. So if these assumptions can be tested against operational policy I can envisage huge energy savings.	
MB	I argue that a robust brief in Stage 1 should be tested by simulation so that users understand the impact of their requirements on the outcomes that they are seeking – such as sustainability targets as envisaged by the Green Overlay. It seems logical to me that one needs a good understanding of forecast use, in order to provide a robust rationale for those targets. This is what I mean by a Brief informed by Operational data. What is your opinion of this logic?	
DS	It makes perfect sense. We envisage in Stage 2 that the design is underpinned by many strategies, and I can see how this work could inform the sustainability strategy for example.	
MB	Yes – I envisioned for Stage 2, that there would be a coupling of the design and In-use strategy. I discuss the need for this at length in my Thesis.	
DS	Yes this makes perfect sense – exactly.	

Do you agree that it would be helpful for users to investigate the issues of In-use as part of a briefing process?

DS	Yes most certainly.	
MB	My reasoning has been that we need a 'Whole Facility Energy Model' and that this models the energy and	

	carbon impacts of In-use.	
DS	Coming back to you what you were saying – as we get better sensors we can obtain better data that we can use in the briefing process.	
MB	This would be the case if we know how to store/ manage the data.	
DS	I agree and this is where we need to reference that data in the BIM.	

What is your opinion of using an energy model to simulate briefing requirements, so that users have a better understanding of their briefing requirements?

DS	The Plan of Work has so many new feeds that are required – and what you are advocating would fit very well with these feeds. We have thirteen groups looking into the detail of these issues – but we need a common language to ensure that these feeds have a common message.	
MB	So the energy simulation / analysis would be one of these feeds?	
DS	During the Stage 2 we see the need for much analysis – but taking a hospital for example, just getting the planning with all of the adjacencies resolved is a huge challenge in its own right – let alone addressing the analysis. There can be a contradiction where some parts of the team wish to fix detailed policies, but the design concept is still evolving. This means we need to get the right information at the right time. This raises the question as to what information is a must for Stage 2 and what could be deferred to Stage 3 when the concept is starting to be fine tuned?	
MB	Surely this would be determined by the decision points in the process and these will be influenced by the overall project strategy? Does this also not mean that we need to fix certain parts of the brief at Stage 2, but can only do this if we have reliable briefing information and data?	
DS	Yes – so a Fire Strategy needs to be fixed at Stage 2 but an acoustics strategy could be deferred to Stage 3?	

MB	In all of your conversation with the 13 authors for the detail of the PoW have you witnessed any of the kind of thinking that I have been promoting – particularly with the emphasis on coupling In-use and design strategies?	
DS	No I haven't. You are uniquely making the point (which is absolutely right) that we need to 'join Stage 7 of the PoW with Stage 0. What you are presenting is a different means of getting to a robust project brief or even a strategic brief. However, I would like to understand how you address Stage 0 in your analysis.	
MB	Yes you are correct in this. Of course at Stage 0 the client will be posing the question: do I need a building? So through the simulation I propose that we analyse the perceived needs and establish the operational parameters that would determine the threshold requirements for a new facility.	
DS	Yes that it is exactly – and given that most acute hospitals are part of a campus then maybe an extension or remodeling might achieve the same outcome.	
MB	So the need to join Stage 7 and Stage 0 together become self-evident.	
DS	Absolutely.	

Can you envisage a more detailed process where the team is engaged in operational iterations and study of different model of service delivery for example?

DS	Certainly, and on reflection my own experience at the new Birmingham acute facility was that when we investigated some of the In-use issues we were finding that we were being briefed by clinicians that could not see	

	beyond the constraints of their existing facility.	
MB	Yes this is how I envisage the operational iterations between designers and clinician.	
DS	I think also that operational outcomes must be part of the analysis, so that we are quite clear what it is that we trying to achieve.	
MB	This thinking thus moves us from what has traditionally been a focus on the 'what' of requirements briefing – spatial requirements – functional requirements and such like, to a focus on the 'how' of requirements briefing – How will this facility be used? – How will operational practices impact the demand for space? – How will clinicians help to drive for low energy – low carbon use?	
DS	Agreed – but I emphasise that we need to focus on outcomes so that the iterations have an objective to them.	

Template for the Energy efficient brief. What is your opinion of this template?

MB	Did you get a chance to study the proposed template? Was there anything that 'jarred' with you?	
DS	Yes I did but was not able to study it completely – but nothing comes to mind that I felt the need to challenge. I have to agree that a brief just based on clinical areas is never going to result in a successful project. Anything that helps to bind operational policies into the process has got to be a good thing.	