

# Understanding hospital electricity use: an end-use(r) perspective

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## Abstract

Increasing energy costs and climate change legislation have prompted efforts to reduce energy consumption in hospitals. In addition to technological conservation strategies focusing on building and systems, staff-centred initiatives such as energy awareness campaigns are increasingly considered by NHS trusts. But hospitals are complex buildings with unique energy requirements and it is unclear to what extent these are influenced by clinical staff. This case study investigation, employing both technical and social methods of inquiry, hence aims to improve the understanding of hospital electricity use from an end-use perspective and to determine the relevance of behaviour and other simple operational changes as strategies to save energy in different hospital areas.

The study findings highlight the importance of a robust understanding of operational characteristics and contextual variables in devising tailored organisational carbon management strategies. A three-tiered process is proposed to identify spaces where simple operational changes could reduce energy demand: it is recommended to, firstly, undertake an engineering analysis of the energy end-uses in the spaces in question, identifying significant loads at a local level. Floor area weighted operating hours and shares of installed loads under (clinical) staff control may then be helpful metrics to approximate the extent to which these loads are influenced by the actions of occupants. Finally, socio-technical constraints on departmental workings should be considered taking into account at least aspects around the shared use of spaces between teams, the available local knowledge on the control of building services and equipment, the morale within the organisation as well as the suitability of the working means.

The need to move away from top-down imposed models of change is recognised, instead taking a user-perspective to understand what may constitute a reasonably achievable transformation in the ways things are done. This does also mean that standards and requirements are not beyond questioning, even in sensitive environments such as hospitals. Instead, collaborative efforts between energy managers and interested clinicians as well as health administrators and equipment technicians could help to demystify clinical processes and achieve a sound understanding of opportunities to reduce the energy use of the health service.

# Student Declaration

I, Paula Morgenstern confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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# Glossary

This glossary clarifies some of the vocabulary used in this thesis. There is ambiguity about many terms used within built environment research; it is hence not suggested that the following definitions are exclusive. Rather, the glossary serves to state how certain terms are understood within this thesis.

## Building occupants

**Administrative staff** Administrative staff provide essential support to doctors, scientists, nurses and other health care professionals in a wide range of functions such as health records staff, clerks or receptionists. Their activities will be essentially computer-based and rely heavily on typing and word processing skills.

**Building operators** This refers to the estates team of a hospital. The team will include amongst others plumbers, electricians, engineers and estates managers. Importantly, the estates team is concerned with the cost-effective running of hospital estates and energy issues are therefore part of their job responsibilities.

**Building users** In hospitals, building users will include at least clinical staff, administrative staff, domestic staff as well as other non-clinical support staff and patients (see <http://www.nhscareers.nhs.uk/explore-by-career/> for a comprehensive overview of job roles within the NHS, many of them based in hospital buildings). For building users, energy issues will be secondary to their core activities.

Clinical staff	A broad category encompassing all medical staff working on the hospital premises. This also includes scientists in laboratories as well as dentists, if applicable. Clinical support workers for example in theatres are also included in this category as their activity remit can extend beyond simple support tasks such as cleaning to clinical activities, such as the handling and checking of medical equipment.
Domestic staff	Domestic staff within hospitals commonly work within one of three key areas: catering, cleaning or laundry services.
Non-clinical support staff	This groups includes all other professionals responsible for the non-clinical running of a hospital. This includes for example security or health and safety officers.
Locums	Locums are health care staff in any job role, who are employed through agencies to temporarily fulfil the duties of others to cover staff shortages within the NHS.

## **Buildings and systems**

Nightingale	Construction type for hospitals typical in the UK in the late 19th and early 20th century. Wards were designed as open-plan dormitories for 24 to 30 patients in north/south pavilions, with separate sanitary towers to one side and court yards between them. Day light and fresh air were important concerns, high ceilings and large windows were consequently common (see also Lomas et al., 2012).
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Nucleus	During the mid 1970s, it was aimed to build standardised low cost hospitals offering a ‘nucleus’ of services, with the option to expand the hospital when capital was available by adding additional blocks. The standard element was a cruciform block plan of about 1000 m <sup>2</sup> connected to other blocks through a central corridor (the hospital street). ‘More than 130 standard Nucleus schemes have been built in the UK’ (Francis et al., 1999, p.37), accounting for roughly 10% of the stock.
Split unit	Split systems are decentralised (duct-less) systems able to provide heating and cooling to single or few adjacent spaces (mini-split or multi-split systems). They are composed of an outdoor and up to five indoor units. The outdoor unit holds the compressor, while the indoor unit contains the expansion valve and a blower to deliver chilled air into the space. Modern day split units often also provide heating through electric resistance heating.

## Evaluation

Ex-ante	Ex-ante evaluations (appraisals) attempt to forecast intended energy savings of future projects before an investment decision is made.
Ex-post	Ex-post evaluations are conducted either on or after completion of an intervention to determine whether the intended objectives could be achieved.
Simple behavioural changes	Changes in the way a building is used by the occupants that are easy to implement and require no extensive infrastructural rearrangements.

Real-world savings potential      An ex-ante potential based on the extent to which a technology may deliver energy savings in-situ or the understanding of building users as to what constitutes a reasonably achievable change in the ways things are done. As opposed to a theoretical savings potential, the real-world savings potential recognises the constraints applicable in real-world socio-technical systems.

Theoretical energy savings potential      A calculated potential representing some form of ideal intervention and disregarding all practical considerations which may affect implementation. The theoretical potential is context-dependent, but unconstrained except through infrastructural arrangements.



# 1 Introduction

This chapter briefly sets the scene and presents relevant background information against which this study positions itself. The main research question is defined and aims and objectives are laid out. The research methodology and the main structure of the thesis are briefly outlined to provide the reader with guidance for subsequent reading.

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## 1.1 Rationale for the study

### 1.1.1 Research context: Reducing carbon emissions in health care

In the UK, hospitals are operated by the tax-funded National Health Service (NHS). The carbon footprint of the NHS and associated authorities amounts to about 32 million tonnes of CO<sub>2</sub> equivalent per year and accounts for 40% of all public sector emissions in England (NHS SDU, 2014). In line with the UK Climate Change Act 2008, the NHS commits to reducing its total emissions by 28% by 2020 against the 2013 level and in the long term by 80% until 2050<sup>1</sup> (ibid).

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<sup>1</sup> In 2015, the interim target of a 10% reduction from 2007 was exceeded by the health service and reductions of 11% could be achieved despite an 18% increase in health care system activity (NHS SDU, 2016).

Energy use in buildings accounts for 15% of NHS carbon emissions, while 72% are from the procurement of pharmaceuticals, medical devices and gases and the remaining 13% from travel as well as the transport of patients and goods (NHS SDU, 2014). Emissions from NHS buildings therefore generate 4 to 5 Mt of carbon equivalent (NHS SDU, 2014; Godoy-Shimizu et al., 2011), compared to 77 Mt from UK residential buildings (DECC 2014). Reducing building energy use is nevertheless important for the NHS in view of rising energy costs<sup>2</sup>, the need to ensure a secure and resilient energy supply in health critical environments (ibid) as well as increasing energy demands across the world (Sumner, 2010).

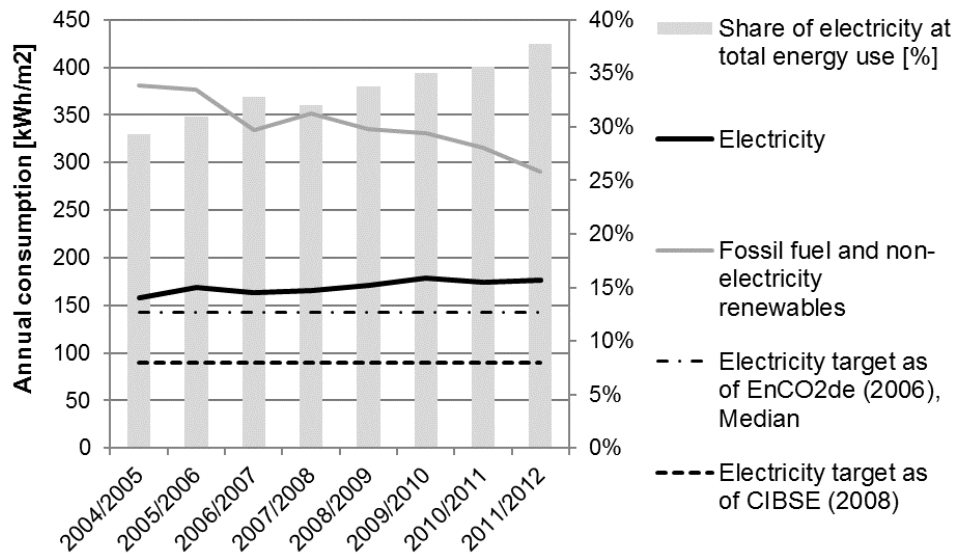
It is also increasingly recognised that health and climate change are linked. The 2015 Lancet commission on health and climate change finds that tackling climate change could be ‘the biggest global health opportunity of the 21st century’ (Watts et al., 2015), while the NHS Sustainable Development Unit (SDU) proclaims with view to climate change that ‘(o)ur business is health and we have a moral duty to act on health threats and to manage future demand on the health service’ (NHS SDU, 2015, p.1).

Strategies to reduce the carbon footprint of the health service are numerous: while general practitioners may best contribute through preventing the need for resource intensive treatments, acute hospitals were recognised to have significant potential to reduce building energy consumption by cutting unnecessary energy services and increasing energy efficiency (NHS SDU, 2014).

Acute hospitals are complex buildings with unique energy requirements that exceed those of many other non-domestic building types (Ziebig and Hoinka, 2013): They are occupied 24/7 by a large number of people, many of whom are vulnerable. Medical requirements necessitate strict control of the thermal environment and of indoor air parameters, especially in operating theatres and treatment rooms. Specialist medical equipment, sterilization, laundries and food preparation further increase electricity use (EnCO2de, 2006; EPA, 2012).

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<sup>2</sup> The NHS’ annual energy expenditure now exceeds £630 million (NHS SDU, 2013). Rising energy prices, growth in technology and increased service delivery have all contributed to this tripling in energy costs from £232 million in 2000 within little more than a decade.



**Figure 1.1:** Historical development of energy use in English general acute hospitals  
(Graph created by author on the basis of publicly available ERIC data)

An analysis of the consumption figures annually provided by English general acute hospitals through the mandatory Estates Return Information Collection (ERIC) shows that hospital energy use is dominated by fossil fuels, largely for space heating and hot water provision (Figure 1.1). But while fuel use intensity for heating has been decreasing over the last decade, electricity intensities are on the rise - likely due to increased medical equipment, more ventilation and comfort cooling as well as IT equipment (Short et al., 2015). Electricity is further the main cost for the NHS: despite accounting for a only a third of total final energy use, more than half of the NHS's total fuel bill is for electricity<sup>3</sup>. The amount of carbon released during the process of electricity generation is also a concern for the health care sector, which relies on national electricity decarbonisation as part of their carbon strategy going forward (NHS SDU, 2016).

<sup>3</sup> In 2007/2008, the last year when electricity and fossil fuel costs were reported separately in official ERIC statistics, electricity costs accounted for 55% of total energy costs.

### 1.1.2 State of knowledge: Energy demand in hospital buildings

Academic research regarding the energy use of existing hospital buildings is sparse, even within the comparatively under-researched field of non-domestic buildings while much knowledge on health care engineering resides outside academia. Operational and facilities management in hospitals has been studied in order to reduce operational costs (Diez and Lennerts, 2010; Jones, 2001; McGuire, 1987). Other studies have focused on the monitoring of air quality issues and indoor temperatures in their crucial role for patient well-being and staff performance; overall (Li et al., 2015) or in certain hospital building types (e.g. Short et al., 2012; Lomas and Ji, 2009) or parts (e.g. Balaras et al., 2007). Further, the drivers of hospital energy use have been debated and are briefly summarized subsequently.

It is well established that floor area and built form<sup>4</sup> drive hospital energy use (Fifield, 2012; Witt, 2013). Regression analysis carried out for the certification scheme Energy Star in the US and Canada also suggested that number of beds, worker density, number of MRI machines (EPA, 2014b) or the presence of laundry facilities (EPA, 2014a) may be predictors of hospital energy use, but some ambiguity remains here due to methodological criticism (Scofield, 2014). Burpee et al. (2014) further argue that the energy use of MRI machines has long been overrated and does on the whole not account for more than 1% of total hospital energy use.

Within hospitals (as in other building types), it was found that seasonal variations in outdoor temperature decisively influence heating and cooling demands. But doubts remain as to how clinical activity relates to total hospital energy use:

- Takakusagi and Yoshino (2011) and Moghimi et al. (2013) identify differences in daily electricity consumption between weekday and holidays in large hospitals in China and Malaysia respectively, suggesting clinical activity is influential. In a study of two US hospitals, Rabanimotlagh et al. (2016) further identify the number of radiological imaging series performed to be a driver of electricity use. In a large UK consultancy project, Bacon (2015) also argues that clinical activity decisively determines space use and therefore the design of health care facilities with important (albeit more indirect) implications for energy use.

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<sup>4</sup> Nightingale designs tended to be more energy efficient as opposed to nucleus, tower or courtyard buildings from a top-down perspective, while differences in service delivery and service quality were not analysed (Witt, 2013).

- Rabanimotlagh et al. (2016) do however find no significant influence of the number of inpatients, outpatients or patients seen in the emergency department on monthly electricity or gas usage. Their study hence concludes that the analysis of daily measures of energy consumption tied to daily measures of activity are needed to clarify the relation, while the outcome may alternatively indicate ‘that nothing is ever turned off in hospitals (p.14)’ regardless of service demand.

Whole building energy performance figures are also increasingly becoming available as best practice guidance for the sector and/or as basis for mandatory disclosure schemes such as the British display energy certificates (DECs). In the UK, there are at least three recent systems of benchmarking that cover NHS properties as a whole (Table 1.1, middle) alongside with a national energy target for NHS Trusts (HM Government, 2006). Internationally, published consumption figures and energy performance targets for hospitals (see Appendix A.1 for details) are on the whole not dissimilar while in particular Germany specifies more ambitious standards (Table 1.1, bottom: based on actual consumption data reported in a survey among 248 hospitals of various sizes). All of the values, however, highlight the energy intensity of hospitals compared to other non-domestic building types such as offices or schools (Godoy-Shimizu et al., 2011).

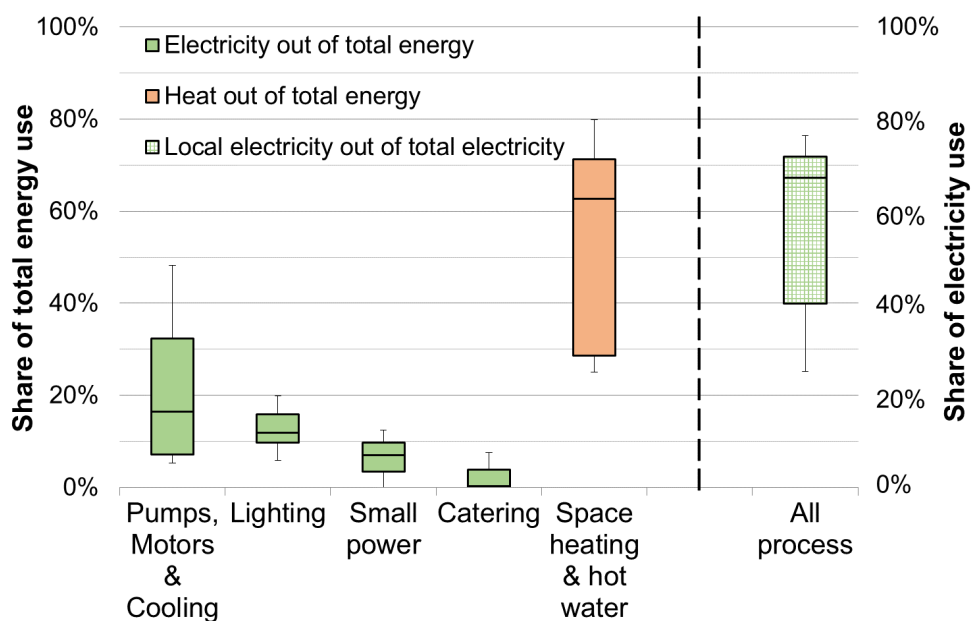
Little evidence is currently available on hospital energy use at a sub-building level. Some studies have focused on energy intensive areas such as operating theatres (Balaras et al., 2007; Beier, 2009) and an engineering doctorate at an architecture faculty in Germany has analysed interrelations between hospital design and energy demand of different space types (Holeck, 2007). Sub-building level electricity data is also becoming available through research on energy intensive equipment (Jensen and Petersen, 2011; Rohde and Martinez, 2015), primarily imaging and radiotherapy (Esmaeili et al., 2015; Twomey et al., 2012). An increasing number of studies is now also aiming to measure hospital electricity use at a sub-building or departmental level with view of providing input data for building simulation (Hagemeier, 2014; Christiansen et al., 2015; Pagliarini et al., 2012). But on the whole, energy data with granularities exceeding entire buildings remains sparse, likely due to access constraints and a prevalent lack of sub-metering. This lack of detailed understanding limits the identification of energy conservation opportunities as well as the exchange of best-practice experiences across heterogeneous hospital facilities.

**Table 1.1:** UK energy target and performance benchmarks in the UK and Germany (see Appendix A.1 for further performance figures, conversion of government targets from GJ/100m<sup>3</sup> based on a ceiling height of 2.7m)

Publication	Comment	Category	Current/Typical kWh/(m <sup>2</sup> · yr)		Target/Best practice kWh/(m <sup>2</sup> · yr)	
			Electric	Thermal	Electric	Thermal
HM Government (2006)	Few other countries specify national energy targets for health care.	Existing facilities			Total energy: 413-488	
		New build & major refurb			Total energy: 263-413	
BRECSU 1996	Re-published unchanged in CIBSE (2012)	Acute Hospital	108	510	74	422
EnCO2de (2006)	Primary UK guide on energy efficiency in health care facilities	General Acute Hospital	143	373	122	317
CIBSE (2008)	Used as basis for UK Display Energy Certificates (DEC)	Hospital (Clinical & Research)	90	420		
		Laboratory or operating theatre	160	160		
Schettler-Köhler (2009)	Benchmarks for German ‘Energieausweis’ (mandatory display certificate following EnEV2007, EnEV2009)	Hospital with up to 250 beds	120	205	84	145
		Hospital with 251 to 1000 beds	115	250	80	175
		Hospital with more than 1000 beds	115	285	80	200

At the time of this literature review, only ten studies globally reported energy audit results for hospitals that specified the magnitude of different end-uses. They confirm that space heating and hot water are dominant, as suggested earlier in Figure 1.1. For electricity, about two thirds of a hospital’s electricity consumption occur locally through lighting, plug loads such as IT or medical equipment or food preparation (‘All process’ in Figure 1.2). The remaining third (more in tropical climates) is accounted for by the provision of building services, in particular cooling, ventilation, compressed gases and elevators. Scope, employed methodology and quality of the reporting however vary widely between the studies; presenting some challenges for a systematic meta-analysis (see Appendix A.2 for details).

This finding nevertheless suggests that a substantial share of a hospital’s electricity demand occurs in a decentralised fashion across the hospital, while high-level audits can not provide insights on how such demand is distributed across a hospital, neither spatially nor in time. Black et al. (2013) conclude similarly that ‘common, small [medical] devices consume large amounts of energy in aggregate and should not be ignored when trying to address hospital energy use (p.1)’.



**Figure 1.2:** Evidence from the literature on the relevance of different energy end-uses in hospitals ( $n = 10$ , see Appendix A.2 for details on the included studies)

### 1.1.3 Reducing hospital energy demand

The 2010 European Energy Performance of Buildings Directive explicitly encourages reductions in building energy demand. To help health care organizations manage the energy use of their buildings, the UK Department of Health publishes and regularly updates the guidance document EnCO2de (2006, latest version from 2015). In addition, many other non-government bodies offer advice for hospital energy managers, in the UK notably through the Carbon Trust’s Carbon Management Programme and previously the Building Research Energy Conservation Support Unit (see Appendix A.3 for a graphic overview of UK guidance documents). A plethora of both historic and current Carbon Management Plans of individual trusts are also available as exemplars, if not as best-practice examples. In other countries, comparable guidance documents exist such as Tippköter and Schüwer (2003) in Germany, Benke et al. (2009) in Austria or Singer et al. (2009) in the US. BREEAM health care further offers assessment of and certification for sustainable health care buildings and ratings of ‘excellent’ or ‘very good’ are sought in the UK since 2008 for new health care buildings and major refurbishments respectively.

Strategies to reduce the energy use of existing hospital buildings are various. Traditionally, they have focused on technical measures such as the retrofitting of fabric insulation and updates to lighting installations as well as to pumps, motors, lifts and space conditioning equipment. Salix Finance, a government arm's length organization providing much of the funding for energy saving projects to NHS Trusts in England, Scotland and Wales, list combined heat and power, heat recovery and LED lighting as most commissioned technologies within the NHS between 2012 and 2014 (Salix Finance, 2014).

Now, it is increasingly discussed whether energy savings in non-domestic buildings may also be achieved through changes in user behaviour (Banks et al., 2012; Jeffries and Rowlands-Rees, 2013). Behaviour change campaigns aimed at raising employee awareness of sustainability and mostly encouraging simple energy efficient actions, such as switching off lights and IT equipment out of hours, have been trialled in offices and other workplaces, with some success (see literature review 2.2.1.1 for more details). The NHS has consequently expressed an interest in this option in the short term as it is thought that it could be more cost-effective than many technological conservation options (Pencheon et al., 2009; Morgenstern et al., 2015a). In EnCO2de 2015, behaviour change also features much more prominently than in previous versions of the guide (Short et al., 2015).

But knowledge on the applicability as well as the limitations of behaviour change campaigns and other staff-centred energy conservation initiatives in hospitals is sparse (see literature review 2.2.1.2): A thorough review of the relevant literature revealed few academic publications on the topic, and many open questions remain in the practical literature (for example around the nature of relevant energy behaviours, stakeholder motivations and lasting impacts specific to the hospital context). A recent survey study by this author however indicated that the majority of energy managers in English general acute hospitals were interested in trialling 'behaviour change' among health care staff as tool for carbon reduction (Morgenstern et al., 2015a), justifying a further exploration of the topic.



## 1.2 Research question, aims and objectives

In addition to technological conservation strategies focusing on buildings and building services, staff-centred initiatives such as energy awareness campaigns are increasingly considered by NHS Trusts to reduce their carbon emissions (Morgenstern et al., 2015a; NHS SDU, 2010). But hospitals have complex energy requirements and it is unclear to what extent these are influenced by clinical staff in different building types and clinical processes. It can further be expected that the nature and function of health care will pose particular challenges to attempts at reducing the end-use of energy. This research therefore aims to improve the understanding of hospital electricity use from an end-use perspective and to identify the scope for local electricity conservation by answering the following research question:

**To what extent can clinical staff influence electricity use in different hospital buildings and departmental processes and what is their potential role in its reduction?**

More specifically, the research will address the following objectives:

- (i) Establish the theoretical maximum electricity savings potential from simple changes in the way different hospital departments are being used by occupants, principally clinical staff;
- (ii) Unpick the governing constraints on energy demand reduction in the complex socio-technical systems that hospital departments constitute;
- (iii) Suggest a process to evaluate the relevance of behaviour and other simple operational changes as tools for carbon mitigation in hospitals; and finally
- (iv) Contribute to the concept of a socio-technical energy conservation potential while discussing scope and limitations of socio-technical methods for research in the built environment.

The scope of the study is necessarily limited (see also 8.2.1). It focuses on electricity usage as major cost to hospitals while space heating, usually by fossil fuel, is the largest component of site carbon emissions in hospitals. The study further addresses local electricity use only (for lighting, small power equipment and localised heating, cooling or ventilation solutions) while excluding electricity used for cooling or central ventilation systems, pumping and medical gas services, which as central services are only with difficulty attributable to separate spaces within a building. Finally, it is focused on clinical staff as opposed to other users of hospital buildings because they represent the least transient occupant group.

### 1.2.1 Stakeholders of the research

This research has a number of stakeholders who will benefit from the different types of contributions (analytical, methodological and empirical) which can be expected to emerge from this research project:

- **Energy managers and facilities professionals:** NHS energy managers and energy managers in other organisations will be able to use the developed framework to gauge to what extent behaviour and simple operational changes may represent a worthwhile energy conservation tool across their building stock. The framework will allow them to focus on building and department types where staff engagement is a valuable resource, while disregarding those where other energy conservation measures would be more promising.
- **Architects and designers:** The research presents a wealth of details on hospital operations and clinical processes understood from an energy perspective. Such evidence will be valuable to architects and designers interested in further low carbon hospital design and may assist them in exploring how different physical and logistical arrangements can enable low carbon health care.
- **NHS Management and the Department of Health:** Robust evidence on the energy savings potentials of operations-focused measures to reduce energy demand in hospital can support (or not) the integration of such measures in energy policy frameworks, for example by the NHS Sustainable Development Unit. The study is further expected to gather evidence and methodological insight for the energy benchmarking of hospitals.
- **The built environment research community:** Academics working within the field of the built environment, which traditionally is dominated by engineering and the physical sciences, may benefit from reflections on the scope and limitations of socio-technical methods for research in this area.

### 1.2.2 Methodological overview

This exploratory thesis adopts a multiple case study approach to address the research question outlined above. A mixed-method study design is considered most appropriate due to its effectiveness in handling both quantitative and qualitative inquiries and its flexibility in integrating their various research instruments. Data collection and analysis are understood within an inductive-pragmatic research paradigm (Morgan, 2007) with a view to identifying transferable factors which enable or constrain specific energy saving strategies and may be applicable to hospitals as well as to the wider non-domestic context. The research design and the application of the mixed-method approach are outlined in chapter 3, where an overview of the analysed cases as well as a brief description of each of the research instruments employed (electricity monitoring, lighting and appliance audit and semi-structured interviews) is given.

## 1.3 Thesis structure and chapter layout

The research is structured into three parts: review, analysis and synthesis (Figure 1.3), the chapters are therein organised as following:

### Part I: Review

#### Introduction (*this chapter*)

An introduction to the study discusses the state of knowledge on hospital energy use. Little academic research is available in the area and the practical literature focuses largely on the energy use of entire buildings or systems. There is now some interest in involving building users in attempts to reduce hospital energy use, but many open questions remain. Among them, the introduction defines the main research question and aims and objectives are laid out. The research methodology and the main structure of the thesis are briefly outlined.

#### Literature review

This chapter reviews the literature which investigates how and to what extent occupants influence non-domestic building energy use. The review firstly compares the understanding of various academic disciplines of people and their actions in the context of building energy use. Secondly, it reviews studies investigating behaviour change initiatives in non-domestic buildings in general and hospital in particular from an individualist viewpoint. And finally, it reaches out beyond the notion of human-building interaction as ‘energy behaviour’, discussing empirical studies from a socio-technical and social practices perspective.

## **Part II: Analysis**

### **Study methodology**

This chapter defines the main areas of investigation of this research and lays out epistemological considerations resulting from nature and domain of the research subject. Various possible research designs are explored and a rationale for the selected multiple case mixed-method study design is presented. Following this, details are provided on the data collection protocol and the analysis strategy.

### **Analysis context: Logistical and spatial arrangements of hospital departments**

This chapter presents the context in which clinical activity takes places in different hospital departments and provides insight into the socio-technical systems framing all energy saving attempts. Five department types with different energy intensities and operating hours are analysed in this study across three case study hospitals. They represent different stages (diagnosis, treatment and care) along the patient pathway within an acute hospital. This chapter aims to provide the reader with some contextual understanding and give credibility to the subsequent analysis.

### **Quantitative findings: Influence of clinical staff on hospital electricity use**

This first findings chapter addresses the first research objective *i*. Based primarily on the collected quantitative data, it investigates the theoretical extent of clinical staff influence on departmental electricity use and estimates the theoretical maximum savings potential from simple changes in clinical operation for each department, identifying transferable drivers.

### **Qualitative findings: Constraints on a theoretical energy savings potential**

This second findings chapter addresses the second research objective *ii*. It analyses the interview data (in the context of other available evidence from audits and monitoring) to determine how the theoretical electricity saving potentials determined earlier were constrained in the complex socio-technical systems that hospital departments constitute. The presentation of findings is guided by Gram-Hanssen's (2013a) empirical analysis framework for social practices.

## **Part III: Synthesis**

### **Discussion**

The discussion chapter brings together findings from the quantitative and the qualitative findings chapters and jointly discusses their implications, thereby addressing the research objectives *iii* and *iv*: The relevance of simple behaviour change as a tool for carbon mitigation across different hospital departments and buildings is evaluated by highlighting important factors which govern both theoretical and actual (real-world) energy savings potentials. Other strategies potentially effective in reducing the energy end-use of hospitals are also presented. The discussion chapter further contributes to the concept of a socio-technical conservation potential while discussing scope and limitations of socio-technical methods for research in the built environment.

### **Conclusion**

The conclusion chapter briefly summarizes the key findings in relation to the research question. It further discusses the implications of this thesis for different stakeholders, taking into account the limitations of study design and methodology. Needs for future work, both in academia and in practice, are highlighted.

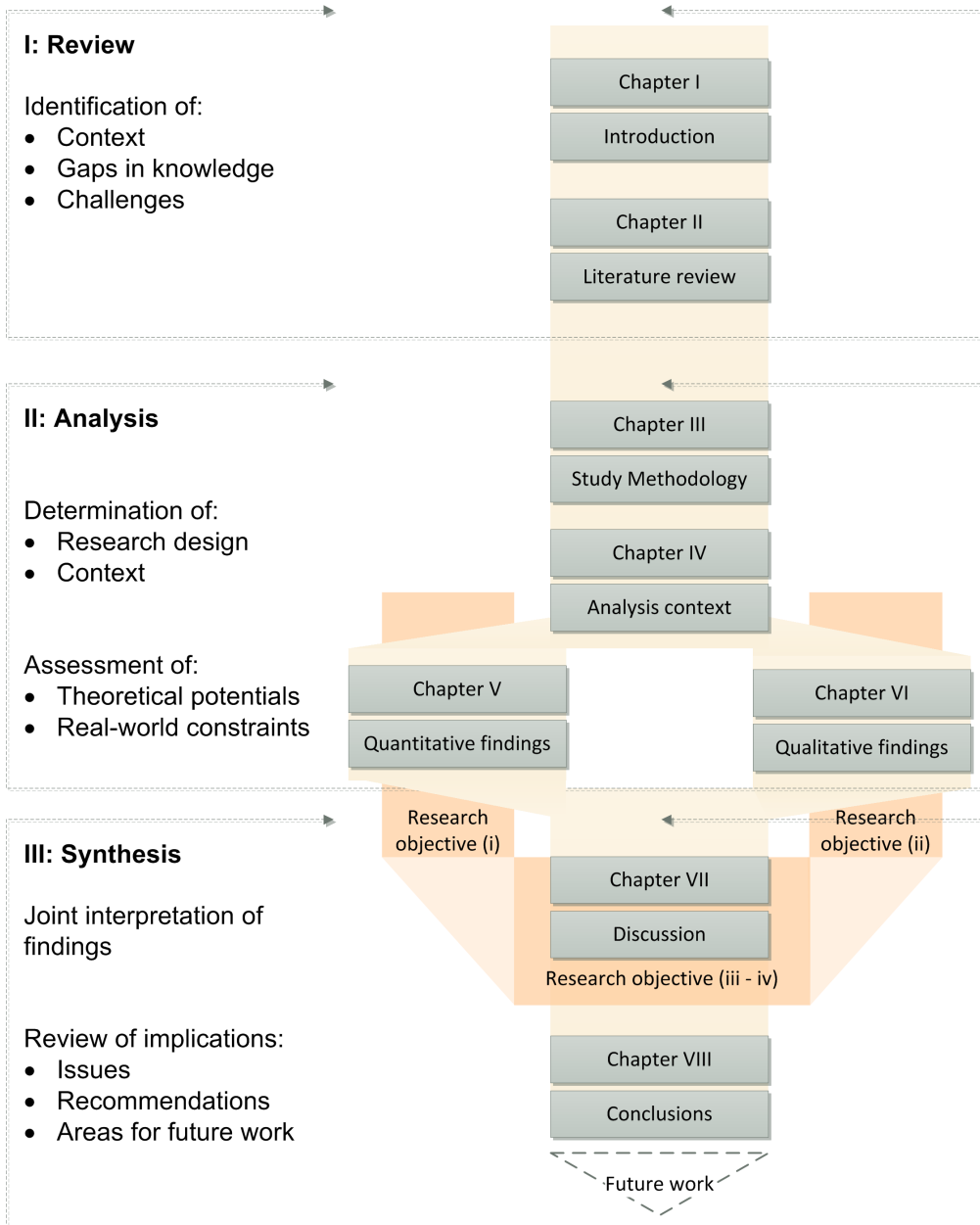


Figure 1.3: Overview of thesis structure

## 2 Occupant influence on non-domestic energy use

This chapter reviews the literature which investigates how and to what extent occupants influence non-domestic building energy use. It draws primarily on academic sources, but government publications and other items from the grey literature<sup>1</sup> are also included where appropriate due to the close link of the non-domestic building sector with occupying organisations and their research outputs. The review (see Figure 2.1 for structure) firstly compares disciplinary understandings of people and their actions in the context of building energy use. Secondly, it reviews studies investigating behaviour change initiatives in non-domestic buildings in general and hospitals in particular from an individualist viewpoint. And finally, it reaches out beyond the notion of energy behaviours and discusses energy saving at work from socio-technical and social practices perspectives.

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<sup>1</sup> The term ‘grey literature’ lacks a firm definition. It is generally understood to describe research outputs produced by non-academic organisations where the outputs have no commercial aims and are not under the control of commercial publishers (Bryman, 2007).

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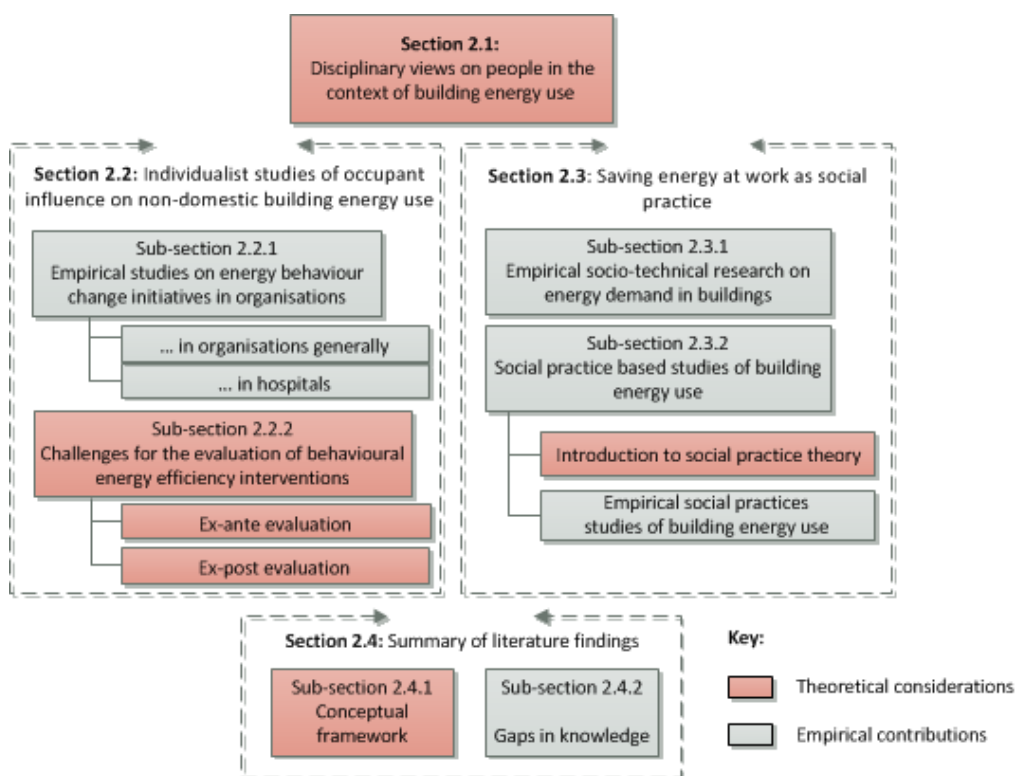


Figure 2.1: Structural overview of the literature review chapter



## 2.1 Disciplinary views on people in the context of building energy use

Over the last years, behaviour change has been discussed as a strategy to reduce building energy use alongside technological options and design practices in both the domestic and increasingly also the non-domestic context (Lucon et al., 2014). Discussed behaviours of individuals (as opposed to group behaviours or organisational behaviours) which relate to building energy use broadly fall into two categories:

- Single non-recurrent changes, mainly investment in energy efficient technologies or on-site renewables: relevant for domestic owner-occupiers (Bruce, 2008) or facilities, technical and board-level staff in organisations (Banks et al., 2012)
- On-going repeated activities: Low energy household (Lopes et al., 2012; Abrahamse et al., 2005) or workplace behaviours (Cox et al., 2012), relevant for all householders as well as organisational core staff but in particular also support staff such as security personnel or cleaners

This study focuses exclusively on the second category within the organisational context.

Low energy workplace behaviours are commonly understood to include simple actions like the after-hour switch-off of lighting and equipment (see Table 2.1 for a comprehensive list), but may extend to more complex behaviours such as the bottom-up development of low carbon strategies. Accordingly, behaviour change initiatives may aspire to the starting or stopping of a behaviour as well as the replacement of one behaviour with another.

**Table 2.1:** List of generic (process independent) low energy workplace behaviours (Cox et al., 2012; Staats et al., 2000; Schahn, 2007; Jiang et al., 2013)

<b>Heating, Cooling &amp; Ventilation</b>	
Closing doors between areas with different temperatures	Increased reporting of problems such as simultaneous heating and cooling
Equal setting of radiator valves for all radiators in one room	Reduced window opening while heating or cooling systems are in operation
Keeping radiators and grates above radiators unobstructed	Reduced use of portable fans/air conditioners
Reduced use of portable heaters	Increase in (some) cooling set points
Reduction in (some) heating set points	Wearing clothes appropriate for the season
<b>Lighting &amp; Equipment</b>	<b>Hot water</b>
Switching off unnecessary lights	Using only as much hot water as needed for hand or dish-washing and showering
Turning off unused equipment	Reporting of dripping taps
Reporting of problems such as unresponsive occupant light sensors	Choice of low temperature programs for dish washers and washing machines
Closing doors of utility and storage rooms to avoid triggering light sensors by passers-by	

Within academia, however, the conceptualisation of occupant influence on building energy use as energy behaviour is contested depending on disciplinary views and resulting assumptions on the nature of people and their actions and interactions with their environment (Sorrell, 2015, see also the 2014 special issue of the journal ‘Architectural Engineering and Design Management’ analysing the impact of building occupants on energy consumption). Lately a number of policy- and implementation-focused reviews have attempted to systematize theoretical stances on interpreting human actions within the context of the built environment to allow a more diverse range of ideas to be taken into account in policy making (Lopes et al., 2012; Chatterton, 2011; Cox et al., 2012). Although necessarily simplistic especially with regard to more complex theories, such overviews seem valuable in advancing the knowledge of energy conservation options through occupant influence at an applied and policy level.

Table 2.2 provides a high level overview of different social science perspectives on energy consumption. Importantly, they all represent theories, i.e. abstracted ways of understanding a phenomenon, while none fully reflects reality:

**Table 2.2:** Social science perspectives on energy consumption  
(Table by Behar (2015), based on information curated by Chatterton (2011))

Philosophical position	Discipline	Understanding of energy
Individualist	Economics	Energy is a tradeable commodity and consumers will adapt their usage in response to price signals.
	Psychology	Energy usage is subject to stimulus-response mechanisms and affected by awareness levels and attitudes.
Socially orientated	Sociology	Energy is largely invisible and its usage is often a by-product of other goals and daily practices.
	Education	Energy use is a skill that is learned through specific experiences.

After all, social theories are vocabularies necessarily underdetermined by empirical ‘facts’. As vocabularies they never reach the bedrock of a real social world, but offer contingent systems of interpretation which enable us to make certain empirical statements (and exclude other forms of empirical statements).

(Reckwitz, 2002, p.257)

Depending on the question asked, each of the perspectives presented in Table 2.2 may consequently allow for useful conclusions and ultimately contribute to sustainability and reductions in energy demand.

*Individualist* and *socially orientated* perspectives can be distinguished:

- Individualist understandings, typical for economic and psychological theories, focus on individual occupants as centre of energy conservation initiatives.
- Socially orientated theories, common in sociology, science and technology studies and also in education sciences, reflect that energy demand also results from social constructions and the systems providing energy services.

In energy policy as well as in built environment research, individualist perspectives have long been dominant for a number of reasons potentially including a closer alignment with assumptions and worldviews typical in engineering and the physical sciences as well as neoliberal policy stances seeking ‘to encourage more sustainable choices among sovereign consumers’ (Hargreaves, 2011, p.80).

*Individualist approaches* do have some decisive strengths: They often result in tangible pathways to action (Stern, 2000) and lend themselves to attempts at quantification as basis for energy policy (Sorrell, 2015). Practical principles of intervention often appear fairly accessible to stakeholders outside of the social science community as well as to decision makers who (at least within the current political and economic system) often operate within positivist mindframes (see section 3.2 for a brief overview of major belief systems). Individualist understandings of energy consumption finally also facilitate reflections on the savings potential of ‘people interventions’ aimed at reducing building energy use en par with technological interventions, therefore offering the option of an integrated assessment of different carbon mitigation strategies (see also section 2.2.2.1).

A number of aspects which have increasingly been identified as crucial in understanding occupant influence on building energy use are, however, overlooked by *individualist approaches* (Shove, 2010). Most importantly, they pose the danger of devolving the responsibility for change to the end-user where fundamental structural changes would (also) be necessary (Shove, 1998). Chances for fundamental transitions to a more sustainable society may therewith be foregone, an issue particularly pressing given the urgency to act on climate change (Moezzi and Janda, 2014). Here socially orientated approaches increasingly offer alternative insights and pathways to change (Whittle et al., 2015).

The strength of *socially orientated approaches* is their ability to appreciate complexity and embrace a whole variety of social and material factors (Cohn, 2014). They recognise issues of power and politics as central features of all proposed methods to affect change and understand that current arrangements partly result from vested interests and decisions which have previously been taken. In doing so, socially orientated theories allow for a more fundamental (re-)assessment of social issues and at best introduce additional degrees of freedom rather than simple mechanistic ideas for and pathways to change.

But:

By being aligned with a language of systems, complexity, interactions and irreducibilities, such an approach must inevitably be modest, since it can only ever offer a partial interpretation. (Cohn, 2014, p.160)

*Socially orientated approaches* therefore often result somewhat intangible at a practical level and remain conceptual rather than resulting in specific recommendations for action (Whitmarsh et al., 2011). This can be problematic for the practical implementation of energy conservation interventions in buildings as well as in the energy policy context. Also, devised practical interventions for change may not differ all that much from those developed on the basis of other approaches (Blue et al., 2014). In their paper on discouraging smoking as unhealthy practice, the authors acknowledge that: ‘It is important to notice that there is nothing especially new about the methods of intervention that might follow’ Blue et al. (2014, p.10) from socially orientated analysis approaches, while others are recognised as ineffective (such as prescribed exercise and advice to individual smokers).

It should consequently seem that individualist approaches conceptualising occupant influence on building energy use as energy behaviours can be helpful in attempts to quantify energy saving potentials. Such potentials may support the prioritisation of efforts with view to developing carbon reduction strategies. In its first part aiming to quantify savings potentials (Chapter 5), this thesis will therefore refer to the concepts of ‘energy behaviours’ and ‘behaviour change’.

Socially orientated approaches have, in contrast, proved particularly useful in identifying additional levers of change and in pointing out intervention strategies unlikely to be effective (Reckwitz, 2002, also quote above by Blue et al.). They will hence be applied in this work to identify real-world constraints on the calculated saving potentials and develop complementary pathways to change (Chapter 6). In doing so, this study aims to combine the strengths of both approaches and bring together engineering and social sciences as frequently called for in the literature (Lopes et al., 2012; Summerfield and Lowe, 2012).

This chapter will now proceed to discussing relevant studies of occupant influence on non-domestic building energy use, firstly from an environmental psychology perspective (section 2.2) and secondly taking a socio-technical or ‘social practices’ view on saving energy in work places (section 2.3).

## **2.2 Individualist studies of occupant influence on non-domestic building energy use**

The influence of occupants on building energy consumption was first shown in the domestic context. In the late 1970s, a study by Princeton University found that the energy consumption of a number of nominally identical town houses varied hugely depending on occupant behaviour (Socolow, 1978). Since then, other studies have confirmed the role of occupants using different methodologies (e.g. Yu et al., 2011) and larger sample sizes (e.g. Steemers and Yun, 2009). Subsequently, numerous interventions encouraging households to reduce their energy and resource use more generally) have been trialled (Darby, 2006; Osbaldiston and Schott, 2012; Abrahamse et al., 2005).

In contrast, there is less research on the impact of occupants on energy use in non-domestic buildings. Increasingly, post-occupancy evaluations have helped understanding how well occupant needs are met in commercial buildings (e.g. Baird, 2010), and implications for sustainable building management have been identified (Bordass et al., 2001). However, relatively few studies in the academic literature explicitly investigate staff energy behaviours in organisations, and less so in health care. In 2013, Abrahamse and Steg (2013) published a comprehensive meta-analysis of social influence approaches in resource conservation (including employee energy behaviours). The majority of the 29 studies included in their analysis however focused on recycling or referred to social situations in neighbourhoods and communities as opposed to in the workplace.

In non-domestic buildings, different occupant groups have differing influences on building energy consumption depending on their respective job roles. For *building operators* and facilities staff, energy issues are part of their job. Aune et al. (2008) stress the importance of this occupant group in energy management. Building operators are however vastly outnumbered by *building users*, i.e. the core staff of the organisations inhabiting a building. The occupation of the latter depends on the organisational focus and will in the majority of cases have nothing to do with energy issues (Pellegrini-Masini and Leishman, 2011). In hospitals, building users will include at least *clinical staff* (doctors, nurses, scientists in laboratories), *administrative staff* (health records staff, clerks, receptionists), *non-clinical support staff* (including cleaners, porters<sup>2</sup>, security staff) as well as *patients* (see also the glossary for definitions of these terms).

Apart from these (semi-)permanent building users, many non-domestic buildings are also occupied temporarily by other occupant groups such as students in university buildings or visitors in hospitals. In continuation, this review will focus on the influence of organisational core staff on non-domestic energy use due to the small influence of transient populations on building energy consumption (Gul and Patidar, 2015). It further specialises on clinical staff within hospitals, as energy behaviours of administrative staff can reasonably be expected to be very similar to the office context, which has previously been researched more widely (Cox et al., 2012; Littleford et al., 2013). Researching the role of domestic staff on building energy use meanwhile represents an important area of further investigation (see also limitations of this study, section 8.2.1).

### 2.2.1 Empirical studies on energy behaviour change initiatives in organisations

A number of theoretical frameworks have been developed within social and environmental psychology to analyse employee energy behaviours in organisations (for example Cox et al., 2012; Lo et al., 2012; Littleford et al., 2013; Tudor et al., 2008). Three main groups of variables are thought to be influential:

- **Contextual factors** such as the nature of the setting and physical control over environment or equipment;

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<sup>2</sup> Porters are those health care professionals responsible for moving frail and often very ill patients between different departments and wards. They also transport equipment that may require expert handling around the building.

- **Individual level factors** such as knowledge, value orientations or self-efficacy; and
- **Organisational level factors** such as social norms and organisational culture.

All of these factors may present levers - as well as constraints - to encourage energy efficient behaviours in the workplace. An application of these frameworks to the development of behaviour change initiatives in hospitals can be found in Short et al. (2015). This brief review will therefore focus on reporting experiences from actual interventions, both in organisations generally (section 2.2.1.1) and in hospitals in particular (section 2.2.1.2).

### **2.2.1.1 Behaviour change campaigns in organisations generally**

Social and environmental psychology literature reports intervention studies targeting employee energy use using various different approaches such as the provision of information, goal setting and giving feedback or rewards (see Table 2.3). Some studies report measured savings, but evaluation methodologies and reporting vary hugely, complicating the comparison of campaign effect sizes. On the whole, studies in peer-reviewed journals or at academic conferences report measured energy savings in organisations between 1 and 12 % for heating and of almost none up to 20% for electricity, while simulations more consistently claim a potential of around 20% of total electricity use. The interest has so far primarily been in university and office buildings, with a more pronounced interest in electricity as opposed to heating use. In terms of intervention approaches, the provision of feedback as well as social modelling techniques based on energy or environmental champions are most researched.



**Table 2.3:** Academic literature on energy behaviour change initiatives in organisations

Author(s)	Intervention type <sup>1</sup>	Building typology	Reported savings
<i>Addressing heating and electricity</i>			
Matthies et al. (2011)	Prompts	University	Electricity: 8%
	Commitment		Heating: 1%
Siero et al. (1996)	Goal setting	Metallurgic company	Total energy: 6 - 7 %
	Feedback		
Schahn (2007)	Prompts	University	Electricity: 6%
	Rewards		Heating: 12%
<i>Addressing heating only</i>			
Staats et al. (2000)	Instructions Feedback	University	6%
<i>Addressing electricity only</i>			
Murtagh et al. (2013)	Feedback	University (Office)	<1.5%
McClelland and Cook (1980)	Instructions	University	6%
Carrico and Riemer (2011)	Feedback	University (Office)	4 - 7%
	Social modelling		(vs. 4% control)
Nye and Hargreaves (2009)	Social modelling	Office	5%
Acker et al. (2012)	Justification	Office	4%
Chen et al. (2012)	Feedback	University (Office)	12%
Soldaty et al. (2013)	Prompts	University	5%
	Feedback		
Mulville et al. (2014)	Feedback	Office	Up to 20% (with large variations)
<i>Simulation of electricity saving potentials</i>			
Kattenstein et al. (2002)		University	18%
Junnila (2007)		Office	20%
Kavulya and Becerik-Gerber (2015)		Office	38%
Elmualim et al. (2013)		University	20%

<sup>1</sup> after Osbaldiston and Schott (2012): *Prompts* were non-informational reminders that focused only on when to perform the next specific action. *Commitment* consisted in asking participants to make some sort of verbal or written commitment to engage in a behaviour. *Goal setting* was the process of asking participants to aim for a predetermined goal. *Feedback* provided information about the extent to which a behaviour had been performed by participants in an earlier time frame. *Rewards* or incentives were any kind of monetary gain (as cash, coupons, rebates, bus passes, gifts etc.) that people received as a result of participating in a programme. *Instructions* indicated how to perform a specific behaviour. *Justifications* were the reasons for performing a specific behaviour, also called declarative information or why-to information. Finally, *social modelling* included any kind of passing of information via demonstration or discussion in which the initiators indicated that they personally engaged in the behaviour (such as in environmental champion campaigns).

Out of the studies listed in Table 2.3, the research project ‘change’ by Matthies and colleagues seems noteworthy (Matthies et al., 2011; Kattenstein et al., 2002): An interdisciplinary team of environmental psychologists and energy engineers achieved an 8% reduction in the lighting and small power consumption of a German university through an intervention package encompassing information in various formats, prompts through stickers and a commitment sheet linked to a lottery. To allow for a better evaluation of the effectiveness of the intervention, the achieved savings were compared to the theoretical maximum electricity savings potential. This theoretical potential was determined through TRNSYS building simulation of optimized energy-relevant staff behaviours, suggesting that 14% of electricity use could theoretically be avoided by switching-off unused computers and power sockets and a further 4% by switching-off lights when sufficient daylight was available or rooms were empty<sup>3</sup>. Providing such theoretical savings potentials also helped to link the energy behaviours targeted through the initiative to their actual environmental impact, a common call in the psychological literature (Stern et al., 1997; Gatersleben et al., 2002).

Studies directly linking organisational energy use to specific employee behaviours have increasingly been emerging but currently remain restricted to individual workstation behaviours in offices (Murtagh et al., 2013; Coleman et al., 2013; Mulville et al., 2014; Bradley et al., 2016). Murtagh (2013) and her interdisciplinary team of psychologists, engineers and computer scientists used individual level feedback on measured workstation electricity consumption in university offices through an on-line application to encourage employees to switch-off their workstations when away from their desks. Pre-intervention, a theoretical savings potential of 32% based on the measured use of a workstation compared to a 40h per week base case scenario was estimated. Measured savings were found to vary widely and were subject to participants joining and leaving the offices or changing desks during the study as well as to seasonality effects during the summer months. Mulville et al. (2014) experienced similar challenges of desk use instability in their study providing comparative feedback at desk-level to employees in a commercial office. Before the intervention, baseline electricity use is extensively analysed and savings potentials are estimated by comparing high, mean and low consumption patterns.

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<sup>3</sup> Building simulation further suggested that 9% of heat may be saved through improved ventilation practices and the reduction of indoor temperatures by one degree.

### **2.2.1.2 Staff-centred energy conservation initiatives in hospitals**

Attempts to promote healthy lifestyles through behaviour change campaigns have a long tradition to address issues such as obesity, smoking, heavy drinking or sexual risk taking and many successful intervention examples originate within the field of public health (NICE 2007). While generally aimed at communities or the wider population, some public health campaigns have also specifically targeted clinicians and aimed to encourage them to maintain high levels of hand-hygiene for infection control purposes (Fuller et al., 2014) or to keep updating their prescribing routines based on the latest emerging scientific evidence (Brennan and Mattick, 2013; Michie et al., 2005). In these cases, campaign goals were presumably aligned with the clinicians' aims to achieve optimal patient outcomes, but limited knowledge and/or a lack of attention paid sometimes kept health care staff from taking the required action. This suggests that for non-core activities such as energy saving similar, if not more, challenges will apply.

A review of the peer-reviewed academic literature has revealed a lack of research studies that focus on staff-centred energy conservation initiatives in hospitals. However, a handful of case studies in the grey literature report energy awareness campaigns or comparable measures in hospitals. While some report on cost or fuel savings achieved as detailed below, the quoted estimates will need to be interpreted with some caution as methods for their estimation are often unclear and results may be influenced by stakeholder interests.

**Historical accounts of staff-centred energy conservation in English hospitals** In England, behavioural energy efficiency in hospitals has been discussed at least two times: in the late 1980s and then again now following a period of reduced interest in behavioural energy efficiency during the 1990s/early 2000s. During the first period, the (then) Department of the Environment published a guide for energy and estate managers on good housekeeping in (BRECSU 1992b) based on experiences acquired in different health authorities during the 1980s.

In 1987, the Somerset Health Authority trialled a good housekeeping programme, which in combination with some capital investment in energy cost reduction projects achieved 25% savings on fuel bills within three years (BRECSU 1992a). Little detailed energy data was available and the sole effect of the staff-centred initiatives could not be separated out, but the report attributes roughly a fifth of the savings (5% of the fuel bill) to the housekeeping measures. Clinical and administrative staff were appointed as ‘energy monitors’ to watch the day-to-day use of equipment and identify opportunities for savings, while they and their departmental managers received training on energy issues and appreciation sessions. In addition, humorous posters were put up to reduce waste and competitions for energy posters and energy saving ideas were held among staff and patients, especially children. Every employee received an energy handbook and new staff were given a special introduction with respect to efficient energy behaviours. The campaign further recognised the importance of senior management commitment and monthly review meetings with high-ranking managers were organised.

An interesting approach to motivating staff is reported from the Pinderfields Hospital Trust (BRECSU 1995). Apart from a poster campaign throughout their hospitals and energy handbooks for staff to take home, the trust also implemented departmental accountability in six pilot areas; pre-allocating energy budgets to departments and measuring actual energy use. The project documentation, however, does not indicate whether departments could use saved money for other purposes or how well this intervention performed generally.

**Promoting energy awareness in English hospitals today** In 2007, the NHS Carbon Management Plan was piloted in partnership with the Carbon Trust in 30 hospitals throughout England and Wales. Most pilots included some behavioural elements (Carbon Trust, 2008; Heape, 2013). The 2015 version of EnCO2de also gives high prominence to organisational carbon management and good housekeeping, stressing that ‘there is a potential danger that the energy management team could spend too much time focusing on technical detail’ (Short et al., 2015, p.31).

Specifically, the Carbon Trust claims that reductions in total energy costs of up to 10% could be possible at no or very low cost in hospitals (Carbon Trust, 2010). The aforementioned 1992 NHS guide also published a 10% savings potential from good housekeeping measures (BRECSU 1992a), while other official publications since then by the NHS Estates (NHS Estates, 2004a) or the NHS Sustainable Development Unit (SDU) (Pencheon et al., 2009) had stressed the significance of staff education and participation, but not presented tangible energy saving potentials. For their Marginal Abatement Cost decision support tool, however, the SDU assumes more conservative energy awareness campaign effect sizes of 3% reductions for electricity and heating respectively (SDU 2010).

In terms of practical advice on staff engagement, the NHS SDU website provides a staff awareness pack (developed in collaboration with the Leeds Teaching Hospitals NHS Trust) to help hospitals run a half-hourly session on sustainability within their existing induction or staff professional development programmes. The advice collection ‘5 to Survive for Nursing Professionals’<sup>4</sup> put together in association with the Royal College of Nursing includes information on low carbon procurement, commuting and business travel. It further encourages the promotion of healthy meals in collaboration with colleagues from the catering department as well as the development of better models of care, but notably excludes any building related actions. The NHS SDU also publishes successful sustainability or energy efficiency projects as best-practice examples on their website, such as that of Operation TLC at the Barts Health NHS Trust (Barts Health NHS Trust, 2013).

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<sup>4</sup> ‘5 to survive...’ advice is also available for other groups of health care professionals including GPs and Estates and Facilities Personnel.

Operation TLC, an award-winning multi-partner behaviour change programme<sup>5</sup> used an Energy Champion approach to promote three low impact, but high frequency energy behaviours (turning off unused equipment, switching off lights and closing doors). The campaign team states that cost savings equivalent to 7% of the trust's fuel bill have been achieved alongside improvement in patient experience through fewer sleep disruptions and less privacy intrusions. This author was involved with the evaluation of the campaign in one of the participating hospitals during the first year of this PhD (scoping study). Findings highlighted that although the hospital's sub-metering levels were comparatively high, difficulties in measuring and attributing changes in energy use to the behavioural campaign were considerable due to the complexity of the underlying consumption profile from building services and appliance use as well as due to the varying engagement of occupants with the awareness campaign across the hospital (Morgenstern et al., 2014).

A recent survey study, also carried out by this author as part of the PhD scoping activities, nevertheless suggests that facilities and energy managers in a majority of NHS Trusts in England are implementing or planning to implement some form of staff-centred energy conservation initiative (Morgenstern et al., 2015a). Information-based initiatives to raise energy awareness among trust staff or patients proved most popular on the behavioural side and accounted for 13% of all energy efficiency measures carried out by NHS trusts in 2012/2013 according to the 70 survey responses. The survey, however, also showed that while cost-effectiveness is a central decision-making criterion for energy managers, it remains somehow unclear to them how much energy and therewith money can really be saved through energy awareness campaigns and other staff engagement initiatives in hospitals, partly due to the heterogeneity of their estates. It is concluded that to overcome this challenge the influence of clinical staff on building energy use needs to be explicitly linked to the respective buildings, processes and their interfaces with the occupants.

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<sup>5</sup> Operation TLC was implemented by Barts Health together with the behaviour change charity Global Action Plan and the energy service providers GE and Skanska. In 2013, it was awarded the widely respected HSJ award for 'Improving environmental and social sustainability' and has since been the role model for further behaviour change programmes carried out in the health care sector (promoted for example in Short et al., 2015).

The survey study further identifies challenges to lasting staff engagement with sustainability issues in busy hospital environments. The authors conclude that ‘it also seems promising to directly involve interested clinical staff in campaigns as experts on health care processes, the use of respective facilities and local pressures. A wider network of actors may be conceivable to complement top-down efforts by the energy management team, potentially including academic experts helping programme evaluations. At the same time, the conflicting demands on the time of both clinical and technical staff within a high pressure environment such as the NHS need to be appreciated. The resources required for staff-centred campaigns can only be made available if a trust’s senior management remains strongly committed to sustainability in times of rising pressures on NHS budgets’ (Morgenstern et al., 2015a, p.17). Similar challenges rooted in the centralised and hierarchical structures of the NHS with high levels of central focus and control had previously been identified by Tudor et al. (2008) based on their study of waste management in the NHS Cornwall.

**Staff-centred energy conservation initiatives in hospitals worldwide** Internationally, a number of behaviour change programmes in hospitals have also been reported on by practitioners<sup>6</sup>. In Canada, the University Health Network (UHN) in Toronto are running an extensive environmental champion programme (coincidentally also called Operation TLC) encouraging clinical staff to widely engage with energy saving and sustainability issues (Cowan, 2011, 2013). In a personal communication, the programme designer reports that actual energy savings from the programme are difficult to determine due to evaluatory challenges. She estimates (on the basis of surveys, visual audits and engineering calculations) that energy savings of about 10-20% may have been achieved over the 7 years programme duration through behaviour change. Voluntary participation in the programme is supposedly rising and energy is claimed to have become more salient across the hospitals, with senior management now asking for energy impacts on investment projects and other (health care) organizations inquiring about the programme. Indeed, other Canadian hospitals also report attempts to motivate employees, for example to help with the reporting of losses and leaks (Marshall and Rashid, 2013).

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<sup>6</sup> A Chinese journal also reports on an energy awareness campaign promoting the adjustment of lamp placements as well as power saving modes for IT equipment on nurses bases. The abstract claims electricity cost savings of 38%, but the article is unfortunately only available in Chinese so details could not be verified by the author (Su, 2011).

In Austria, the partly EU-funded recommissioning project ‘Re-Co’ - aiming to improve operational energy efficiency of non-domestic buildings through auditing and the implementation of low-cost measures ([www.re-co.eu](http://www.re-co.eu)) - also included four hospitals. Energy coaches, comparable to energy champions, participated in workshops to identify behavioural savings opportunities. Apart from common energy behaviours such as light switching and switching off monitors during breaks, they included the combining of little used refrigerators as hospital specific energy behaviour (Benke, 2012). Specific energy savings from the behaviour change campaign are not reported, but the implementing team estimates the user-sided savings potential to lie between 10 and 15%.

Few other studies investigated hospital specific energy behaviours or analysed how generic energy behaviours play out across different hospital buildings and department types. Jensen and Petersen (2011) have looked at reducing stand-by energy use of medical as well as laboratory equipment. They conclude that for some departments, stand-by electricity consumption from non-transportable equipment ‘most often accounts for more than 50% of annual power consumption’ (p.1516). At the same time, it is very difficult to obtain information from clinical staff or equipment manufacturers as to whether the equipment or parts of it can be switched off, whether recalibration is necessary after switch-on and how long it takes or whether the equipment is affected by frequent switching. Based on monitoring as well as some estimates, Pierce et al. (2014) and his team of anaesthetic practitioners assessed the daily electricity use required to provide a day’s general anaesthesia in operating departments. They conclude that the pumps of the anaesthetic gas scavenging system removing gases hazardous to health from theatre departments should be switched-off after hours and then properly activated as part of the pre-anaesthetic check.



### **2.2.2 Challenges for the evaluation of behavioural energy efficiency interventions**

Robust evaluations are considered a prerequisite for improvement and learning (Preiser and Vischer, 2005). They can offer evidence on impacts of policies, programmes or interventions, illustrating not only what changes were produced but also why and how these changes came about (Hills and Junge, 2010). Rigorous design based on a suitable theoretical framework is however a precondition for evaluations to deliver sound results. Plenty of literature and guidelines exists on programme evaluation in general (see Hills and Junge, 2010, for an excellent discussion of the topic) as well as on the evaluation of technical energy efficiency programmes (e.g. Vine and Sathaye, 1999). But less guidance is available for behavioural change programmes in buildings, neither on ex-ante (section 2.2.2.1) nor on ex-post (section 2.2.2.2) evaluations.

There has been a continued call for better evaluation from both academia and practitioners (e.g. Banks et al., 2012). Importantly - and in contrast to technical measures where energy and cost savings are the main focus - behavioural energy efficiency interventions may co-generate a number of non-energy-benefits in particular regarding patient experience (Gray, 2011), employee satisfaction and morale (Knight and Haslam, 2010) as well as organisational image (Pellegrini-Masini and Leishman, 2011). These ‘knock-on benefits’ and potential ‘knock-on costs’ need to be taken into account to allow for comprehensive cost-benefit analyses of behavioural interventions (Skumatz et al., 2000; Banks et al., 2012).

### 2.2.2.1 Ex-ante: Assessing the energy savings potential of operational changes

Ex-ante evaluations, or appraisals, attempt to forecast intended energy savings of future projects before an investment decision is made (Hills and Junge, 2010). Their relevance in the context of organisational energy management has variously been argued: Azar and Menassa (2014) stress the need for a framework to quantify such saving potentials from improved operations of the commercial building stock. They claim that a comprehensive framework will support the integration of operations-focused measures in energy policies and justify the costs of their further exploration. Energy managers are also known to often need justification as to why their organisations should invest in (behavioural) energy efficiency, making savings potentials helpful (CIBSE, 2012). Moreover, the psychological literature calls to more comprehensively assess the potential environmental impact of pro-environmental and energy behaviours (Stern et al., 1997; Gatersleben et al., 2002; Matthies et al., 2011, see also section 2.2.1.1). Terminology and methodologies to determine energy savings potentials, however, are yet to be standardized.

**Terminology: What is an energy savings potential?** Energy benchmarking methodologies for buildings make reference to two types of performance standards: an absolute standard based on what a building does and a relative standard where the assessed building is compared to a notional building identical in shape and form with the same servicing systems (e.g. Bordass et al., 2014). So are the UK Display Energy Certificates (DEC), now mandatory for all public buildings, based on absolute standards while compliance with Part L of the Building Regulations is granted in the UK based on relative benchmarks. Potentials as understood in this study are also relative, i.e dependent on the context of the investigated building and its configuration.

Moezzi and Janda (2014) name three kinds of (relative) potentials which could be tapped to reduce building energy use: a technical, a behavioural and a social potential.

- For the authors (based on ideas by Rosenfeld et al., 1993), a *technical potential* denotes a best-case energy efficiency scenario based on engineering and economic calculations unconcerned with the probability of a successful implementation of the proposed measures.

- Similarly, a *behavioural potential* describes a savings potential from simple changes in energy behaviours, i.e. ‘without assuming dramatic or onerous changes in behaviours’ (Moezzi and Janda, 2014, p.5), disregarding any analysis of how compelling supposed benefits are to occupants or other considerations on ways to achieve this behavioural potential. Incidentally, the concept of a behaviour potential has helped to establish a policy-friendly counterpoint to a conventional focus on technological efficiency alone. In the tradition of socially orientated schools of thought (see also section 2.1), Moezzi and Janda (2014) are, however, highly critical of such simplistic notions of the role of human actors in achieving reductions in energy use.
- They hence move on to propose a *social potential* describing the gap between current arrangements and ‘a world where social organization is optimized for energy performance’ (Moezzi and Janda, 2014, p.6). As work in progress, the notion of the social potential currently remains somehow vague in the text despite a number of examples. Following further developments, the concepts may however become an extremely useful tool to highlight (and potentially even quantify?) additional pathways for change.

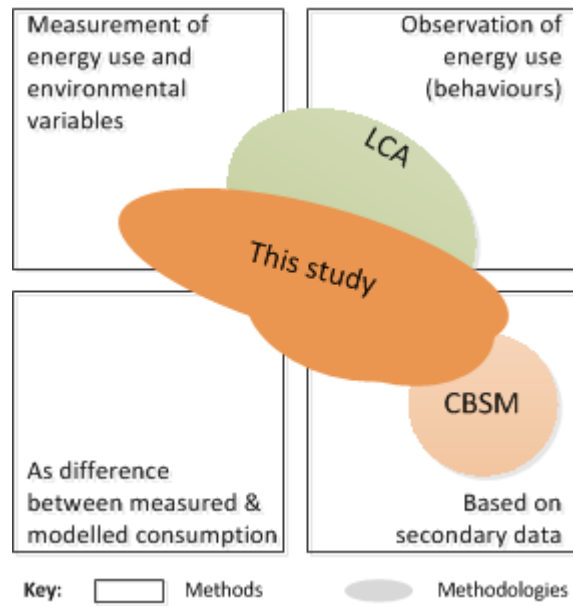
Other scholars are less critical of behavioural potentials and stress their importance in bringing the influence of occupants on building energy use to the attention of implementers and climate policy (Lucon et al., 2014). In the domestic context, the term ‘behavioural wedge’ was used to describe ‘the reasonably achievable potential for near-term reductions by altered adoption and use of available technologies’ (Dietz et al., 2009, p.18452). In this definition it does remain somehow debatable what may be understood as ‘reasonably achievable’, likely pointing out a major weakness of the concept of (behavioural) potentials in general. Ucci et al. (2012) develop a questionnaire tool to assess how well organisations are doing in managing energy-use behaviours of occupants in existing non-domestic buildings. In a very applied article, they do not specifically define their term ‘behaviour change potential for energy saving’, but the developed questionnaire items comprise specific switch-off actions but no fundamental transformations.

This work will subsequently use the term of a *theoretical savings potential* to describe a calculated potential representing some form of ideal intervention and disregarding all practical considerations which may affect implementation. The theoretical potential is context-dependent but unconstrained except through infrastructural arrangements. As opposed to technical, behavioural or social potentials, the term theoretical savings potential may refer to operational changes achievable through either technical, behavioural or organisational/structural measures. This terminology is preferred due to its emphasis on the theoretical nature of the estimated potential, stressing the value of the concept in prioritisation and strategy development rather than focusing on specific pathways to change.

**Methods and methodologies to quantify occupant influence on building energy use** Methods to quantify the energy use of existing non-domestic buildings in general can be divided into measurement-based and calculation-based approaches (the latter include steady-state or dynamic simulations) (Agami Reddy, 2011; Wang et al., 2012). Surveying and energy audits are common measurement-based tools to obtain information on organisational processes at a building or systems level, to identify energy conservation opportunities and estimate savings potentials (Russen et al., 2010; Field et al., 1997; Hirst, 1982). Depending on their level of detail, energy audits can include the analysis of fuel bills, walk-throughs, the study of installed equipment and operating data as well as on-site measurements.

Energy audits (Masoso and Grobler, 2010) as well as a number of other measurement-based methods have been used to assess factors related to occupant energy behaviours:

- Window opening behaviours, lighting switching as well the use of shading have been monitored using time-lapse digital photography (see for example Hagemeyer (2014) for an example in the hospital context).
- Temperatures and light levels were recorded using distributed data loggers (for example Mahdavi et al., 2008; Schakib-Ekbatan et al., 2015).
- Electricity consumption of equipment was monitored at plug level (for example Murtagh et al., 2013).
- Some studies (for example Tetlow et al., 2012) recorded observations of light switching over a certain period of time.
- The location of occupants within a building, especially relevant for HVAC operations, was monitored using a range of techniques (see Spataru and Gauthier, 2014, for a detailed review).

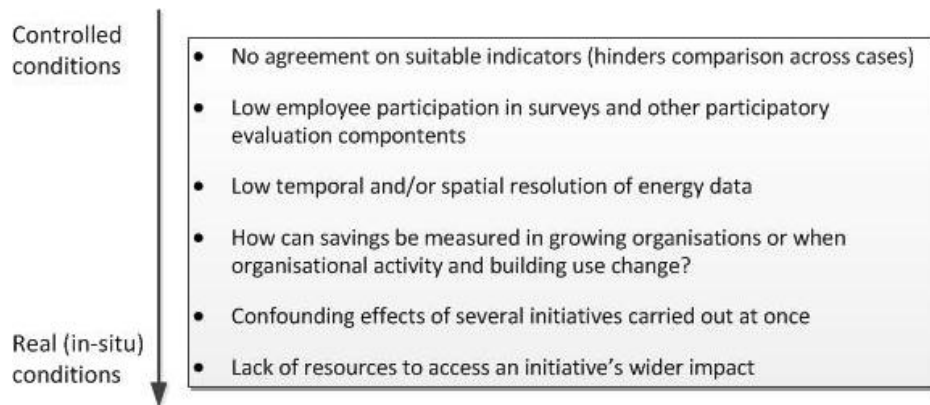


**Figure 2.2:** Graphical overview of methods and methodologies to quantify occupant influence on building energy use discussed in this section

An increasing interest in advancing the understanding of occupant influence on building energy use has also emerged from a building simulation perspective. This is for example reflected in the formation of the IEA-EBC Annex 66 for the definition and simulation of occupant behaviour in buildings in 2013. It is hoped that a better understanding of occupant energy behaviours may help to reduce the performance gap prevalent in the understanding of the energy performance of non-domestic buildings (CIBSE, 2006). Predicting building energy consumption based on statistical or engineering estimates and attributing remaining differences from measured energy consumption to occupant behaviour is generally common, but may - in overlooking structural and modelling uncertainty - not stand up to scrutiny while as a top-down method offering little insight into what is actually going on on the ground.

Beyond methods, a number of methodologies have further informed the analysis of occupant influence on building energy use in this study (Figure 2.2). Life cycle assessments (LCAs) are used to obtain detailed information on environmental aspects and potential impacts, including the energy consumption associated with a product, process, or service (EPA 2015). In health care, LCAs are common to investigate the environmental impact of drug and consumable use (for example Overcash, 2012). LCA has also been applied to the delivery of imaging in hospitals, measuring in detail the electricity use of imaging equipment during different scans and estimating the energy use for lighting and building services (Esmaeili et al., 2015; Twomey et al., 2012). Such detailed bottom-up studies seem invaluable in understanding to what extent hospital energy use is influenced by the decisions of clinical and other staff in different health care processes.

The explicit link of estimated potentials to specific energy behaviours is also a strength of McKenzie-Mohr (2000)'s community-based social marketing (CBSM). CBSM recommends to begin thinking about any pro-environmental behaviour change initiative by creating a list of all related behaviours, regardless of whether a behaviour seems highly insignificant in terms of impact or virtually inconceivable in terms of uptake. Based on this initial list, an informed decision can be made as to which behaviours to promote in order to maximise greenhouse gas emission reductions. CBSM advises to determine the potential impact of any behaviour change based on information from the literature or through expert consultation if no reliable information are available otherwise. Based on the CBSM methodology, Bruce (2008) from the municipality of Townsville in Australia created a list of 241 behaviours related to residential energy demand, classifying potential impact and likelihood of each behaviour. No comparable inventory of energy behaviours was found in the non-domestic context, despite calls to base behaviour change initiatives on detailed assessment of the potential impact of energy behaviours (Banks et al., 2012; Short et al., 2015).



**Figure 2.3:** Challenges for the evaluation of energy behaviour change interventions (Schahn, 2007; Matthies et al., 2011; Lakeridou et al., 2012; Zibarras and Ballinger, 2011; Cox et al., 2012)

#### 2.2.2.2 Ex-post: Assessing energy savings achieved in actual interventions

Ex-post evaluations are conducted either on or after completion of an intervention to determine whether the intended objectives could be achieved (Hills and Junge, 2010). For energy awareness campaigns or other behavioural initiatives in organisations, ex-post evaluation has so far mostly been attempted through what theory describes as a quasi-experimental approach using interrupted time-series (Shadish et al., 2001). This approach is known to be problematic for gradual rather than abrupt interventions and those where effects might be delayed. Especially in complex non-domestic buildings with limited available meter data, links between measured changes in energy consumption and actual occupant activities can be hard to establish (Morgenstern et al., 2014). This can limit the understanding of the extent to which behaviour change programmes are actually effective in motivating employees to reduce workplace energy use. Figure 2.3 summarizes additional challenges for energy interventions commonly encountered in practice.

The methods used to determine actual energy reductions from interventions are on the whole not dissimilar from those applicable to determine savings potentials (see section 2.2.2.1). Many evaluatory attempts have relied on meter data and self-reported data from pre-and post intervention questionnaires with occasional incidents of behavioural monitoring, observing for example light switching in jointly used rooms (Tetlow et al., 2012) or window positions from the outside of buildings (Matthies et al., 2011). The use of such additional datasets seems highly commended to increase the understanding of intervention pathways.

Additional research could be especially beneficial in establishing suitable indicators to specify the energy impact of behavioural energy efficiency intervention taking into account the resources (financial, personnel) realistically available to evaluation. On the other hand, non-experimental alternatives such as theory based evaluations linked to the intervention logic might be more promising in the first place (Petersen, 1998; Morgenstern et al., 2014). The reporting of achieved campaign effect sizes within the context of theoretical achievable potentials to allow for a comparison across contexts and buildings also seems crucial (Matthies et al., 2011).

### **2.2.3 Section summary and implications for this study**

This section on individualist studies of employee energy behaviours presented a number of staff-centred energy conservation initiatives in non-domestic buildings in general and in hospitals in particular. Such studies claim some success in reducing organisational energy use, while evaluation poses a major challenge, especially in complex buildings like hospitals. Apart from reductions in energy consumption and costs, the importance of intangible benefits relevant directly for the employees as opposed to the organisation (such as comfort or increased reliability of equipment) has been stressed. It further seems that the culture of an organisation and how much priority is given to sustainability by its senior management is crucial in motivating an efficient end-use of energy. For hospitals in particular, the lack of studies investigating energy behaviours specific to the context was highlighted.



It was further established that an assessment of energy savings potentials is important within individualist frameworks to allow for investment decisions between different carbon mitigation strategies. The literature was reviewed for available methods and methodologies to estimate such potentials, which guided the research design of this study: given that little secondary data was available in the hospital context, affecting also the viability of simulation-based approaches, a measurement-based methodology was applied in this study (chapter 3). This chapter will now proceed to discussing relevant studies taking a socio-technical or ‘social practices’ view on saving energy in work places.

## **2.3 Saving energy at work as social practice**

In contrast to traditions of thought focusing on individuals and their choices, socially orientated perspectives common in sociology, education sciences and science and technology studies, reflect that energy demand occurs as a result of social organisation and the structures established to provide energy services. While individualist perspectives have long been dominant in the built environment, sustainability research agendas increasingly recognise the need to include more complex and system-orientated notions of human interaction with buildings and infrastructure (Summerfield and Lowe, 2012). This section presents a selection of important empirical socio-technical studies on energy demand in buildings (section 2.3.1) before proceeding to introducing social practice theory and a number of empirical studies undertaken within this framework (section 2.3.2).

### **2.3.1 Empirical socio-technical research on energy demand in buildings**

Empirical research is crucial for evidence-based policy as well as for the test and refinement of theories (Summerfield and Lowe, 2012). Currently there are still few data-driven socio-technical studies available in built environment research, while new insights are constantly emerging - especially in dwellings (Chiu et al., 2014). It therefore seems important to briefly review applied socio-technical studies in other areas in order to gain insight into value and implementation of such approaches. This section hence introduces a number of important empirical studies of socio-technical systems generally.

The concept of socio-technical systems was initially operationalized for the empirical analysis of real-world situations by Trist and Bamforth (1951) in their seminal study on social and psychological consequences of different coal mining methods. Based on data gathered in repeated discussions with expert groups and long interviews with miners as well as managers, Trist illustrates how scale and spatio-temporal structure of the three shift cycle for longwall coal-getting negatively impacts on worker morale and productivity. Suggestions for changes in social organisation<sup>7</sup> which had previously been overlooked emerged from this analysis approach.

More recently, Schatzki's account of the Shaker<sup>8</sup> medical herb business again pointed towards the relation between activity and site (Schatzki, 2002). In a historic case study used to illustrate the author's theory of what defines social life, Schatzki draws out how the activities of collecting, chopping and drying medical herbs are intertwined with both the physical arrangements of the Shaker villages as well as the social order of the Shaker society including their religious convictions and a strong sense of community. Amongst others, the case study exemplifies Schatzki's concept of *spatial prefiguration* according to which a site prefigures the path of an activity taken which in turn shapes the site. This concept of prefiguration seems crucial also in the analysis of energy consumption in buildings.

From a different perspective, the PROBE studies undertaken primarily in office buildings<sup>9</sup> (Bordass et al., 2001) and other examples of commercial post-occupancy evaluation (POE) (Baird, 2010; Preiser and Vischer, 2005) have contributed hugely to a socio-technical understanding of building energy use and occupant satisfaction. The focus of such studies is however often to understand and benchmark the physical and energy performance of buildings. Data from occupants is mostly collected through standardized survey instruments, somehow limiting the scope to reflect on contextual variables (Chiu et al., 2014). More recently, Gul and Patidar (2015) include semi-structured interviews with facilities personnel as well as some ordinary building occupants in their POE of a multi-purpose university building. This helps them to uncover potential changes to timer settings of automated HVAC systems, suggesting that especially in complex buildings with a mixed use of space such flexibility is invaluable.

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<sup>7</sup> such as developing a formal small-group organization on the filling shift or an acceptable solution for authorities on the cutting shift

<sup>8</sup> The Shaker were a religious community in the 19th century in the US. They were characterised by a communal lifestyle, pacifism, the celibate and a model of equality of the sexes as well as their simple living, architecture, and furniture.

<sup>9</sup> PROBE included the analysis of a small medical centre containing doctors' and dentists' surgeries.

### **2.3.2 Social practice based studies on building energy use**

A number of theories and frameworks have been proposed to facilitate the socio-technical analysis of increasingly complex and multidisciplinary research questions. The multi-level perspective (MLP) investigates change by including three different socio-technical scales and has been influential in investigating societal transitions (Geels and Schot, 2007). Further, ‘energy cultures’ aims to help identify opportunities for behaviour change by taking a culture-based approach to behaviour which also draws from lifestyles and systems thinking (Stephenson et al., 2010). In the (UK) built environment research community, social practice theory has increasingly gained academic and policy attention (Chatterton, 2011), partly due to its potential to integrate technical data on building and energy performance with qualitative explorations of social or cultural components of everyday life (Foulds et al., 2013).

#### **2.3.2.1 Introduction to social practice theory**

A theory of social practice was originally developed in the late 1970s by the British sociologist Anthony Giddens. Over the last two decades, Elizabeth Shove from Lancaster University has further developed social practice theory (SPT) in relation to sustainability and energy consumption. Fundamentally, SPT aims to ‘transcend the dualism of structure and agency (Shove et al., 2012, p.3)’ by proposing social practices as elements ‘shaping society and human doings over space and time’. To understand the influence of occupants on building energy use, research may hence focus neither on the individual occupant nor on the cultural and material arrangements of organisations and buildings alone, but on collective indoor climate and equipment practices.

According to Shove et al. (2012), practices are routinised activities that occur repeatedly in a very similar form in different places and moments. They represent broad cultural entities that shape an individual’s perceptions, interpretations and actions within the world (Hargreaves, 2011). Cohn (2014) points out that ‘everyday practices are always locally situated and composite’ while they have no absolute delimitation. Similar to the definition of a system in engineering, the boundaries of what is understood to constitute a certain social practice will depend on the research question as ‘it is perhaps impossible and even undesirable to try and identify when exactly an action starts and when it ends, or the extent to which one action is distinct from another’ (Cohn, 2014, p.160). Used skilfully, social practices can therefore represent a useful analytical framework to disentangle a range of different questions associated with a move towards a more sustainable built environment.

**Table 2.4:** Social practice theory elements for empirical analysis

(Table originally by Gram-Hanssen, 2011, Gram-Hanssen’s contribution added by author)

Schatzki (2002)	Warde (2005)	Shove et al. (2005)	Reckwitz (2002)	Gram-Hanssen (2011)
Practical understanding	Understandings		Body	Know-how and embodied habits
		Competences	Mind	
			The agent	Institutionalized
Rules	Procedures		Structure/Process	knowledge
Teleo-affective structures			Knowledge	
			Discourse/Language	
	Engagement	Meanings		Engagements
Entities	Consumption items	Products	Things	Technologies

Individuals are in SPT conceptualised as carriers of practices who shape society while in turn being shaped by societal structures. Importantly,

they are neither autonomous nor the judgemental dopes who conform to norms: They understand the world and themselves, and use know-how and motivational knowledge, according to the particular practice. There is a very precise place for the ‘individual’ [...]: As there are diverse social practices, and as every agent carries out a multitude of different social practices, the individual is the unique crossing point of practices.

(Reckwitz, 2002, p.256)

Regarding social practices as the central unit of enquiry therefore invites the joint analysis of bodily routines of behaviour, mental routines of knowing and understanding, the use of objects as well as how all of those hang together.

Several authors have attempted to make SPT usable for empirical analysis by conceptualising common elements through which social practices are defined (Table 2.4). For the research of occupant influence on building energy use the synthesis of previous categories presented by Gram-Hanssen (2011) has been well utilised (see section 2.3.1), likely due to its accessible, straightforward presentation and a focus on contemporary rather than historical events and sources of data. A further description of each of the four elements shaping a practice according to Gram-Hanssen (2011) can be found in chapter 6 where the analytical framework is operationalized in this thesis.

Social practice theory has been criticised for its strong focus on routines and elements holding practices together, implying that a practices lens may be somehow limited in understanding how change can happen (Warde, 2005; Gram-Hanssen, 2011). A number of directions for further development have been proposed, below a list of those voiced in particular by researchers utilising SPT for empirical analysis:

- Instead of focusing on single practices, more attention should be paid to connections, alliances and conflicts between practices (Hargreaves, 2011). This in line with Gram-Hanssen's proposition that different practices might share elements, implying that changes in one practice may help to induce changes in another (Gram-Hanssen, 2011).
- Hargreaves also suggests further inquiry into how practitioners are being recruited into a practice and how this affects their (social) identities. Placing a higher focus on practitioners appears to starkly contrast understandings of SPT which strictly focus on the practice as suggested for example by Shove, but may offer additional insights relevant to change-making by taking account of social and power relations.
- Palm and Darby (2014) propose to explore how practice theory connects to different aspects of learning and how feedback processes, for example through post-occupancy evaluation (POE), may bring about change. The importance of POE in closing feedback loops for building design and operation is increasingly recognised (Leaman et al., 2010) and synergies with practice based investigations could mutually increase insights.

As it stands, SPT continues to evolve and can be expected to make further contributions to our understanding of human action in the built environment.

**Table 2.5:** Empirical social practice based studies of energy demand in buildings

Context	Focused on social practices	Combining social practices and technical monitoring
Domestic buildings	Behar (2015)	Chiu et al. (2014)
	Sweeney et al. (2013)	Foulds et al. (2013)
	Walker et al. (2014)	Gram-Hanssen (2010)
	Palm and Darby (2014)	Gram-Hanssen (2009)
	Galvin (2015)	
Non-domestic buildings	Christina et al. (2015, Retail)	Dantsiou and Sunikka-Blank (2015, University)
	Hargreaves (2011, Office)	Palm and Darby (2014, Research laboratories)

### 2.3.2.2 Empirical social practices studies of building energy use

Empirical studies gathering and analysing data guided by social practice theories are increasingly emerging within research on energy use in buildings (Table 2.5). Especially in the domestic context, the analytical framework was variously shown to be useful in providing insights on the interplay between dwelling energy use and the occupant’s everyday life. Fewer practice-based studies so far analyse the energy demand associated with organisations and non-domestic buildings, but some enthusiasm is notable here too and more research can be expected to emerge in this area shortly. It is increasingly sought to combine social practice explorations (commonly relying centrally on interviews) with the monitoring of technical buildings parameters (including temperatures, humidity and carbon dioxide levels or energy consumption) to produce insights beyond those obtainable through non-integrated approaches.

In the *domestic context*, practices around standby-consumption of (mainly entertainment) equipment (Gram-Hanssen, 2009), the seeking of (thermal) comfort (Gram-Hanssen, 2010; Foulds et al., 2013; Galvin, 2015) and the occupant experience of low carbon technologies (Behar, 2015) and retrofits (Walker et al., 2014; Chiu et al., 2014) have been explored. Three main implications, two topical and a methodological one, can be synthesised which will also apply in the non-domestic context and are therefore relevant to this thesis:

- **Temporal organisation of daily life:** Attention needs to be paid to the temporal organisation of daily life, appreciating expectations of ‘convenience’ and ‘speed’ associated with routines as well as when may be a reasonable moment to instigate change. Hand-overs were found to traditionally clash with busy periods in residents’ lives (while trying to make themselves at home in new dwellings or post-retrofit), suggesting repeated inductions at a later time may be more promising in making low-carbon technologies work in practice (Behar, 2015). Practices associated with low energy demand were found more likely to be taken up if they proved convenient with respect to achieving practice goals or saved time, such as showering versus bathing in the attempt to achieve cleanliness (Walker et al., 2014).
- **Complementing material changes with knowledge and engagement:** Evidence is increasingly emerging that established practices will not necessarily change or be replaced with changes in technology and the material environment. Pre-retrofit heating, cooling and ventilation practices often persisted, albeit with differing intensities, following retrofits (Chiu et al., 2014) or relocations to a new home (Behar, 2015). This contradicts earlier findings where changes of habits were found to often occur together with technological rearrangements (Gram-Hanssen, 2009). In contrast, all studies agree that changes in knowledge and motivation, potentially complementary to technological rearrangements, were also crucial. So while technological rearrangements may seem like a straightforward and hence potentially attractive route to change, their role may not be overestimated and it would appear important to also focus on aspects of knowledge and especially engagements.
- **Post-rationalisation of habits:** Several studies have found that people, if pressed during interviews, would explain their habits to make them seem rational (Gram-Hanssen, 2010) or by repeating what deemed ‘experts’ had been saying (Foulds et al., 2013). Mismatches between stated practices and monitoring were occasionally identified, casting doubt on the robustness of findings. Hitchings (2012) argues that people can be helped to talk about habitual and seemingly mundane everyday practices by undertaking serial interviews to build rapport or by carefully tabling alternative ways of behaving to explore own routines among a range of others without feeling ridiculed or stigmatized. The work by Foulds et al. (2013) suggests that subtly probing householders in the context of findings from technical monitoring may also help to ascertain how a household actually uses the dwelling, but potentially only if a good relationship between occupants and researchers has previously been established.

Most studies within *non-domestic buildings* were undertaken within the context of behaviour change interventions of some form, identifying what had worked and what not and providing suggestions on or even assisting with the implementation of improvements. It seemed overall that researching energy practices in a work context adds additional complexity as opposed to studies looking at dwellings. The time and effort required to carry out such studies is one likely reason why they have so far primarily been restricted to PhD projects which tend to operate on longer time frames than many other research projects within current funding arrangements (see Appendix B.1 for a summary of relevant studies).

One study of particular importance to this work conducts a social practices based case study investigation in four 24-hour research laboratories (Palm and Darby, 2014). Out of the above settings, continuously operating research laboratories can be expected to match the context and the challenges of hospitals most closely. The study uncovers issues with ‘the meaning of a 24-hour building (p.80)’ resulting from a lack of critical engagement with questions like ‘How much provision for 24-hour work is really needed, and how can it be provided most effectively (p.89)?’ or ‘What does scientific activity mean in the 21st century (p.89)?’. Based on secondary data from an energy audit, Palm and Darby further highlight that notions of energy wastage, for example from night-time lighting, do not correspond to the actual make-up of the laboratories’ base-loads. They hence stress that building energy management requires the understanding of factors that are both physical and social.

It is notable that all of the above studies in non-domestic buildings stress aspects of organisational culture and rules while this element (which Gram-Hanssen, 2011, describes as ‘Institutionalised knowledge’) featured somehow less prominently in the domestic context. This resonates with notions within psychology pointing towards social norms as additional lever to reduce workplace as opposed to household energy use. In contrast, there appears to be less certainty about the role of technology as agent to change energy practices in the workplace. The findings do however suggest that infrastructure or installations of poor quality may hinder low carbon practices (as well as employee well-being and productivity), in line with findings from Walker et al. (2014) and Chiu et al. (2014) in the domestic context.



### **2.3.3 Section summary and implications for this study**

Socially orientated schools of thought reflect that energy demand occurs as a result of social organisation and the structures established to provide energy services. The empirical analysis of such arrangements requires socio-technical approaches in order to appreciate the relevance of both physical and social factors. One theory aiming to describe the interactions between these factors is social practices theory. Within built environment research, Gram-Hanssen (2011)'s framework for the analysis of social practices has proven helpful and will therefore also be applied in this study.

Empirical socio-technical studies highlight that service requirements and the resulting energy demands are complex and intertwined, in particular in non-domestic buildings. Awareness campaigns, energy competitions and other simplistic attempts at changing energy-related practices, be it of householders or of employees, are understood to have limited success because engagements, routines and knowledge issues are not considered. It is recommended that increased attention is also directed towards the definition of services themselves, questioning operating hours, temperature preferences and space requirements. It is finally pointed out that while technology can be helpful in reducing energy demand, this is not deterministic and faulty or poorly defined technology can impact on occupant comfort and satisfaction while adversely affecting carbon emissions.

## **2.4 Summary of evidence from the literature**

This literature review suggests that staff-centred energy conservation initiatives in hospitals may achieve energy and cost savings while potentially also benefiting patient outcomes. The academic work investigating occupant influences on hospital energy use is however very limited and further research focusing on energy consumptions and cultural elements relevant in health care seems beneficial. The opinions on the viability of behaviour and other simple operational changes are further divided, with many scholars reflecting critically on the scope of such initiatives in the sensitive hospital context as well as on practical and ethical issues associated with attempts to place responsibility for organisational energy use on the shoulders of individual employees.

Energy managers within the NHS and other organisations encountered over the course of this study<sup>10</sup> did, however, argue a number of practical reasons why they may decide to pursue behaviour and other simple operational change initiatives as part of carbon mitigation strategies:

- The budget available to energy efficiency measures may be limited due to an organisation’s financial status, its priorities and the availability of funding mechanisms for larger capital projects.
- The time frame within which energy demand reductions can be achieved may be short because the organisation is due to relocate or undergo other forms of restructuring.
- In tenanted spaces, the control of physical parameters may be outside of an organisation’s control.

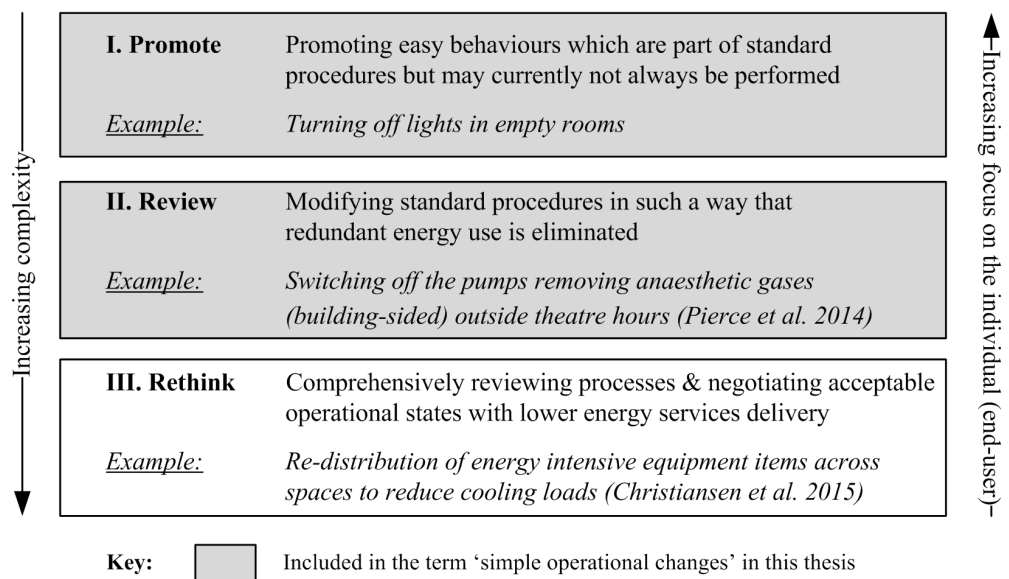
Pragmatically, a further exploration of staff engagement and other strategies of simple operational changes hence seemed justified in hospitals, while taking account of socially orientated and socio-technical concerns. A framework is presented which will support the conceptualisation of potential changes in clinical routines throughout the remainder of this study (section 2.4.1), aiming to broaden the remit of staff-centred energy conservation initiatives in organisations. At an applied level, a number of open questions are summarized in section 2.4.2.

### **2.4.1 Conceptual Framework**

World-views and the resulting assumptions of people, their actions and the degree to which those actions are structured and prescribed by the context vary between academic disciplines. While individualist understandings, typical for (micro-)economic and psychological theories, focus on individual occupants as centre of energy conservation initiatives in buildings, socially orientated theories, common in sociology or science and technology studies, reflect that energy demand also results from social constructions and the systems providing energy services. Social practices theory (focusing on collective practices which shape an individual’s perceptions, interpretations and actions within the world) has been proposed as an analytical framework aiming to bridge the gap between structure and agency (Shove et al., 2012) and has been well utilised for the research of occupant influence on building energy demand.

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<sup>10</sup> mainly during the survey study published in Morgenstern et al. (2015a) as well as in networking interactions



**Figure 2.4:** Conceptual framework of conceivable energy-related operational changes in organisations

Importantly, all theories represent abstracted ways of understanding while none fully reflect reality. Different theories can therefore offer different insights on the interplay of occupants and non-domestic buildings, i.e. the service infrastructure they provide. In response, pragmatic approaches combining models and methods in service to increasingly complex and multi-dimensional research questions are increasingly emerging (Morgan, 2007, see also section 3.2). The use of multiple-model approaches to compare and contrast findings generated through different lenses has also been advocated at a practical and policy level (Chatterton, 2011).

Accordingly, it was found useful to distinguish three levels of operational change conceivable in hospital departments (Figure 2.4). Each level of change may achieve some reductions in building energy use. The three levels differ in complexity and how strongly they focus on the behaviour of individuals as opposed to changes in social and physical arrangements and can be expected to apply equally in other non-domestic building types. More complex changes may often be associated with longer implementation time-scales owing the need for (infra-)structural changes. Simple changes may, in contrast, not deliver the required reductions in carbon emissions while potentially overlooking synergies with improvement attempts in other areas (such as public health). By bringing together the different levels of change (albeit inevitably very simplified) in one conceptual framework, it is hoped to illustrate a wider range of options to those researching and especially those designing practical interventions to reduce non-domestic building energy use.

#### **2.4.2 Gaps in knowledge: Occupant influence on hospital energy use**

In the past, a number of staff-centred energy conservation initiatives have been carried out in hospitals, generally claiming to achieve reductions in total energy use between 5% and 20% (Table 2.6). These reported reduction estimates are (although associated with some uncertainty) roughly in line with relative effect sizes reported in the academic literature for offices and university buildings, while exceeding them in absolute terms due to the energy intensity of hospital buildings. A recent survey study by this author further suggested that facilities and energy managers in a majority of NHS Trusts in England are currently implementing or planning to implement some form of staff-centred energy conservation initiative (Morgenstern et al., 2015a), justifying further explorations in this area.

Many open questions remain within the psychological<sup>11</sup> and sociological<sup>12</sup> arena. This literature review, however, also highlights several themes which would benefit from technical insight, the primary skill set of this thesis' author:

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<sup>11</sup> For example: What is the best way to engage busy hospital staff with sustainability issues and keep them engaged in the long term?; Can a transfer of energy behaviours between home and workplace be a motivator?; What about staff who are disinterested or cynical about climate change?

<sup>12</sup> For example: How can attempts at energy demand reduction in hospitals (be made to) overlap with the sustainable provision of health (care) to ageing populations?; How can technology be employed to instigate changes in current energy practices in workplaces?; How can social practices theories be further developed and improved for the empirical analysis of organisational building energy use?

**Table 2.6:** Reported energy savings from clinical staff engagement in hospitals  
Please note the limited comparability of the reported savings due to differences in intervention type, programme duration as well as available detail on evaluation methodologies.

Type	Source	Reported energy savings
Case reports	Somerset Health Authority, UK (BRECSU 1992a)	5% of total fuel bill
	Operation TLC, UK (Barts Health NHS Trust, 2013)	7% of electricity
	Operation TLC, Canada (Cowan, 2013)	10-20% of energy
	<i>Re-Co project, Austria (Benke, 2012)</i>	<i>Potential: 10-15% of total fuel bill</i>
Guidelines	NHS SDU MAC curves (SDU 2010)	3% for electricity, 3% for heating
	Carbon Trust (2010, based on NHS Carbon Management programme)	10% total energy

- Theoretical energy savings potentials:** Theoretical energy savings potentials are calculated potentials representing energy savings achievable through an ideal intervention while disregarding practical considerations and constraints which may affect implementation. Studies within social and environmental psychology argue that the estimation of such potentials is crucial for two reasons:
  - Firstly, estimating savings potentials allows for the selection of environmentally significant behaviours and practices to be targeted in change initiatives, thereby ensuring that impacts on energy costs and carbon emissions may be substantial and justify the undertaking of an initiative (Stern et al., 1997; Gatersleben et al., 2002; Matthies et al., 2011).
  - Secondly, knowledge on theoretically achievable savings helps evaluation by allowing insights on how much of this potential could actually be tapped by an intervention (Matthies et al., 2011). For comparisons of initiatives across different buildings and organisations, a metric taking account of the achieved savings in the context of projected savings seems a more meaningful indicator of success than reporting achieved savings only.

- **Understanding hospital energy use:** The careful selection of targeted behaviours and/or practices on the basis of theoretical energy savings potentials is hence crucial for achieving operational reductions in hospital energy use (be it through behaviour change campaigns or re-arrangements at a physical, social or organisational level). Background to this study (section 1.1) and literature review, however, suggest that the understanding of hospital energy use at a sub-building level is currently fairly limited. The gap between clinicians using building and (medical) equipment and building operators looms large and little is known about how area characteristics impact on energy use. Further research explicitly linking energy use to the respective hospital departments and their activities therefore seems recommended.
- **Evaluation in complex buildings:** Due to the complexity of building services and appliance use in hospitals, it is very difficult to measure and attribute changes in energy use to behavioural initiatives even in hospitals with above-average sub-metering. Nevertheless, this is commonly attempted especially in consultancy where pressures to present actual savings are high. Further research would be beneficial to establish whether it is at all realistic to place individual energy behaviours reliably within the context of total hospital energy use, and if so how this may be achieved (see also Morgenstern et al., 2014).
- **Engagement in clinical areas:** Survey findings and much anecdotal evidence related by hospital engineers and other practitioners in health suggest large differences in achievable energy savings from operational measures across heterogeneous hospital estates<sup>13</sup>. Apart from applied intervention means and the type of promoted changes, this appears to be due to a number of factors including process, building characteristics and staffing pressures. The relevance of each of these factors and their interplay, however, have so far not been comprehensively analysed and would merit further investigation.

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<sup>13</sup> This theme of heterogeneity was repeatedly encountered in numerous conversations and contexts throughout this study. The evidence remains anecdotal, but the recurrence of the theme seemed to highlight its importance. To give but two examples, the author took part in evaluatory audits of ‘Operation TLC’ at Barts Health and NUS’s Green Impact Programme at University Hospital Bristol. Both initiatives observed higher engagement with their campaigns outside of ward areas. This impression was substantiated through the analysis of metered electricity data at Barts’ Royal London Hospital (RLH) where higher energy savings were achieved in day-clinics and administrative areas, while many wards could achieve no savings at all.

On the whole, it appears evident that many staff engagement initiatives in hospitals are currently not sufficiently linked to this particular type of building and its function. It is in this vein that this study seeks to make its contribution by providing detailed insight into the energy use of different hospital building parts and processes while appreciating the working realities of clinical staff. The research question, aim and objective as well as the study methodology are laid out in the following chapter 3.





# 3 Study Methodology

This chapter defines the main areas of investigation of this research and lays out epistemological considerations resulting from domain, nature and scope of the research subject. Various possible research designs are explored and a rationale for the selected **multiple case mixed-method study design** is presented. Following this, details are provided on data collection methods and analysis approach. The study has been approved by the UCL Research Ethics Committee (Project ID: 5434/001), details on the ethics process can be found in Appendix C.3.

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### 3.1 Research aim and objectives

Literature review and survey study (see chapter 2 and Morgenstern et al., 2015a) suggested that staff-centred energy conservation initiatives could be part of carbon reduction strategies in hospitals in the future. Current assumptions of their potential, however, seemed rather optimistic and more importantly rather undifferentiated with respect to operational characteristics. Going forward, it seems advisable to assess behavioural energy conservation initiatives more closely related to the physical context of the respective hospital building and its service infrastructure as well as the health care processes relevant in different departments. To address this gap in knowledge, this PhD thesis proposes the following **research question** (as outlined earlier in section 1.2):

To what extent can clinical staff influence electricity use in different hospital buildings and departmental processes and what is their potential role in its reduction?

More specifically, the research addresses the following **objectives** through the analysis of multiple case studies:

- (i) Establish the theoretical maximum electricity savings potential from simple changes in the way different hospital departments are being used by occupants, principally clinical staff;
- (ii) Unpick the governing constraints on energy demand reduction in the complex socio-technical systems that hospital departments constitute;
- (iii) Suggest a process to evaluate the relevance of behaviour and other simple operational changes as tools for carbon mitigation in hospitals; and finally
- (iv) Contribute to the concept of a socio-technical energy conservation potential while discussing scope and limitations of socio-technical methods for research in the built environment.

The **hypothesis of the study** is that the theoretical extent of staff influence on local electricity use (not taking into account constraints) will depend on infrastructural arrangements (such as control interfaces for building services) and the nature of departmental processes (defining electricity requirements and operating hours). Two basic indicators are initially proposed to capture these concepts:

1. *Local control*: The extent to which electricity demands can be influenced locally by clinical staff as opposed to being defined elsewhere (for example centrally through facilities management) or through other actors (for example automated sensors or other stakeholders).

2. *Time not in use:* The extent of after-hours or hours with reduced service requirements allowing for a lower electricity demand.

It is thought that more local control and more time not in use will theoretically increase clinical staff influence on local electricity use. Constraints on the theoretical influence are then assessed using an empirical social practices framework (Gram-Hanssen, 2013a).

The thesis adopts a multiple case study **approach** due to the exploratory nature of the research question outlined above. A mixed-method study design is further considered most appropriate due to its effectiveness in handling both quantitative and qualitative inquiries and its flexibility in integrating their various research instruments. The research design and the application of the mixed-method approach are outlined subsequently and a description of each of the research instruments employed (electricity monitoring, lighting and appliance audit and semi-structured interviews) is given.

### 3.2 Commitment to pragmatism

Research within the field of the built environment has traditionally been dominated by engineering and the natural sciences (Schweber and Leiringer, 2012). During the last years, however, energy conservation has become an important focus and the research agenda has expanded to include the role of building occupants and their interaction with the buildings. Epistemological, ontological, methodological and ethical debates traditionally championed by the social sciences have therefore become important within built environment research.

This study considers itself within a pragmatic research tradition (see Table 3.1 for a simplified overview of major paradigms, i.e. basic belief systems). According to C.S. Peirce, one of the early scholars influential in developing pragmatic ideas, pragmatism holds that the meaning of any statement lies in its impact on experience. Empirical research into the practical bearings of ideas is therefore crucial in the creation of knowledge. According to Tashakkori and Teddlie (1998, p.22), pragmatism consequently values the posed research questions higher than specific beliefs or methodologies.

Pragmatic beliefs were shown to be useful in empirical real-world research, especially when both social and technical phenomena are investigated within the same study (Robson, 2011). There are however challenges associated with pragmatic approaches, which can build on less foundations than more established research traditions and may lack well-defined protocols. Pragmatic research further requires the mastering of a much wider range of theoretical positions and data collection and analysis approaches, which may present a threat to research quality. Actions to ensure the quality of both the gathered evidence and its interpretation must hence be carefully considered across all steps of the research process.

**Table 3.1:** Brief overview of major paradigms<sup>1</sup>

Element	Positivism	Interpretivism	Pragmatism
<b>Ontology</b> What exists?	Social phenomena and their meanings have an existence that is independent of social actors.	Social phenomena and their meanings are continually being accomplished by social actors.	Social phenomena have an independent existence but their meanings are continually being accomplished by social actors.
<b>Epistemology</b> What constitutes valid knowledge?	Clear distinction between scientific (confirmable by senses) and normative statements (truth not really establishable, therefore considered irrelevant).	There is a difference between people and the objects of the natural sciences. Social actions have subjective meanings which are relevant.	Depending on the research question, both objective and subjective views may work in practice and are therefore relevant.
<b>Methodology</b> How can the real be examined?	Primarily quantitative approaches	Primarily qualitative approaches	Mixed-methodologies

At a methodological level, Morgan (2007) has pointed out three characteristics placing the pragmatic approach between qualitative and quantitative approaches:

- **Relationship to research process:** Pragmatism sees no problem with asserting both that there is a single ‘real world’ and that all individuals have their own unique interpretations of that world. In this study, this dualism is reflected in particular with respect to the buildings and the control interfaces they provide for occupants and how those are contrasted by the individuals’ perceptions on their control over building services.

<sup>1</sup> There is little agreement between authors especially from different disciplinary backgrounds on terminology and the precise principles encompassed in different paradigms. The information presented here has largely been adapted from Bryman (2007), Bryman (2012) and Creswell (2009) while other sources may offer different interpretations.

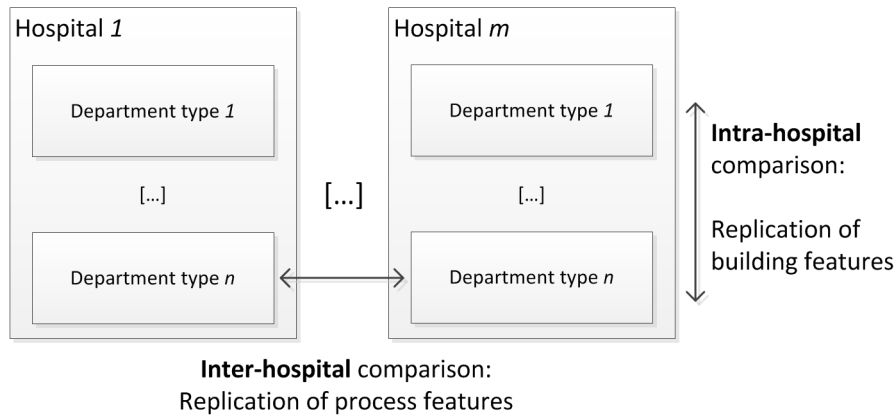
- **Inference from data:** Morgan (2007) advocates the transferability of research results based on the investigation of the factors that affect whether the knowledge gained in one context can be transferred to other settings. Here, such pragmatic focus was the basis of the research question aiming to identify factors across different hospital buildings and processes.
- **Connection of theory and data:** Instead of being purely inductive or deductive, the pragmatic approach acknowledges the movement back and forth between both modes of reasoning when converting observations into theory and assessing those theories through action. In this study, such abductive logic is employed both through the mixed-methods research design and in the actual research process carried out in a real-world setting.

### 3.3 Research design: Multiple case studies

#### 3.3.1 Rationale for a case study design

Yin (2003) suggests that the choice of an appropriate research design needs to be guided by the type of research question posed, the extent of control an investigator has over actual behavioural events, and the degree of focus on contemporary as opposed to historical events. This study is concerned with exploring the interplay between hospital staff and their department's energy use, asking 'how' influential staff are with respect to departmental energy use and 'why (not)' they may be able to enact energy savings. It is focused on contemporary events over which the investigator has no control. As typical for building-performance studies, it is sought 'to expose and reveal contexts rather than controlling for them' (Leaman et al., 2010, p.571).

A case study design consequently seems appropriate over archival analysis, surveys or experimental designs. This decision is further favoured by the novelty of the research subject, making the investigation exploratory in nature as opposed to theory testing (Creswell, 2009) while the currently available evidence is considered too thin for more quantitative survey-based approaches. Finally, case studies designs enable the researcher to deal with large amounts of data emerging through different methods, as required to master the complexity of research questions in real-world situations (Leaman et al., 2010).



**Figure 3.1:** Embedded multiple case study design ensuring validity through inter- and intra-hospital replication of building and process elements

This project uses an embedded multiple case study design (Yin, 2003, p.39), considering each investigated hospital a case. The unit of analysis are individual departments within each hospital (see Figure 3.1), allowing for the comparison of different departments within the same hospital (intra-hospital comparison) and of each department type across different hospitals (inter-hospital comparison). As opposed to single case designs, the evidence from multiple cases is often considered more compelling and such studies are overall regarded as more robust (Yin, 2003). Given that this investigation is conducted in the domain of the built environment which has traditionally been dominated by a strong quantitative research tradition, this argument seems particularly important. Multiple as opposed to single case designs are however time intensive, restricting the achievable depth of the enquiry. For this study, they are nevertheless regarded a reasonable compromise given the interest of the health service to urgently reduce carbon emissions across a stock of heterogeneous buildings.

How many cases need to be investigated in multiple case designs depends on the complexity of the phenomena in question (Yin, 2003). This study's hypothesis on factors determining the influence of clinical staff on hospital electricity use is comparatively straightforward and an excessive degree of certainty is not required, in which case Yin recommends two to three literal replications of each element to ensure validity. Within each case study hospital, at least three departments are consequently analysed to ensure the literal replication of building components since alterations to individual departments through changes in use or retrofitting have to be expected in fast-changing environments such as hospitals. Further, at least two departments of each type are investigated to ensure the literal replication of the process element.

On this basis and with view to the huge variety of processes with very different characteristics ongoing in hospitals, it is settled for three case study hospitals and five different department types overall. While limiting the possible depth of the investigation into each department type, this strategy allowed some overview of the spaces prevalent in hospitals - crucial if any considerations for hospitals as a whole were to be attempted. A wide strategy further offered the additional benefit of providing evidence for the development of composite hospital energy benchmarks based on the technical analysis of the electricity data (published in Morgenstern et al., 2016a).

Case study research has in the past been criticised for a lack of analytical rigour (Gray, 2004). A number of strategies are hence applied in this study to ensure quality, as conceptualised through the four elements external, measurement and internal validity as well as reliability (Bryman, 2012, p.47). They are described in more detail in Appendix B.2.

### 3.3.2 The case studies

The study focuses on general acute hospitals as they occupy 60% of the total floor area within the NHS according to ERIC data. Subject to access constraints and the collaboration interest shown by NHS trusts, three case study hospitals (Table 3.2) are selected using a purposeful maximum variation sampling strategy (Patton, 1990, p.172) in line with the exploratory aim of the study. The sampling criteria relevant for maximizing sample diversity were identified from literature review and scoping activities to be:

- **Hospital age and resulting built form:** expected to yield a variety in the implementation of building services and building service interfaces with occupants such as – Centralised or localised space heating; – Manual or automatic light switches; – Operable, locked or no windows; and
- **Hospital size:** expected to influence extent and realisation of service delivery as well as staffs' relation to their workplace.

The unit of analysis for this study is an individual department. Five department types prevalent in general acute hospitals (Gray et al., 1997) were selected for analysis reflecting variety across two aspects crucial to the research question:

- High (operating theatres, laboratories, imaging) versus low (wards, day clinics) electrical intensities; and
- Continuous (Wards, Some operating theatres, Laboratories) versus intermittent operation (Day clinics, Some imaging departments, Day theatres).

**Table 3.2:** Key characteristics of case study hospitals  
(Data from ERIC 2013/2014 if not stated otherwise)

Hospital	The Royal London Hospital (RLH)	Newham University Hospital (NUH) <sup>1</sup>	King's College Hospital (KCH)
NHS Trust	Barts Health NHS Trust		King's College Hospital NHS Foundation Trust
Gross internal site floor area (GIA)	247 686 m <sup>2</sup>	44 401 m <sup>2</sup>	142 610 m <sup>2</sup>
Number of available beds	708	344	884
Bed utilisation (%)	95%	81%	97%
Dominant age range (% of GIA)	2005 to present (67%)	1975 - 1984 (49%)	pre 1948 (45%)
Dominant built form	Deep Plan	Nucleus	Nightingale
Electricity consumption intensity [kWh/(m <sup>2</sup> · yr)]	170	220	204 <sup>2</sup>
Heat consumption intensity [kWh/(m <sup>2</sup> · yr)]	188	220	312
Overall patient satisfaction (Stars out of 5) <sup>3</sup>	3.5 (n = 217)	2 (n = 157)	4 (n = 108)

<sup>1</sup> Since 2012 officially as Newham General Hospital part of Barts Health.

<sup>2</sup> Based on average from 2011 - 2013, intensity in 2014 ERIC data was 407 kWh/(m<sup>2</sup>· yr) which was suspected to be a data entry error as there was no evidence suggesting a sudden doubling in electricity load on the ground

<sup>3</sup> Source: NHS Choices, Reviews and Ratings. Accessed 22/07/2015. Overall score is based on the average of all ratings awarded in the past two years to each hospital for the question 'How likely are you to recommend this service to friends and family if they needed similar care or treatment?'

These selected pathways further represented different stages along the patient pathway within an acute hospital:

- from the **diagnosis** of an illness (through imaging or the analysis of blood or other body fluid samples in a hospital's pathology laboratory);
- via its **treatment** (exemplified here through surgery in an operating theatre and the day treatment for specific conditions such as cancer or kidney malfunctions);
- to the inpatient **care** on wards.



Given the abundance of possible clinical pathways, this approach excludes many relevant hospital department types while the selection nevertheless allows for some understanding of hospitals from a health care perspective. Other hospital departments with relevant energy intensities such as sterile services or those where access constraints impeded data collection, for example in accident and emergency services, are also excluded from the study in accordance with the resources available to the project. At least two departments of each type were investigated to increase external validity (see section 4.1 for an overview of investigated departments).

## **3.4 Research methods: A mixed-methods approach**

### **3.4.1 Rationale for using mixed-methods**

In case study research, especially for the investigation of organisations in the field of business and management research, the combined use of different methods is well established (Bryman, 2007, p.642) and is recommended when ‘the use of either quantitative or qualitative approaches by themselves is inadequate to address complexity’ (Creswell, 2009, p.203). Mixed-method approaches can further strengthen the validity of resulting theories through the opportunity to observe data convergence or divergence in the various strands of data (Tashakkori and Teddlie, 1998).

In line with this tradition and the theoretical commitment to pragmatism as outlined in section 3.2, this study uses a mixed-methods approach. Due to the socio-technical nature of the research question, an interdisciplinary strategy gathering both social and physical data is chosen to obtain a rich picture of hospital electricity use. Table 3.3 lists the applied data collection techniques; they are further illustrated in the following sections 3.4.2 and 3.4.3 detailing each method. While the social data were mainly qualitative, the technical data were dominated by quantitative elements but also included some qualitative elements.

**Table 3.3:** Overview of study data collection methods

	Quantitative	Qualitative
<b>Technical</b>	<ul style="list-style-type: none"> <li>• Collection of half-hourly electricity data at ward/departmental level</li> <li>• Short term monitoring of equipment and occupancy schedules</li> <li>• Audit of lighting and appliances</li> </ul>	<ul style="list-style-type: none"> <li>• Walk-arounds with facilities staff</li> </ul>
<b>Social</b>		<ul style="list-style-type: none"> <li>• Semi-structured interviews with clinical staff</li> <li>• Analysis of facilities and clinical policy documents and communications</li> </ul>

Following a typology of mixed-method research strategies presented by Tashakkori and Teddlie (1998, p.43), the study design can be characterised as concurrent and giving equal weight to both types of data collection methods (QUAN + QUAL). Quantitative methods are employed to develop a detailed representation of each department's electricity use and estimate a theoretical energy savings potential from operational changes. Qualitative methods contribute to contextualising both use and potential changes, therein highlighting constraints in a real-world setting. Findings are integrated across all cases to identify transferable factors which characterise medical staffs' influence on departmental electricity use and their potential role in its reduction. The purpose of the mixed-method use can therefore be classified as expansion, seeking to extend the breadth and range of the inquiry (Greene et al., 1989).

Using mixed-methods and integrating different paradigms in a pragmatic way requires the mastering of many different skills (Creswell, 2009). Despite this risk, it seems crucial in energy demand research generally (and for this research question in particular) to understand how objective results generated through quantitative methods relate to subjective perceptions for example of building occupants (Gram-Hanssen, 2013a). To address arising challenges in this study, the literature is reviewed for exemplary studies using comparable research designs (see section 2.3.1), method training courses are attended and frequent discussion is sought with experts of various disciplines.

### 3.4.2 Quantitative data collection methods

The study employs quantitative data collection methods to analyse local electricity use in different hospital buildings and departments and to establish the respective extent to which it is influenced by clinical staff. Local electricity use, primarily from lighting and appliance use, occurs in addition to centrally provided energy services such as ventilation and space conditioning where the energy is consumed by central plant and can only with difficulty be attributed locally. Following a review of available methodologies (section 2.2.2.1), the understanding of local electricity use is primarily built from two components used to complement and validate each other as suggested by Field et al. (1997) and Mortimer et al. (2000): a departmental level electricity use profile (top-down) and a bottom-up end-use model based on a detailed audit of lighting and appliances use.

Within the *bottom-up model*, the electricity use  $W$  of each item  $i$  is estimated as suggested by CIBSE TM54 (2013) for small power equipment. For lights, parasitic consumption for controls and emergency lighting is taken into account based on departmental floor area (BSI 2007). Item electricity use  $W_i$  is calculated as the product of the item's average power consumption during operation  $\bar{P}_i$  and the duration of its use  $t_i$ , both of which are investigated. Additionally, average item power draw outside of operation  $\bar{N}_i$  (often referred to as stand-by although terminologies are not clear) has to be accounted for in some items.

$$W_i = \bar{P}_i \cdot t_i + \bar{N}_i \cdot (8760 [h/yr] - t_i) \quad (3.1)$$

Such an approach focuses on average electricity usage and disregards peak power consumption which (although of interest for load shifting strategies and for power system stability in hospital areas such as imaging) seems less relevant to an initial understanding of clinical staff impact on energy use. More complex estimation procedures, e.g. for lighting or cooling energy use, are likewise disregarded because the study's main challenge is understood to be from the collection of and uncertainties in data inputs. A simple formulation of item electricity use is hence preferred.

**Table 3.4:** Case study departments and employed data collection methods

Department type	Hospital	Description	Electricity data from sub-meters	Measurements at main incomer	Measurements at circuit level	Lighting and appliances audit	Short-term monitoring	Measurement of environmental variables	Interview with clinical staff
Operating theatres	NUH	One emergency and one non-emergency theatre suite			○	○			○
	RLH	2 emergency theatre suites and 3 non-emergency theatres suites	○			○			○
Day theatres	RLH	6 day theatres suites, Recovery, 2 Offices	○			○			○
Laboratory	NUH	Entire pathology department including main lab, specimen reception, offices	○			○			○
	KCH	Main laboratory and two offices		○		○		○	○
Imaging	RLH	3 X-ray rooms, primarily for bedbound inpatients			○	○	○	○	○
	NUH	3 X-ray rooms serving all patient populations including emergencies, also a mammography and a fluroscopy room	○			○			○
Day Clinic	RLH	Renal dialysis: Day clinic with up to 30 chronic dialysis units	○			○			○
	KCH	Chemotherapy Day Unit for 15 patients		○		○		○	○
Ward	NUH	General Surgical Ward, 25 beds	○			○	○	○	○
	KCH	General Surgical Ward, 28 beds		○		○			○

### 3.4.2.1 Departmental electricity data

At least half-hourly electricity data was collected of each department's main incomer, comprised of power (including fan coil units if present) and lighting loads but excluding central services, i.e. ventilation and cooling. For some of the departments at the RLH and in NUH, automatic meter readings were available on the trust's energy management system (Table 3.4). For the others, electrical measurements were carried out at the distribution boards serving the respective departments using various types of equipment (Table 3.5).

**Table 3.5:** Specifications of measurement equipment

Data logger	Current Transformer	Overall accuracy <sup>1</sup>	Data interval	Used in hospitals
CurrentCost EnviR Energy Monitor	Corresponding CurrentCost CTs (0.5 - 100A)	$\pm 3$ %	2 hours	NUH, RLH, KCH
HOBO UX120-006Ms	CTV-C (10 - 100A)	$\pm 2.1$ %	10 minutes	RLH, KCH

<sup>1</sup> according to manufacturer specifications

Due to funding constraints, the use of comprehensive energy analysers was not possible in this project and it was hence focused on the measurement of currents only. Energy consumption was then calculated through multiplication with voltages and power factors provided by facilities staff or literature, introducing a systematic error into the energy use profiles. In all departments, loads were monitored for 28 days to capture day of week (particularly weekend) influence on electricity use.

For two departments, the NUH Theatres and the RLH Inpatient X-ray department (Imaging), more detailed current measurements were undertaken at circuit level because distribution boards did not overlap with departmental boundaries. While total departmental consumption could be calculated as sum of all measured circuits, this approach offered additional details on loads and durations of use for individual rooms or systems as input into the bottom-up model.

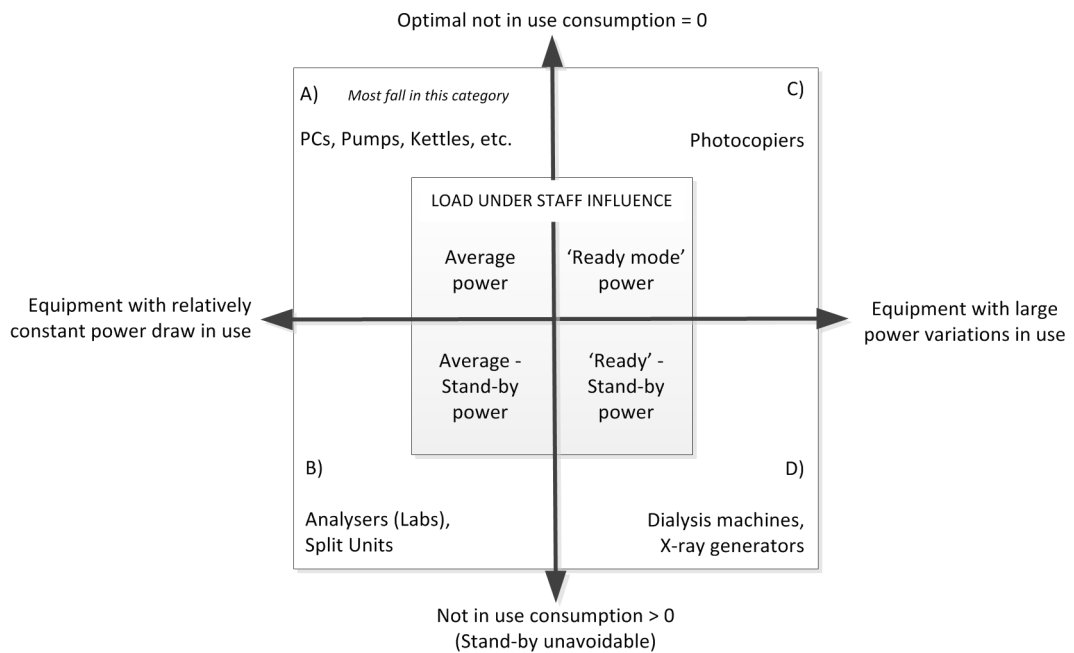
### 3.4.2.2 Lighting and appliances audit

Surveying and energy audits are common diagnostic tools to obtain information on existing non-domestic buildings and organisational processes and identify energy conservation opportunities at the buildings or systems level (BSI 2012a; BSI 2012b). Methods, level of detail and duration of audits can vary widely and will in the commercial context be tailored to client needs (Russen et al., 2010). Field et al. (1997) and in more detail Mortimer et al. (2000) have described methodologies to assess the end-use energy consumption of non-domestic buildings based on site-visits including the room-to-room inspection of the building, visual inspections of installed loads and consultations with staff as well as the analysis of secondary data on plant and equipment listings, equipment ratings and time-schedule information. Accordingly, the collection of input data for this study's bottom-up electricity model takes place in two phases for each department: on site and as desk research.

**On site:** Each department is visited at least two times for the audit, ideally within the course of two weeks. Firstly, the authorisation for the fieldwork is obtained from the departmental manager and a guided walk-through is undertaken with them to understand departmental processes and boundaries and identifying potential interview partners (see section 3.4.3.1). A second visit for the actual field data collection is then scheduled at their convenience. During the second visit, a room-by-room inspection of the area covered by the metered electricity data is carried out recording information on:

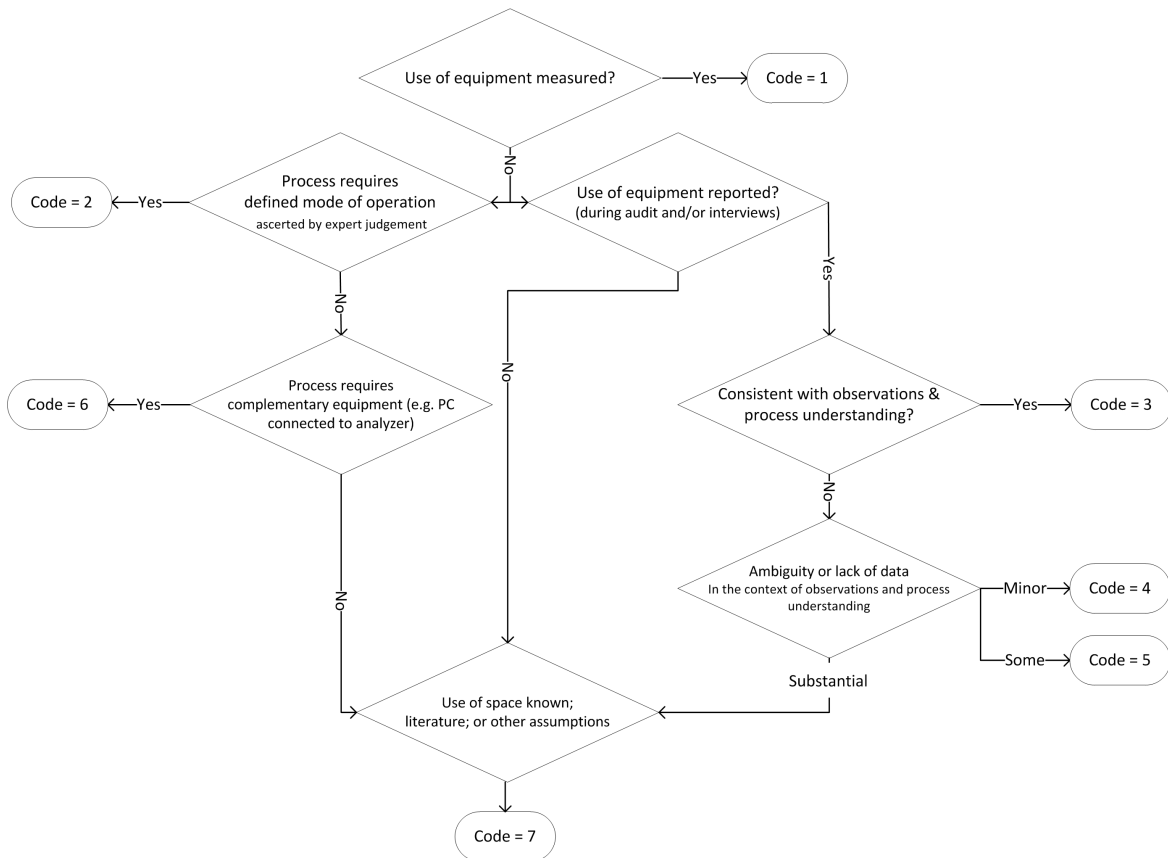
- type of use and reported duration of use of each room;
- lighting installations (identified based on lamp type and size, type of control gear and if in doubt light colour and strike time) and lighting controls;
- HVAC installations and controls;
- windows and their operability;
- equipment items (including name plate ratings if available), their use schedules as well as the extent to which they could be switched off by clinical staff (see Figure 3.2 for a typology of equipment types including some common examples encountered in each group);
- spot-measurement of appliance wattage where possible; and
- the operational state of all items during the researcher's visit

Please refer to Appendices for an overview of used codes and a filled example of a data entry sheet (C.1) as well as a list of all encountered equipment (D.1).



**Figure 3.2:** Equipment typology to code equipment during audits  
(see also section 3.5.1.3, II for details on sector labels)

While information on the inventory is primarily observed or extracted from documentation, much of the *duration of use* information is reported by staff. In the literature, paper-based self-administered surveys are often used to extract such information but are found impractical in the dynamic hospital context where staff are rarely based in one space only. In addition, some of the more intense clinical areas such as labs and theatres are subject to strict health and safety regulations and introducing additional paper does not seem appropriate. A researcher-led approach asking a limited number of questions face to face to extract durations of room and equipment use is therefore preferred. In addition, duration of use information is also extracted from the in-depth interviews (section 3.4.3.1). Corresponding statements are validated against each other and followed up if inconsistent. Durations of use have to be inferred from a general understanding of the departmental processes for rooms where no occupants are encountered (see Figure 3.3 for a flow chart of the process). Occasionally, lighting or equipment power consumptions are reported in conversation with technical staff.



**Figure 3.3:** Process for determining *duration of use* information for equipment and corresponding certainty codes for data inputs. For lighting and rooms a comparable process is followed.

**Desk research:** In a second step, the average *power consumption* of all items is determined in desk research based on information from literature for the specific piece of equipment or equipment type<sup>2</sup>. If information on average consumption is unavailable, estimates are based on power ratings according to the respective plate rating or the equipment manual, taking into account that plate ratings provide measures of maximum as opposed to average consumptions. It is appreciated that the relation between average and rated power consumptions can vary widely for different loads (Christiansen et al., 2015), but in the absence of better data it is relied on the following heuristics: For office equipment, CIBSE state that actual power consumption is about 10 - 25% of the nameplate rating (CIBSE 2012). For hospital equipment in particular, Hosni et al. (1999) provide the following rule of thumb: for items with nameplate ratings up to 1000 W, the average consumption will be between 25% and 50% of the plate.

<sup>2</sup> Many detailed studies of measured plug loads in offices are available, especially in the US context (e.g. Moorefield et al., 2011; Acker et al., 2012; Webber et al., 2006; Roth and McKenney, 2007) but also in the UK (Menezes et al., 2012). They provide a solid basis for power consumption estimates of IT equipment, while some usage hours may need to be adapted to the hospital context. Christiansen et al. (2015) provide detailed measurements on the electricity consumption of medical plug loads in hospital laboratories and Black et al. (2013) evaluate the energy use of miscellaneous electronic devices specifically in hospitals. Connor (2011) reports a detailed analysis of renal dialysis, including energy consumption measurements of different dialysis machines (figures provided personally by author). Hinz et al. (2012) provide data on anaesthetic machines.



**Table 3.6:** Codes specifying the source of data inputs for average lighting *power consumptions*

Code	Source of data input for average lighting power consumption
1	Measurement of actual consumption
2	Actual consumption reported in documentation
3	Declared wattage observed, consumption of control gear inferred based on lamp type
4	Lamp type observed in detail, Wattage and consumption of control gear inferred
5	Declared wattage (and/or control gear consumption) reported
6	Lamp type reported without detail, Wattage / Control gear consumption inferred based on reported data
7	Other assumptions (e.g. lamps covered: consumption inferred from assumptions on lamp type based on shape of luminaire and colour of light)

During the data collection on the ground, it soon became evident that the quality of data collectable from system identification, reports and secondary sources varied widely due to a number of reasons including:

- Difficulties for auditor in identifying unknown specialist equipment and understanding switch-off conditions;
- Limited availability of energy use information in the literature for small medical equipment (see also Black et al., 2013);
- Unclear reports of equipment users as to whether equipment can be switched off (see also Jensen and Petersen, 2011)
- Irregular nature of processes making it difficult for occupants to describe typical events and average durations of use; and
- Transient nature of NHS employment in some departments (specialists working across hospitals and many agency staff) resulting in limited knowledge of local customs

A classification system is hence adopted to code the certainty of each data input; allowing for the analysis of uncertainty on estimated savings potentials. In scenario modelling (e.g. CAR 2012), uncertainty is often characterised at three levels, with some variation on ‘low - medium - high’. For this project a more granular scale specifying seven levels is used where codes are primarily descriptive in character and aim to provide the reader with an understanding of the origin for each data input (Tables 3.6 - 3.7, Figure 3.3). It may be noted that codes do not specify a discrete level of uncertainty across the three categories lighting, equipment and duration of use because the overall range of uncertainty varies widely depending on the analysed item.

**Table 3.7:** Data source codes for average equipment *power consumptions*

Variable	Data source	Specific item	Equipment type <sup>1</sup>
			Code
Average power consumption	Author's measurement	1	(2)
	Case series or case report, peer reviewed	2	3
	Manufacturer technical manual	2	3
	Non peer reviewed academic publication (e.g. open sources data bases, expert opinion)	3	4
	Other non-academic sources	4	5
Power rating	Plate rating / Power rating from manufacturer technical manual	5	6
	Case series or case report, peer reviewed	5	6
	Non peer reviewed academic publication	6	7
	Other non-academic sources	7	7
Other	Other assumptions (incl. assumption on type of equipment if in doubt)	7	7

<sup>1</sup> Reference group definition depends on complexity, e.g. 'medical fridge, 300L, energy star' but also 'standard desktop PC'

### 3.4.2.3 Additional quantitative data collection methods

For each department, an understanding of local electricity use is primarily built from two components: a top-down analysis of measured electricity use and a bottom-up end-use model based on the lighting and appliances audit. Over the course of the fieldwork, additional data collection methods are added to the protocol (Table 3.4) as additional measurement equipment becomes available to this study. While the additional data is not consistently collected across all departments (see limitations section 8.2.2), where available it does support interpretation and helps close the gap between top-down and bottom-up understandings of electricity use.

**Short-term equipment monitoring:** The most accurate method to obtain information on equipment electricity use is to monitor items individually. Doing so will both provide detailed information on power consumption and on usage hours (Murtagh et al., 2013), which ultimately is especially relevant for large consumers (Robison and Reichmuth, 1992). In this study, Current Cost individual appliance monitors with the EnviR data loggers are used to log the profile of selected pieces of equipment such as radiology monitors in imaging departments, ward kitchens serving patients with warm meals and general IT equipment. Sensitive medical or laboratory equipment could not be monitored with the individual appliance loggers due to concerns about safety and disruptions. This is a known problem in the hospital context (Black et al., 2013; Hagemeyer, 2014; Christiansen et al., 2015) and presents one of the difficulties for built environment research in this building type.

**Measurement of environmental variables:** In some departments (Table 3.4) lighting levels as well as ambient temperatures are recorded every 10 minutes over a period of two to four weeks using HOBO U12-012 data loggers (accuracy for temperatures  $\pm 0.35$  °C and 80% for light intensities at 550 nm). Especially for spaces without natural light (frequent in most visited departments), the analysis of local lighting levels allows statements as to whether lights were on or off at each point in time. Temperature data is of interest in departments where thermal discomfort is reported and cooling fans or fan heaters are consequently common.

### 3.4.3 Qualitative data collection methods

The focus of the qualitative investigation is on understanding hospital electricity use from an end-user perspective in order to identify constraints on the optimally efficient local use of electricity. Constraints are understood broadly and conceptualised through the elements of knowledge, embodied habits, meanings and technologies as introduced by Gram-Hanssen (2013a) in an empirical operationalization of social practices theory for the understanding of energy demand. This framework has been well utilised for the investigation of energy demand in the built environment (see section 2.3.2.2), likely due to its accessible, straightforward presentation and a focus on contemporary rather than historical events and sources of data. It further allows for the integration of both social and technical data and has therefore been chosen as analytical framework for this study. The main method for the collection of qualitative data are semi-structured interviews with clinical staff, complemented by information from facilities management and the analysis of trust policy documents. In accordance with the Data Protection Act 1998, this study is registered with UCL Data Protection (Z6364106/2013/05/59) and has been approved by the UCL Research Ethics Committee (Project ID: 5434/001).

#### 3.4.3.1 Semi-structured interviews with clinical staff

This study carries out 22 semi-structured interviews across all case departments as well as 2 pilot interviews outside of the case hospitals (Table 3.8). The interviews last between 30 and 70 minutes and take place in the respective departments to ensure routines and local control elements can easily be recalled by participants. In the RLH theatres, the interviews could not be carried out in full due to access constraints and time pressures on staff. Instead, 10 conversation fragments are recorded during a site visit by speaking to staff in quiet moments while the theatres are operational. Jointly the fragments cover the interview guide approximately twice.

**Table 3.8:** Formal characteristics of interviewees

Code	Role	Official position	Qualification level	Time in position
A	Anaesthetic nurse	Junior	Medium	Less than a year
B	Biomedical scientist	Senior	High	More than five years
C	Biomedical scientist	Senior	High	More than five years
D	Biomedical scientist	Junior	High	More than five years
E	Biomedical scientist	Senior	High	More than five years
F	Health Care Assistant	Junior	Low	Two to five years
G	Health Care Assistant	Junior	Low	More than five years
H	Health Care Assistant	Junior	Low	More than five years
I	IT support	Senior	Medium	More than five years
J	Radiographer	Senior	High	More than five years
K	Radiographer	Junior	Medium	Two to five years
L	Radiographer	Senior	Medium	More than five years
M	Registered nurse	Junior (Locum)	Medium	Less than a year
N	Registered nurse	Junior	Medium	One to two years
O	Registered nurse	Senior	Medium	More than five years
P	Registered nurse	Junior	Medium	One to two years
Q	Registered nurse	Junior	Medium	One to two years
R	Registered nurse	Senior	Medium	More than five years
S	Registered nurse	Junior	Medium	More than five years
T	Registered nurse	Junior	Medium	Two to five years
U	Scrub nurse	Junior	Medium	More than five years
V	Scrub nurse	Junior	Medium	More than five years
P1	Junior doctor	Junior (Locum)	High	Less than a year
P2	Medical student	Junior	Medium	Less than a year
X	Excerpts from fieldnotes of the RLH Theatres site visit will be denoted with X			

In theory, focus groups might seem the appropriate means to qualitatively collect comprehensive views on departmental energy use from different building occupants. Clinicians, however, are busy people and it became clear during the scoping fieldwork that assembling 4 to 6 staff - considered a sensible number of participants for a focus group (Silvermann, 2011) - is very difficult at any time. It is consequently decided to conduct research interviews, which while being more feasible in practice can likewise yield the desired insights. The value of interviews to unpick practices has been demonstrated by Hitchings (2012). In this study, semi-structured interviews are chosen in the face of the specialist context and the resources available to the project because they allow for the exploitation of prior information from literature, hospital documents and energy data while maintaining the flexibility to uncover new themes (Gillham, 2005).

Semi-structured interviews require large amounts of time for preparation, analysis and interpretation (Gillham, 2005). Their number in this study is consequently restricted: As a rule of thumb, Creswell (2009) recommends between 20 to 30 interviews for theory development while Guest (2006) argues that data saturation can be achieved based on twelve interviews among a group of relatively homogeneous individuals. In this study, the sampling frame for the interviews is primarily defined by the strategy for case selection as argued in section 3.3.1. It is consequently settled on two interviewees in each of the 11 departments in order to achieve a total number of interviews within the suggested range and in line with available resources. In two departments, a third interview is carried out because information is inconsistent or initial participants are very pressured for time resulting in limited data.

Given the small number of interviewees per department, their selection is important while practical challenges in motivating participation have to be taken into account. Accordingly, a purposeful typical case sampling strategy is applied, focusing on staff in job roles typical for each department type (Patton, 1990, p.173). A minimum time in the respective position of 6 month is specified in order to ensure reasonable knowledge of local circumstances<sup>3</sup>. Staff are notified in advance of the upcoming visit of the researcher and information on project aims as well as potential benefits to the trust are provided through the departmental manager as well as through written information material in the staff room.

In order to motivate participation in the interviews, it is stressed that their duration would not exceed an hour and cakes are offered as both incentive and thank you. Interviewees would generally volunteer their participation, while some are asked to participate by their line managers. In line with ethical good practice, all interviewees sign informed consent declarations (see Appendix C.3) but especially in the latter cases it is ensured that participants understand their right to withdraw from the study at any time without consequences.

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<sup>3</sup> A minimum of one year was consider even better to ensure knowledge of both heating and cooling season, but could not be achieved in all cases. Overall, however, work place stability was found to be relatively high with 64% of the interviewees being in post five years or more.

**Table 3.9:** Question topics for semi-structured interviews with clinical staff

#	Topic	Sub-Topic	Purpose of topic
1	Personal experience in the department	<ul style="list-style-type: none"> <li>• Daily routine</li> <li>• Workplace satisfaction</li> </ul>	<ul style="list-style-type: none"> <li>• Putting the interviewee at ease and building an atmosphere of confidence</li> <li>• Exploring the relationship of the interviewee with their workplace</li> </ul>
2	Area description	<ul style="list-style-type: none"> <li>• Processes</li> <li>• Operating hours</li> <li>• Cleaning and Maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Clarifying previous understanding of departmental function and boundaries</li> <li>• Investigating processes and operating hours for comparison with the electricity use profile</li> </ul>
3	Lighting	<ul style="list-style-type: none"> <li>• Lighting levels</li> <li>• Lighting controls</li> </ul>	<ul style="list-style-type: none"> <li>• Exploring satisfaction with lighting levels and control options</li> </ul>
4	Medical equipment	<ul style="list-style-type: none"> <li>• Types of prevalent equipment</li> <li>• Equipment power down</li> </ul>	<ul style="list-style-type: none"> <li>• Classify medical equipment used in the department</li> <li>• Explore switch-off of medical equipment</li> </ul>
5	IT equipment	<ul style="list-style-type: none"> <li>• Shared use of computers</li> </ul>	<ul style="list-style-type: none"> <li>• Investigate issues around the diffusion of responsibility for IT and meeting room equipment</li> </ul>
6	Heating and cooling	<ul style="list-style-type: none"> <li>• Thermal comfort levels</li> <li>• Coping strategies</li> </ul>	<ul style="list-style-type: none"> <li>• Explore whether supplementary heating and cooling is used in the department and if applicable how windows are operated</li> </ul>
7	Electricity use profile		<ul style="list-style-type: none"> <li>• Discuss abnormalities visible in the top-down electricity consumption profile</li> </ul>
8	Ecological values	<ul style="list-style-type: none"> <li>• Own values</li> <li>• Social norms</li> </ul>	<ul style="list-style-type: none"> <li>• Exploring views on saving energy at home and in the workplace</li> <li>• Comparison with others</li> </ul>
9	Saving energy	<ul style="list-style-type: none"> <li>• Ideas on how to save energy</li> </ul>	<ul style="list-style-type: none"> <li>• Sharing knowledge on energetic best practice</li> <li>• Identifying constraints on potential savings options in practice</li> </ul>

In semi-structured interviews, the development of the interview guide is crucial as questions hope to be motivating for the interviewees and productive for the researcher (Gillham, 2005, p.72). Based on the review of the literature as presented in the sections 2.2.1.1, 2.2.1.2 and 2.3.1, nine main topics are identified which are associated with departmental routines from an energy perspective and local constraints on electricity conservation (Table 3.9). The questions themselves (see Appendix C.2) are developed and improved in three stages:

1. Draft
2. Consultation with supervisors and an experienced qualitative researcher: review of initial question order to improve the dynamic of the interviews, rewording of questions to increase understanding by people without technical background, introduction of scales for perceived control and thermal comfort to allow for some quantitative analysis of interviews
3. Piloting with two clinical staff external to the selected case hospitals: clarification to questions on heating versus temperature control and on arrangements helping or hindering efficient resource use

During the interviews, the same questions are asked to all interviewees using prompts to ensure approximately equivalent coverage of topics. All interviews are tape recorded and transcribed (Silvermann, 2011) (see Appendix D.3 for exemplary excerpt from an interview transcript).

At KCH, the third case study hospital, lines of enquiry which had so far not resulted productive with respect to the research question are removed from the interview guide (Section 7, Questions on maintenance in sections 2, 3 and 6; marked with (\*) in Appendix C.2) to tighten the investigation and not take up too much of the participant's time given its shortage within the hospital context. By this time, it was generally felt that although the additional interviews added variation on infrastructure and processes, few new themes were emerging suggesting some level of data saturation.

#### **3.4.3.2 Other qualitative data collection methods**

In addition to the interviews, policy documents on departmental procedures are collected where available to substantiate the interpretation of audits and interviews. This includes health and safety documents, nursing policies as well as communications to patients. At the level of the whole hospital, communications on sustainability and actions of the IT department are collated. Fieldnotes are maintained following walk-arounds and encounters with technical staff while installing monitoring equipment.



## 3.5 Data analysis

### 3.5.1 Quantitative strand: Representing departmental electricity use

Based on measured electricity consumption data and the detailed lighting and appliances audits, the quantitative strand of this work aims to create models of local electricity use for each department as basis for the ex-ante estimation of electricity savings through behaviour and simple operational changes. In this, the *top-down analysis* based on measured electricity use enables departmental performance to be understood within the wider context of department type and hospital building (Hong et al., 2013), as well as the identification of abnormalities such as high base or after hours loads. The *bottom-up model* allows for a more detailed performance diagnosis identifying end-uses (Burman et al., 2014) and is also used as basis for the quantification of potential operational changes. To allow for the comparison of results between departments of a type in the face of infrastructural differences in set-up, it is focused on spaces and activities characteristic for each department type (see section 4.7). Details for each department type are described in chapter 4.

#### 3.5.1.1 Top-down analysis of electricity use

Patterns of electricity usage in daily and weekly profiles, weekday and weekend day consumptions, base loads and peak loads are examined in order to provide characteristics of the hospital departments' energy use. Missing data points are replaced with the average energy consumption of the respective time period during all comparable weekdays. Base loads are defined as the mean of the minimum power readings as recorded in each 24 hour period, and peak loads as the mean of the maximum readings as recorded in each 24 hour period.

Data from interval energy use and floor areas from floor plans (verified by spot measurements on-site) allows for predictions of annual consumption intensities to be made. They are scaled up to a year based on mean daily weekday and daily weekend day consumptions during the measurement period, assuming bank holidays are as weekend days. This approach disregards seasonal differences in electricity consumption (mainly from fan coil units and some lighting use) and further assumes the measurement period is representative for the year which may underestimate variation in clinical activity for some department types (imaging for instance tends to see more patients during winter).

### **3.5.1.2 Bottom-up representations based on audit data**

All audit and secondary data on average power consumptions and durations of use is tabulated using individual tables for room, lighting and equipment information - similar to the examples provided by Mortimer et al. (2000). Where available, measured lighting intensities patterns are analysed for weekdays and weekend days to estimate average durations of lighting use. In the tables, the certainty of each data input is specified for both power and duration of use dimensions. The tables are then used to estimate the electricity use for six end-use categories potentially relevant locally in hospitals (Carbon Trust, 2010): lighting, medical equipment, IT equipment, catering, local heating or cooling and other, primarily pumps for anaesthetic gas scavenging or ultraclean ventilation in theatres.

Results are presented in the format suggest by CIBSE 2006 and compared with measured consumption data at departmental level. A modest amount of energy-balancing (Mortimer et al., 2000) or reconciliation (Field et al., 1997) through changes in the most uncertain data inputs is considered appropriate if all items remain consistent with the available evidence. Disagreements are understood to require further investigation as to the source of the discrepancy, both at the desk and on the ground; iteratively improving the model representation of the department.

### **3.5.1.3 Assessing theoretical savings potentials**

In a further step, potential changes in energy behaviours and clinical operations are conceptualised from the conducted interviews and audits, the analysis of the electricity use profiles, the input of clinical and technical experts and from literature (for example Pierce et al., 2014; Twomey et al., 2012; Maughan and Ansell, 2014; Batty et al., 1988). A systemic process guided by the importance of each end-use is used to question what operational changes seem conceivable for each of them (see Appendix E.1 for proposed changes in each case study department). A broad approach is taken including different levels of changes according to the framework presented in section 2.4.1:

I) **Promoting simple energy behaviours:** To quantify the theoretical savings potential from promoting simple energy behaviours (Level I in Figure 2.4), a statistical approach based on measured electricity use is used given the difficulties associated with estimating current switching frequencies (Morgenstern et al., 2015b). This approach based on typical (median) and best practice values (lower quartiles) of the collected data is similar to Mulville et al. (2014), as well as to methodologies common in building performance benchmarking (Hong et al., 2013; Liddiard and Wright, 2008). Departmental savings potentials  $S$  (absolute or as here in %) are computed as sum of the difference between median ( $kWh_{50}$ ) and lower quartile ( $kWh_{25}$ ) energy use for all metered days (if applicable week or weekend days only) during each of the  $n$  daily measurement periods  $t$ :

$$S = \frac{\sum_t^n (kWh_{50} - kWh_{25})^t}{\sum_t^n kWh_{50}^t} \quad (3.2)$$

A general disadvantage of statistical approaches is that they provide no insight into where differences in operational energy use stem from and how these savings can be tapped (Burman et al., 2014). In this study, this problem can partly be overcome by interpreting projected savings within the context of the electricity model and other available evidence. The approach however remains limited to departments where no clear drivers of energy use (such as number or type of treatments) are effective. Data from a reasonable number of days is further required, which in this study was problematic for weekend days in some departments. It is also assumed that within the 28 days of available data, seasonal difference from daylight hours are negligible while electricity use from local heating or cooling, if applicable, has to be investigated separately.

II) **Modifying standard procedures:** Further savings may be achievable by modifying standard procedures in such a way that redundant energy use is eliminated (Level II in section 2.4.1). To estimate the theoretical energy savings potentials  $S$  from such changes, they are translated into the terms of the bottom-up electricity model based on the assumption that - as new procedures - their current frequencies are negligible. In many instances, staff influence on item electricity use  $W_i$  is considered to be mainly through decreasing durations of use  $t_{avoided}$ , while reductions in power use  $P_{avoided}$  depend on the type of equipment. For equipment with large power variations in use, such as dialysis machines, calculations are based on ready mode  $\bar{R}_i$  rather than average power consumption  $\bar{P}_i$  to exclude the influence of power peaks (see Figure 3.2 for equipment types).

$$S = \frac{\sum P_{avoided} \cdot t_{avoided}}{\sum W_i} \quad \text{with } P_{avoided} = \begin{cases} \bar{P}_i & \text{if equipment type is A} \\ \bar{P}_i - \bar{N}_i & \text{if equipment type is B} \\ \bar{R}_i & \text{if equipment type is C} \\ \bar{R}_i - \bar{N}_i & \text{if equipment type is D} \end{cases} \quad (3.3)$$

The data input classifications in the model quickly provide an overview of how certain each of the savings estimates are. For savings estimates based on the most uncertain inputs, codes are translated into uncertainty ranges based on expert judgement (Eisenhower et al., 2012). Scenario analysis can then be used to identify a realistic range for the technical potential of suggested changes. Generally, a conservative approach is chosen preferring to underestimate the savings potential given the shortage of funds within NHS facilities management and the urgent need to select strategies that deliver (Morgenstern et al., 2015a).

III) *Complex operational changes:* The modelling of structural changes in clinical operation based on a comprehensive review of processes and the negotiation of acceptable operational states with lower energy services delivery remains out of scope in this study. Some instances are however qualitatively discussed in the discussion chapter 7.3.3.

### 3.5.2 Qualitative strand: Contextualising potential changes

As opposed to the quantitative data which is firstly analysed case by case and only then across cases, the qualitative data was primarily analysed across cases using a variable-oriented strategy (Miles and Huberman, 1994) to identify context of and constraints on potential operational changes. All interview transcripts as well as policy documents and other communications were inserted into NVivo 10, a computer-assisted qualitative data analysis software (CAQDAS) package. There is no agreement on the merits of CAQDAS and while some authors fear its use may result in the fragmentation and loss of context of qualitative data, others stress the improved efficiency and transparency of the analysis process (Bryman, 2012, p.592). Given the overall volume of the data collected during this project through both quantitative and qualitative methods, analysis speed seemed crucial and the use of CAQDAS in general and NVivo in particular was therefore considered appropriate.

The analysis of the qualitative data followed a thematic analysis process as outlined by Creswell (2009, p.185), in which it is iterated between coding the interview transcripts and documents, identifying themes and interrelations between them and then interpreting their meaning. Codes were developed as a combination of predetermined and emerging codes, the former being guided by Gram-Hanssen's (2013a) empirical analysis framework for social practices as well as the interview guide. Gradually, the codes were refined and conceptually similar codes were grouped together. Following Bryman (2012, p.580), themes were then based on topical repetitions in the data, theory-related material, categories indigenous to the hospital context and aspects interviewees seemed to omit in their answers (missing data). Subsequently, analytic research notes were developed exploring each theme in greater depth (see Appendix D.4 for an example). Cross-tabulations of evidence on physical arrangements and occupants' experience were further used to explore how the identified constraints mapped onto the factors believed to determine theoretical saving potentials (Appendix D.2).

### 3.6 Summary of the study methodology

This study sets out to investigate the extent to which medical staff influence electricity end-use in different hospital buildings and departmental processes. On this basis, the relevance of simple behaviour change as a tool for carbon mitigation in hospitals will be evaluated, while taking account of the challenges and constraints effective in health care. Background to the study and literature review have highlighted the lack of research on hospital energy use in general and on the viability and relevance of staff-centred energy conservation initiatives there in particular. This study consequently adopts an exploratory approach with a view to developing theory applicable to hospitals, and potentially the wider non-domestic sector.

A case study research design is considered appropriate due to the complex, socio-technical nature of the research question. Case studies have previously proven beneficial in dealing with large amounts of data, obtainable through a number of different research methods (Flyvbjerg, 2006). Research in the built environment has however a strong quantitative tradition, emphasising technical dimensions and large-scale survey research. A multiple case study approach is hence preferred over single case analysis which, although restricting the achievable depth of the enquiry given the available resources, promises evidence more compelling to the field. Case study analysis has further been criticised for a lack of analytical rigour. This study consequently puts a number of mechanisms in place to ensure quality, including a replication of factors believed to be crucial in the research design, a detailed field-work protocol and the extensive collaboration with both technical and social science experts.

This study considers itself within a pragmatic research tradition. A concurrent mixed-methods approach using both quantitative and qualitative methods is applied in service to the research question. The quantitative methods are employed to develop detailed representations of the electricity use in different hospital departments and to estimate energy savings potentials from operational changes. For this, two main approaches are used which complement and validate each other: a top-down analysis of measured departmental electricity consumption data and a bottom-up end-use model based on a detailed audit of lighting and appliances use. The focus of the qualitative investigation, which primarily relies on semi-structured interviews with clinical staff in all departments, is on understanding hospital electricity use from an end-user perspective in order to identify constraints on the optimally efficient local use of electricity.

The study has a number of contextual and methodological limitations, the implications of which for the present and future studies are discussed in detail in section 8.2. Importantly, it focuses on reductions in local electricity end-use as opposed to improvements at a fabric or systems level. While this may somehow limit the scope for energy savings, it represents a novel strategy which may contribute to an increased understanding of the interplay between building energy use, service delivery and occupant needs. The research study was further crucially constrained by the lack of available data on hospital energy use and the difficulties associated with primary data collection in complex as well as inaccessible environments. In the face of these challenges, the study represents a significant advance on the available evidence, and will support larger scale and more structured data collection efforts in the future.

The next chapter 4 presents an energy perspective on the (clinical) activities taking place in different hospital departments to provide the reader with some insight into the socio-technical systems governing all energy saving attempts in hospitals.





# 4 Logistical & spatial arrangements of hospital departments

This chapter uses energy and process data collected by the author to present the context in which clinical activity takes places in different hospital departments. Few studies are currently available detailing clinical processes in hospitals from an energy perspective (section 1.1.2). There is further a growing awareness that a detailed understanding of contextual factors is paramount to identify feasible opportunities for change (section 2.3). This chapter therefore aims to provide the reader with some insight into the socio-technical systems governing all end-use energy saving attempts in hospitals.

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## 4.1 Overview of analysed departments

As laid out in section 3.3.2 on the case studies, five department types with different energy intensities and operating hours and representing different stations of clinical patient pathways (diagnosis, treatment and care) were analysed in this study across the three case study hospitals (see Table 4.1 for departmental core characteristics). The following chapter presents each department type, providing details on processes, resulting electricity requirements and clinical staff influences on them as indicated by the research question. The analysis is structured along two dimensions: given the importance of schedules and timing in the health care context, evidence on temporal routines is provided. A further interest is taken in spatial arrangements since hospital spaces are coherently designed to be supportive of the logistics of health care processes.

**Table 4.1:** Overview of core characteristics of investigated departments

Type	Hospital	Department	Usable floor area [m <sup>2</sup> ]	Core Opening Hours	Floor area weighted opening hours <sup>1</sup> [h/yr]	Estimated peak occupant density [m <sup>2</sup> /occupant]
Imaging	NUH	Radiology	161	24/7	5394	18
	RLH	Inpatient X-ray	249	9am to 5pm on weekdays	3550	23
Laboratory	KCH	Blood Sciences Lab	258	24/7	7643	18
	NUH	Pathology	505	24/7	6957	19
Theatres	RLH	Main theatres	970	24/7	4985	28
	NUH	Main theatres	66 <sup>2</sup>	24/7	6258	15
	RLH	Day theatres	1998	8am to 6pm on weekdays <sup>3</sup>	3322	27
Day Clinic	RLH	Outpatient Dialysis	910	7am to 11pm from Monday to Saturday	4069	15
	KCH	Chemotherapy	184	9am to 5pm on weekdays	2270	8
Ward	KCH	Lister Ward	567	24/7	7095	16
	NUH	Silvertown Ward	427	24/7	7403	13

<sup>1</sup> calculated on a per-room basis as  $\frac{\sum \text{Room annual operating hours (h/yr)} \cdot \text{Room floor area (m}^2\text{)}}{\text{Department floor area (m}^2\text{)}}$

<sup>2</sup> Department: 466 m<sup>2</sup>; Theatres suites: 203 m<sup>2</sup>; Area of measured electricity use: one theatre suite only with 66 m<sup>2</sup>

<sup>3</sup> Initiative lists, i.e. planned surgery to reduce waiting lists, are occasionally run on Saturdays.

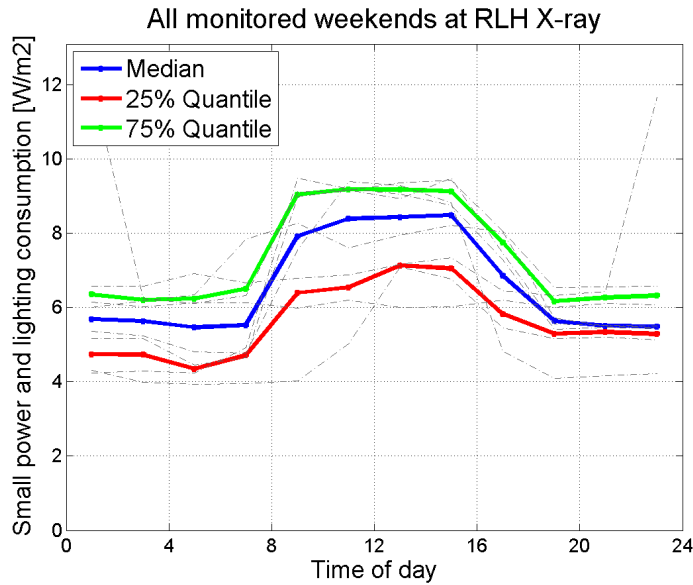
## 4.2 Diagnosis: X-ray Imaging

For patients to be adequately treated in a hospital, their illness needs to be correctly identified. Modern medicine provides varied and sophisticated means to do so, ranging from verbal consultations and physical examinations over the analysis of blood or urine samples (see section 4.3 on laboratories) to the use of highly specialised imaging equipment such as CT or MRI scanners. A frequently used tool for the diagnosis of fractures and other issues related to bone abnormalities as well as pathologies of lungs or bowels is the X-ray, in clinical terms also referred to as plain X-ray because no contrast solution is given.

Physically, plain X-ray uses radiation of a wavelength between 0.01 to  $10^{-9}$  metres which transcends skin and muscle tissue but is absorbed by bones and other dense materials to provide a simple black and white image of the area of interest. The required X-ray beam is generated within the tube of the X-ray generator, in which the interaction of a cathode-anode pair emits both the desired radiation as well as a substantial amount of waste heat. An additional cooling system is therefore required, making X-ray equipment comparatively energy-intensive (Twomey et al., 2012). Although the images do not show as much detail as those obtained using other modalities, plain X-ray is in wide spread use due to its comparatively low investment and running costs as well as its speed. The focus of current clinical developments in X-ray is to reduce the required doses of radiation as it is harmful to surrounding tissue, a prospect beneficial also from an energy perspective.

### 4.2.1 Logistical arrangements

In this study, the X-ray facilities at NUH and at the RLH were investigated. In acute hospitals, all types of patients are frequently investigated using X-ray: inpatients, outpatients, GP patients referred for diagnosis as well as patients in theatres and in the Accidents & Emergencies department (A&E). Depending on the size of a hospital, separate facilities can be available for the different patient groups or all may be seen within the same area. At the RLH, one of the biggest hospitals in London, more than 400 patients are investigated daily using X-ray technology and five separate parts of the building are dedicated to this purpose. At NUH, in contrast, all X-ray patients excluding those undergoing surgery (about 200 a day) are seen within the main radiology department adjacent to A&E. Despite these differences in set-up, the actual practice of taking an X-ray compared well across both hospitals.

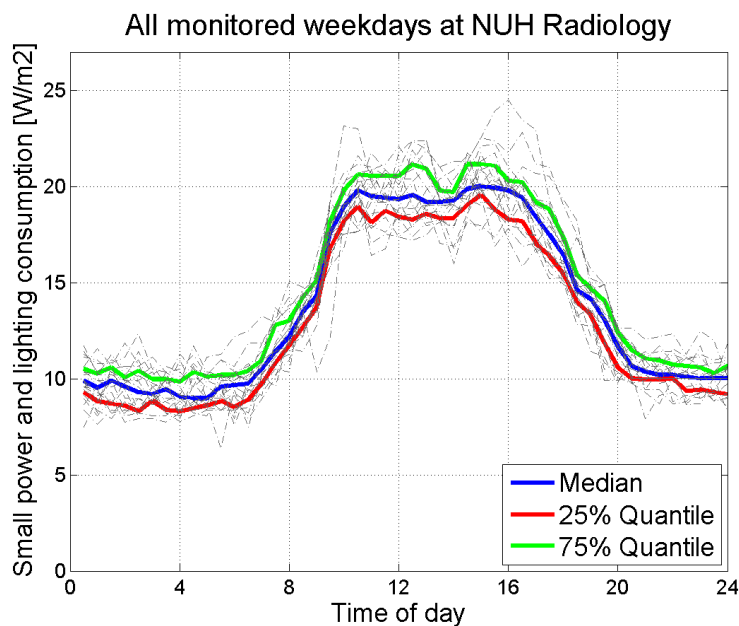


**Figure 4.1:** Monitored weekend electricity consumption of RLH Inpatient X-ray<sup>1</sup>

The operating hours differed between the two X-ray facilities. The RLH Inpatient X-ray department opened between 9am and 5pm from Monday to Friday only and was closed on weekends. The weekend profile (Figure 4.1) however suggested substantial electricity use which - based on measured lighting levels and circuit monitoring - could be attributed primarily to lighting loads<sup>2</sup>. X-ray at NUH, in contrast, was open 24/7 to provide emergency services for A&E patients, while mammography and fluoroscopy services scheduled screenings from 9am to 5pm on weekdays only. The weekday profile (Figure 4.2) confirmed the prolonged activity into the evening hours with less activity after 8pm when the area was manned with one radiographer only as opposed to three during the day.

<sup>1</sup> All electricity profiles in this chapter display small power and lighting consumption if not stated otherwise. If applicable, this may include fan coil consumption as well as individual split units retrofitted to address overheating issues. The data for all measured days is presented by dashed lines.

<sup>2</sup> The weekday/weekend factor based on the measured electricity data however was 1.1, a factor more akin to continuously operating departments than to those with clear after hours (see also Table 5.3.1).

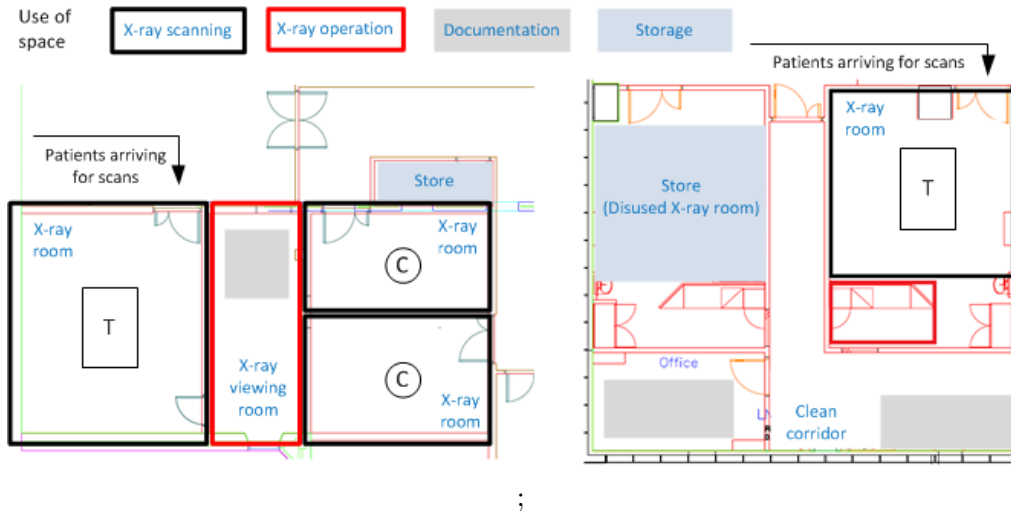


**Figure 4.2:** Monitored weekday electricity consumption profile of the NUH X-ray facilities

#### 4.2.2 Spatial arrangements

With the exception of mobile X-rays taken during surgery, X-ray imaging took place in dedicated rooms where the equipment (the ‘machines’ as staff referred to them) was permanently installed. The rooms (Figure 4.3, framed in black) centred around a height-adjustable table on which patients were placed, or around chest stands offering support to patients if images were taken standing-up. The X-ray machine itself could be floor or ceiling mounted and was commonly moved on a rail system to allow for the flexibility of imaging different body parts.

Due to the toxicity of X-ray radiation, the operator (normally a trained radiographer) was placed at some distance from the patient, protected through a lead glass shield (RLH) or in an adjacent room (NUH) shared between three X-ray rooms (Figure 4.3, operating areas framed in red). The patient’s medical record was available to the radiographer electronically on the computer at the operating point to enable decisions on diagnosis pathways and necessary radiation rates. Women aged between 12 and 56 awaiting imaging between torso and pelvis needed to confirm in writing that they were not pregnant as radiation could be harmful or even lethal to the foetus. Big floor standing printers to produce this and other forms were found in the operating (NUH) or the main corridor (RLH).



**Figure 4.3:** Set-up & use of space of X-ray facilities at NUH (left) and RLH (right)  
Floor plans provided by the RLH, amended by author

The entire imaging process would - depending on patient mobility, number of exposures and imaged body part - take between 5 and 20 minutes while the exposure itself was limited to a few milliseconds. Most operators preferred the X-ray room to be dark during this time, although modern equipment no longer strictly necessitated this due to improvements in detector performance. X-ray rooms (as well as imaging departments more generally) therefore tended to be equipped with dimmable lighting under operator control. Apart from allowing lights to be kept on during imaging which could especially for children make the experience less intimidating, state-of-the-art detectors were now digital as opposed to photographic and images were therefore available immediately on the operator's computer. Traditional X-ray view boxes and analogue imaging processors could still be seen in older radiology departments and theatres at NUH, but had now become obsolete.

The emergence of computers and digital technology had also substantially changed the role of radiologists, those professionals responsible for reading and interpreting the images taken by the radiographers ('reporting'). They now worked at 'reporting stations' composed of computers equipped with two or more specialist, high-resolution monitors which allow the detailed inspection of images for diagnosis. Commonly, two or more of such stations were placed together in so called reporting rooms. In their character comparable to offices, the reporting rooms would also have dimmable lights and were used intermittently by the radiologists<sup>3</sup>.

Every radiology department would further have an officer in charge of the electronic images stored in systems such as the picture archiving and communications system (PACS) or the radiology information system (RIS). In smaller hospitals such as NUH, this officer may also be in charge of departmental IT issues more generally, while in bigger hospitals such as the RLH specialisation tended to be higher while IT support was accessible centrally.

The local electricity use of X-ray departments was composed of two components: energy-intensive X-ray machinery on three phase supply and single phased lighting and ancillary appliances. In this study, a detailed analysis was only undertaken for the single phase components<sup>4</sup> because they proved more relevant to the research question while the electricity use of large scale imaging equipment is increasingly being discussed elsewhere in the literature (e.g. Esmaeili et al., 2015; Harsem, 2011; Hagemeyer, 2014).

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<sup>3</sup> Radiologists, like other physicians, must have earned an MD degree and passed a licensing examination, as well as having completed a practical residency in radiology. Less commonly, the reporting may be carried out by 'reporting radiographers'. Very occasionally, ordinary radiographers might also access reporting stations to alter images (for example to correct mistakes in declaring whether an image was left or right).

<sup>4</sup> Additionally, the consumption of two of the three RLH X-ray machines was monitored over 2 weeks to get an understanding of how equipment consumption related to overall departmental consumption. The results showed that with 22 kWh/(m<sup>2</sup> · yr) the X-ray equipment itself accounted for 26% of total local electricity use while 61 kWh/(m<sup>2</sup> · yr) were for small power and lighting, highlighting the relevance of the latter. The measurements at the RLH and also other work for instance by Jensen and Petersen (2011) further illustrated that beam generation accounted only for 5 - 15% of the time during which X-ray equipment was in use. Cutting residual electricity use, mostly from pre and post processing and to move bed and machine arm, could therefore also contribute to energy conservation. The potential will depend on the degree of machine/room utilization, equipment type and respective manufacturer recommendations as well as departmental policies specifying whether equipment was powered down outside operating hours or left in idle mode (Twomey et al., 2012). At NUH, all X-ray equipment currently remained in ready mode for emergency purposes 24 hours per day on 365 days per year. In contrast, the X-ray equipment at 'RLH Inpatient X-ray' was switched off completely (including generators) outside of the core hours because emergency X-rays were taken elsewhere.

The comparison of small power and lighting consumption profiles suggested that the NUH X-ray department was more energy intensive than its RLH counterpart. This was primarily due to

- older lighting technology (T8 and T12 versus T5 compact fluorescents);
- some remaining analogue image processing technology while RLH was purely digital; and
- supplementary local cooling solutions such as split units and fans at NUH, where RLH heat loads were met exclusively by the central chillers through ceiling mounted chilled beams.

Lights, single-phase medical and IT equipment could mostly be switched off by clinical staff in the X-ray departments. This was with the exception of resuscitation equipment which was constantly being charged, and split units and network printers (remained in stand-by) at NUH. Treatment room lights were dimmable and therefore offered additional degrees of control in comparison with other department types.

### 4.3 Diagnosis: Clinical pathology laboratories

The field of pathology has a major role in diagnosing diseases, helping choose optimal treatments and monitoring their effectiveness by analysing patient tissue, blood and other body fluid samples. Currently, 60 - 70% of diagnoses are based upon a number of pathology specialities, of which the four major disciplines are listed below (NHS Estates, 2005; Commission for Healthcare Audit and Inspection, 2007). Smaller disciplines such as cytology, immunology, virology and infection control may in larger trusts be located in additional departments or in smaller trusts constitute sub-specialities of the listed:

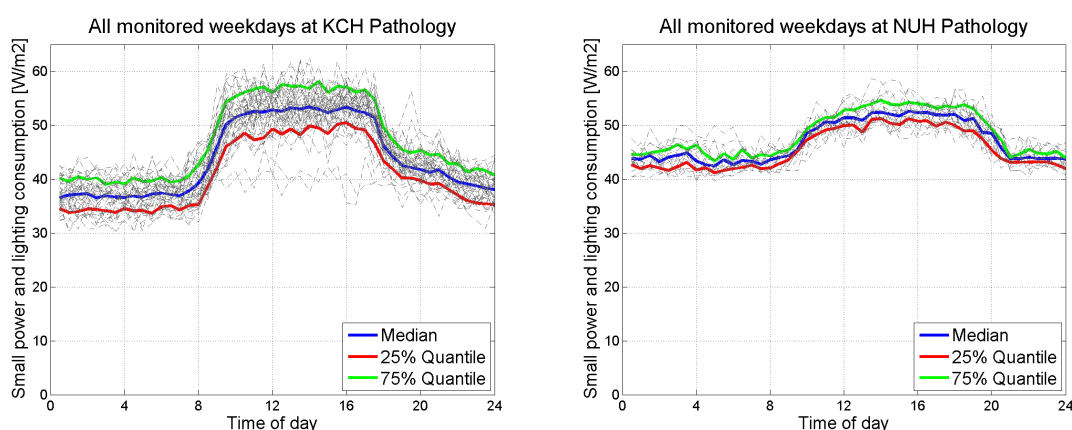
- **Haematology:** checks on the status of a patient's blood and blood-forming tissues, identifies abnormalities of blood coagulation such as haemostasis and thrombosis, often also in charge of blood transfusions and the operation of a trust's blood bank;
- **Clinical biochemistry:** examines the level of electrolytes, enzymes, hormones and other chemicals in specimens of body fluids and tissues, mostly blood serum or plasma;
- **Microbiology:** isolates disease-causing micro-organisms such as bacteria, viruses, fungi and parasites using a range of specialist culture and non-culture technologies and platforms and seeks suitable antibiotics (for the treatment of bacterial infections), anti-fungals and anti-viral medications;
- **Histopathology:** detects abnormalities in tissue samples from surgical operations and biopsies.



The demand for pathology services has been growing continuously over the last years due to technological developments, clinical guidance advocating more tests for example in cancer care and an increased demand for tests from the primary care sector (GPs) (NHS Estates, 2005). In 2005, primary care diagnostic requests constituted around 40% of the work performed in hospital pathology departments (NHS Estates, 2005), while one of the NUH staff interviewed for this project in 2014 estimated that 65 - 75% of their samples were from GPs. The need to meet this increased demand for pathology services, the development of interdisciplinary diagnostic technologies as well as efficiencies obtainable from sharing similar equipment have increasingly led to the creation of multi-disciplinary blood science laboratories. In this study, parts of the KCH Blood Sciences Lab and the NUH Pathology department were investigated, both of which integrated haematology and biochemistry services.

### 4.3.1 Logistical arrangements

It is the norm for clinical pathology laboratories in acute hospitals to provide a 24/7 service. At KCH, full laboratory service was provided on weekdays between 9am and 5pm, while essential GP samples were also analysed on Saturdays until noon. Inpatient samples, in particular urgent ones and those from A&E, were being dealt with at any time, if necessary by an out-of-hours team. The weekday electricity profile of the lab showed a slow decrease of activity in the evenings in line with the gradual reduction of staff from over thirty during core hours until midnight when only three staff remained in the lab for the night (Figure 4.4, left).



**Figure 4.4:** Comparative electricity consumption profiles for laboratories<sup>5</sup>

<sup>5</sup> KCH data included working days with reduced activity around Christmas and New Year's Day.

At NUH, the laboratory was smaller and samples for microbiological or specialist tests could not be analysed locally but were sent to the bigger pathology department at the RLH. The NUH department nevertheless operated around the clock to meet demands for tests required in emergency care while full service was provided between 9am and 5pm on weekdays like at KCH (Figure 4.4, right). Between 8pm and 8am and on weekends (except Saturdays from 11:30am to 4:30pm when there were two extra staff) the laboratory was staffed by two people, one in the haematology team and one in biochemistry. On average, laboratories represented the department type with the longest average operating hours (see also Table 4.1).

### 4.3.2 Spatial arrangements

Both investigated laboratories were classified at containment level 2, implying that the access to the laboratory was restricted to authorised persons and specified disinfection procedures must be used. Containment level 2 spaces are recommended to be maintained at an air pressure negative to atmosphere, but it is appreciated that this may be difficult in practice due to constant footfall in and out of the rooms<sup>6</sup>. The general work-flow in the two investigated labs was found to be quite similar despite the difference in size (Figure 4.5, highlighting also required electrical equipment). Both external (GP) and internal samples were received by specimen reception, catalogued, batched and then distributed to the responsible parts of the laboratory. In NUH, specimen reception resulted to be a major bottleneck in the operation of the pathology department due to staffing pressures there.

Depending on the required tests, batches of samples then had to be prepared by centrifugation. Generally, all biochemistry samples were centrifuged and about half of the haematology specimen (coagulation tests and transfusion samples were spun but not full blood counts which were the most numerous haematology tests). Non-tempered centrifuges were assumed to draw no power when not in use.

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<sup>6</sup> Regulations on the Control of Substances Hazardous to Health (COSHH) specify ventilation requirements for laboratory and other hospital spaces. COSHH requires that laboratories from and above containment level 3 are maintained at negative air pressures through specialist ventilation arrangements, while at lower containment level this is a recommendation only.

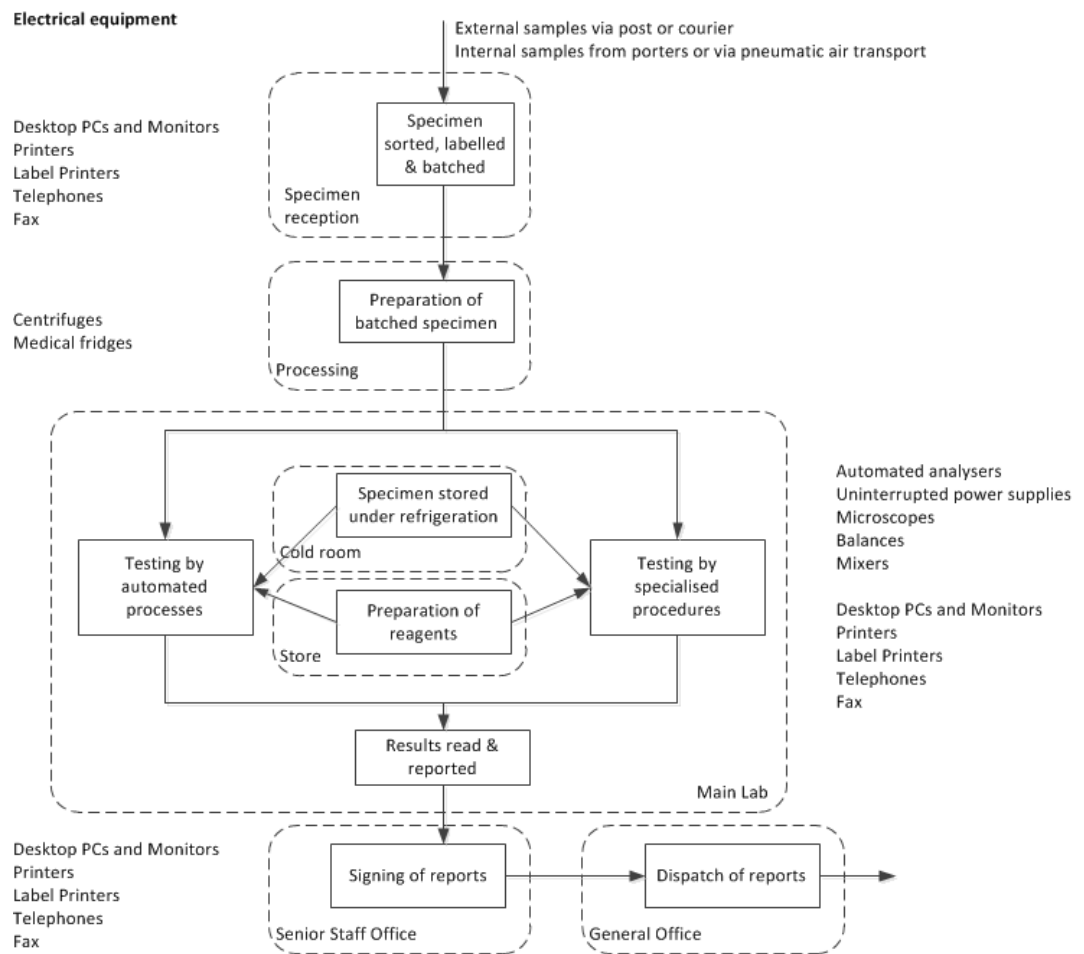


Figure 4.5: Workflow and spatial arrangements of laboratories

**Table 4.2:** Inventory of major automated analysers in pathology laboratories  
(see also Appendix D.1 for more details)

Discipline	Hospital	Major automated analyser	Number per department	Average load during operation [W]	Data input code
Haematology	KCH	Siemens Advia 2120	2	311	5
		Stago STA-R Evolution	2	500	5
	NUH	Beckman COULTER LH 750	2	430	5
		Sysmex CA 1500	2	312	5
		Ortho AutoVue Innova	1	476	5
Biochemistry	KCH	Siemens Advia Centaur XP	3	375	5
		Siemens Advia 2400	3	400	5
		DiaSorin LIAISON	1	350	5
	NUH	Architect i4000SR	1	1150	5
		Olympus AU2700	1	1350	5
		Olympus AU640	1	900	5

The main laboratory of both hospitals was designed to be open-plan with windows on one long side and a corridor on the other. At KCH, the room was dominated by a U-shaped conveyor belt measuring roughly 25 m in length (Siemens Aptio Track System, referred to as ‘the track’). The track continuously transferred samples from the specimen reception area directly to the analysers at KCH while at NUH analysers were loaded manually. Such automated analysers performing the most common biochemical and haematological tests have been crucial in meeting the increasing laboratory workload over the last years. At the same time, they are electricity intensive (see Table 4.2 for details on automated analysers installed at KCH and NUH) and generate high heat loads so that strategic engineering solutions for ventilation and space cooling become necessary<sup>7</sup>. Most analysers were in use continuously, but could according to laboratory staff be switched into stand-by during long periods of low demand. When coming out of stand-by, calibration and quality control runs often became necessary.

<sup>7</sup> It was noted that none of the visited laboratories allowed for cross ventilation while especially at KCH ceilings were low (2.55 m), likely introducing further challenges to air flow.

Both pathology departments included various store rooms (including cold rooms at NUH which at KCH were outside the analysed boundaries) where specimen were stored under refrigeration (2 - 6% of total floor area). Up to a quarter of the departmental floor area was taken up by office spaces for both process and administration. The latter were operating during core hours only allowing for some office equipment to be switched off. At NUH, the blood bank consisting of two blood fridges and two big plasma freezers was also part of the main pathology department while it was located outside of the analysis boundaries at KCH.

On the whole, laboratories were found to be energy intensive departments with high load densities. While active loads seemed comparable between the two investigated labs, base loads were higher at NUH. This was surprising given the continuously operating track system at KCH but will likely be a result of higher loads from analysers and cold storage. There may nevertheless be some potential for base load reductions in the NUH Pathology department, a supposition also repeatedly voiced by different members of the hospitals facilities management team who claimed that ‘laboratory staff would just leave everything on’.

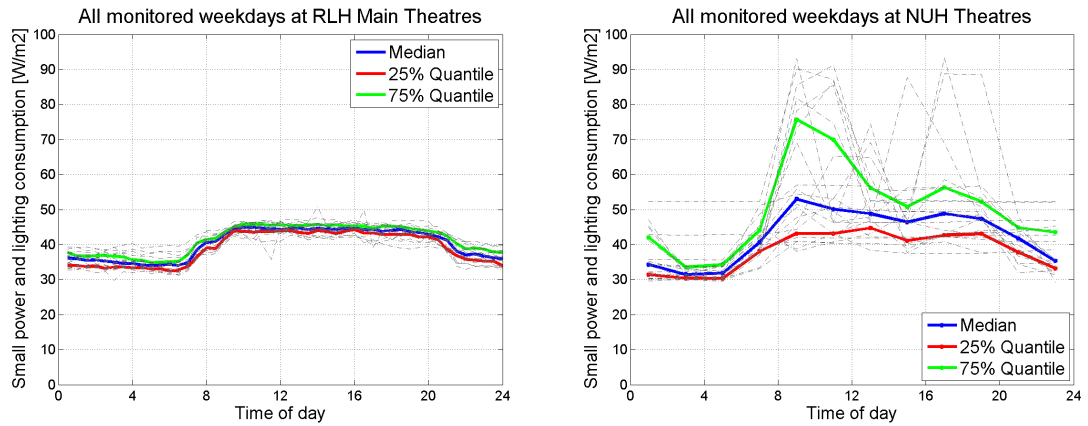
#### **4.4 Treatment: Surgery in operating theatres**

For many medical conditions surgery can be necessary to alleviate them and every acute hospital will therefore be equipped with a number of theatre suites (constituted by theatres, anaesthetic rooms, scrub, preparation and (dirty) utility rooms) as well as recovery facilities where patients are supervised immediately after surgery. Additionally, most theatre departments include some administrative areas and facilities for staff changing and resting. Larger hospitals often have dedicated day theatre departments for ambulant procedures as well special paediatric theatre departments for surgery on children in addition to the main theatres. In this study, the main theatre departments at RLH and NUH were investigated. To get some sense for the differences between full and ambulatory surgery, the study also included an analysis of the RLH day theatres.

#### 4.4.1 Logistical arrangements

Surgeries can be differentiated into two categories: elective (planned) and emergency. Planned surgery follows patient lists (commonly simply referred to as lists) compiled by the theatre manager balancing patient needs and the availability of staff and facilities. In addition, emergency surgeries characterised by a need for swift action to avoid patient death or permanent disability are carried out at any time during day or night. During 2012/13, about a quarter of surgical hospital admissions were emergencies in the UK (Royal College of Surgeons, 2014). This was also reflected at NUH, where operational data from the Trust's accounting system was available to this project and showed that 30% of surgeries were emergency surgeries during September 2014 and 22% during October 2014 respectively. Infrastructural provisions matched this need with one in five theatres being dedicated emergency theatres with round the clock disposition in both analysed hospitals.

In theory, there were two four-hour blocks of elective surgery daily (9am to 1pm and 2pm to 6pm at NUH; 8:30am to 12:30pm and 1:30pm to 5:30pm at RLH), both of which were preceded by equipment preparations and team meetings and followed by cleaning activities (30 minutes each). In practice, many cases took longer than scheduled due to unforeseen complications and staff were accustomed to staggering their lunches and working overtime. The electricity consumption profile for both main theatre departments (Figure 4.6) in fact suggested continued activity into the evening in more than just the emergency theatre on a regular basis. On weekends, both departments would run some elective cases to keep patient lists manageable, but less staff were working and the focus would be on emergency surgery. Administrative areas such as theatre reception and record offices tended to be staffed from 9am to 5pm or from 8am to 6pm on weekdays only.



**Figure 4.6:** Weekday electricity consumption profiles for main theatres<sup>8</sup>

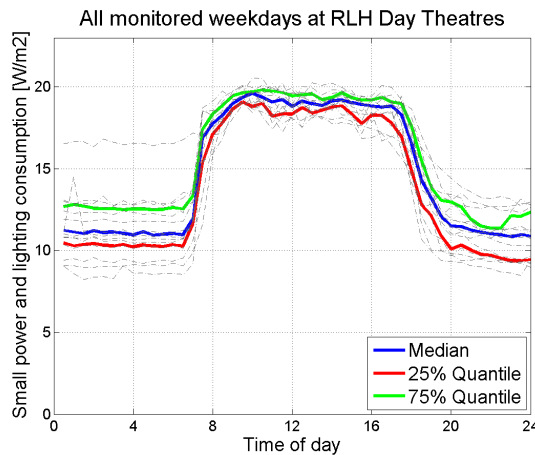
Day surgery was performed from Monday to Friday (with occasional cases on Saturdays) and according to lists only. Cases tended to be less invasive than full surgery, with shorter recovery times and ideally no ward stay before nor after the intervention. At the RLH, there was a short stay ward adjacent to the day theatres for patients coping poorly with the effects of the surgery, but most patients would go straight to the discharge lounge and return home after as little as 20 minutes there. In contrast to the main theatres where patients were bedbound, day theatre patients were moved about using trolleys which proved more flexible and easier to push for staff. The official operating hours of the RLH Day theatres corresponded to those of planned surgery within the main theatres and while day theatre staff were faced with similar challenges from unstable patients and overrunning lists, the departmental electricity profile confirmed that they were able to go home at 6pm more often (Figure 4.7).

<sup>8</sup> The difference in measurement areas for the departments (one theatre suite at NUH, five suites at RLH) influenced load diversity: Measured peak loads were hence much higher in NUH.

#### 4.4.2 Spatial arrangements

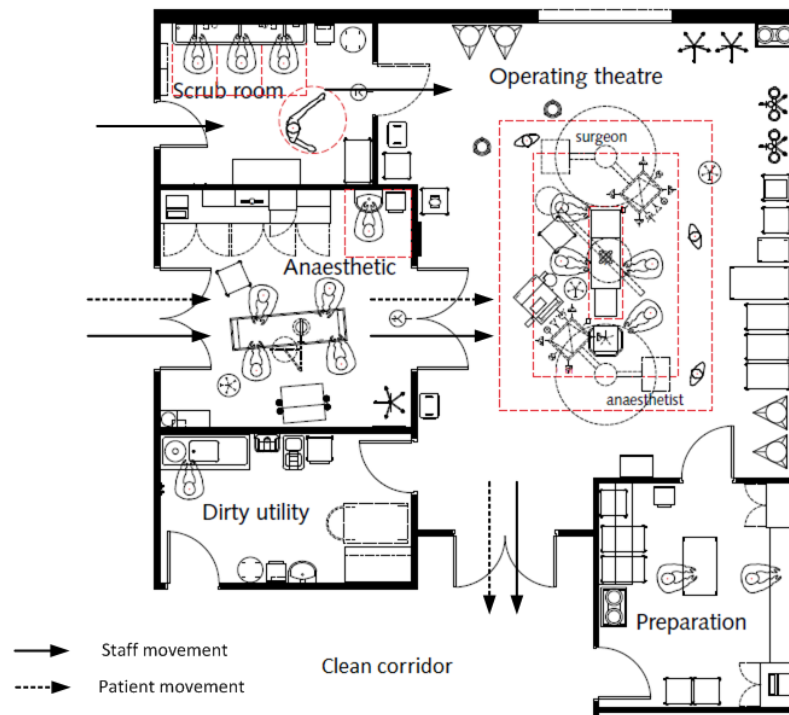
Operating theatres follow a consistent layout supportive to the logistics of surgery (see Figure 4.8 for a typical operating theatre suite): patients in beds or trolleys enter the theatre suite through the anaesthetic room where they are put to sleep by anaesthetist and anaesthetic nurse/operating department practitioner (ODP). Meanwhile, the surgeon and his team (generally up to two assistants to the surgeon, two to three scrub nurses and a support worker) enter the theatre through the scrub room where they wash and disinfect themselves in order to become sterile. The surgical instruments are prepared and disinfected in the preparation room, sometimes also referred to as laying up room. After surgery, the patient is taken into recovery for post anaesthetic care through the main theatre doors while the next patient may be prepared in the anaesthetics room.

All visited theatres at RLH and NUH corresponded well to the recommended layout, with slight deviations in access arrangements for preparation rooms and the provision of dirty utilities. The most notable difference was the size of the provided facilities with NUH being much more spatially constrained: The average operating theatres at Newham had only 37.6 m<sup>2</sup> as opposed to 57.5 m<sup>2</sup> (RLH Main Theatres) and 56.4 m<sup>2</sup> (RLH Day theatres) while a standard size of 55 m<sup>2</sup> is recommended for all inpatient operating theatres (NHS Estates, 2004c). All other NUH rooms were also found to be much smaller than at RLH while both interviewed NUH theatre staff pointed out that the lack of space at times complicated patient care.



**Figure 4.7:** Weekday electricity consumption profile of RLH Day Theatres





**Figure 4.8:** Room layout for a typical operating theatre suite with individual scrub room according to design guide lines  
(Schematic from NHS Estates (2004c, p.26), directions of movement added by author)

Theatres were on the whole found to be rather electricity intensive areas (see Figure 4.6 for loads). They had high base loads which compared well across the two investigated main theatres. The use of medical equipment during surgery and requirements for facilities such as ultra clean ventilation (UCV) canopies (see section 5.2 for further details on UCV) are believed to be decisively defined by the surgical speciality<sup>9</sup> (NHS Estates, 2004c).

<sup>9</sup> To give but one example, orthopaedic surgeries may only be carried out in theatres equipped with UCV canopies because any infection risks rejection of implanted components. Orthopaedic surgeries tend to be rather long with average case times of two hours while requiring frequent imaging (typically using mobile X-ray) to ensure correct implant positioning. On the other hand, minimal invasive surgeries using for example endoscopic 'keyhole' techniques are becoming increasingly popular in surgical specialities such as urology (focuses on diseases of the male and female urinary tract system and the male reproductive organs) and otolaryngology (deals with disorders and conditions of the ear, nose, and throat region and related areas of the head and neck). Minimal invasive surgery is much quicker and up to 30 patients can be seen daily, often as day-case procedures in rooms more akin to regular treatment rooms than to fully equipped operating theatres.

In this study, operational data from the Trust’s accounting system was available for the NUH Theatres providing details on actual theatre use by list speciality. It could be shown that periods of high local electricity use (with loads exceeding  $60 \text{ W m}^{-2}$  in Figure 4.6, right) reliably corresponded to trauma or fracture lists while general or ear, nose and throat surgery seemed to be less electricity intensive<sup>10</sup>. Day theatres, where many patients are operated using local anaesthesia only, were also less electricity intensive overall due to less specialist ventilation arrangements and fewer medical appliances.

Other electrical equipment typically in use in theatre departments included cold storage, warming cabinets, the anaesthetic machines in theatres and anaesthetic rooms, the IT equipment for the documentation of procedures and the surgical task lighting, controllable both locally by the surgeon and through the theatre panel. The theatre panels also allowed for dimming other theatre lights as well for defining temperature and humidity set-points, controlling blinds if applicable and operating the UCV canopy while also featuring several warning lights for high medical gas concentrations or fire.

Controlling the atmospheric concentrations of anaesthetic gases is crucial in theatre departments to meet requirements on the control of substances hazardous to health (COSHH). To this purpose, all visited theatres operated anaesthetic gas scavenging systems (AGSS) serving both theatres and anaesthetic rooms<sup>11</sup>. Statements of all stakeholder groups (clinical staff, technical staff and consultants) as well as monitoring data confirmed the continuous running of AGSS in both case hospitals. Theoretically, however, AGS pumps may be switched off out-of-hours by clinical staff in both hospitals through a switch in the theatre panel.

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<sup>10</sup> Trauma and fracture lists generally ran at NUH on Tuesday mornings and Wednesday or Thursday afternoons. In some hospitals, ear, nose and throat surgery is carried out mostly in day theatres, confirming the reduced need for specialist ventilation and a resulting lower electricity use.

<sup>11</sup> Literature indicates power ratings for AGS pumps between 500 W and 2.2 kW (Pierce et al., 2014), with pumps generally serving one or more theatres and adjacent anaesthetic rooms. For this study, the anaesthetic scavenging pumps serving two NUH theatre suites were monitored over the course of four weeks. The average total load resulted  $63.2 \pm 1.8 \text{ W}$ , drawn consistently at any time over the course of 24 hours. This seems little compared to the nominal load of 1.8 kW per blower, but may be a result of a theatre retrofit reducing the area scavenged from. At RLH, AGSS electricity use estimates are based on manufacturer specifications.

## 4.5 Treatment: Day Units

Outpatients departments (OPD) are visited by a larger number of people than any other part of a hospital and could be considered the hospital's 'shop-windows' (NHS Estates, 2004b). Appearance and running of both the building and the service are therefore particularly important there as initial impressions might remain. High patient throughputs, however, can put pressure on the spaces. In general, OPDs have three major functions:

1. specialist consultation and examination;
2. treatments not requiring acute day or inpatient ward stays;
3. screening of patients, pre-operative assessments and follow-ups for treatments elsewhere in the hospital.

This study focused on the second type of outpatient departments, also known as 'day units', because the energy demand of OPDs undertaking primarily assessments and consultations was expected to be less specialist and more akin to settings already comparatively well researched in the context of smaller health care premises and offices (e.g. Murray et al., 2008).

Two examples of treatment-focused OPDs were investigated<sup>12</sup>: the outpatient haemodialysis unit at RLH and the outpatient chemotherapy unit at KCH. *Haemodialysis* is one possible treatment for patients whose kidneys are in a state of renal failure. It involves diverting blood into an external machine, where it is filtered to remove waste products such as creatinine and urea before being returned to the body. Established renal patients on maintenance haemodialysis attend the unit three times per week with each session lasting around four hours (Department of Health, 2013).

*Chemotherapy* is the repeated use of cytotoxic drugs to destroy cancer cells during 4 to 8 treatment cycles over the course of 3 to 6 months (Cancer Research UK, 2015). Depending on the drug and the type of cancer, there are many ways to administer the anti-cancer drugs including as injection into a vein, or orally as capsule or tablet. In day units, intravenous infusions over anything from 30 minutes to several hours are used while the drugs are injected into the patients veins by infusion pumps at carefully controlled rates. For cancer that has spread to the brain or spinal cord, the chemotherapy is inserted directly into the patient's cerebrospinal fluid via a lumbar puncture. This procedure takes about 20 minutes and needs to take place in a separate, permanently designated area for intrathecal chemotherapy.

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<sup>12</sup> Due to practical challenges (service provision, access constraints) it was not possible to work with two departments of the exact same nature within the case study hospitals.

### 4.5.1 Logistical arrangements

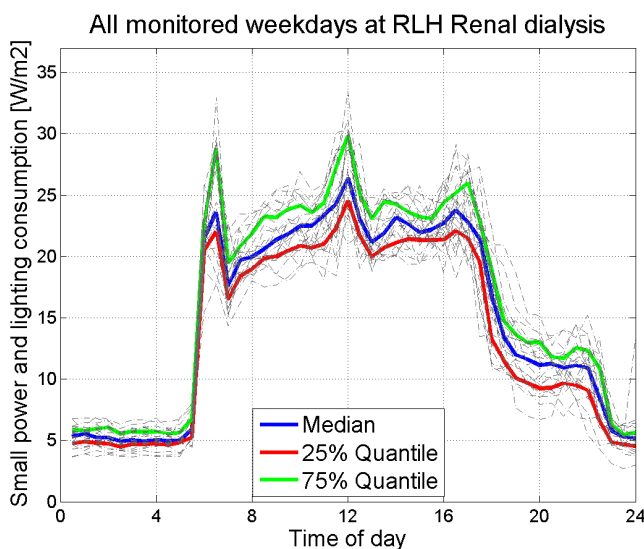
As opposed to laboratories, theatres and most imaging departments which feature at least some 24/7 spaces, day units are characterised by defined operating and clear after-hours. The RLH Haemodialysis day unit operated between 7am and 11pm from Monday to Saturday (closed on Sundays), while the KCH Chemotherapy day unit had a more confined rhythm and opened Monday to Friday from 9am to 5pm only. The closed day(s) electricity profiles for both units confirmed the absence of activity with median electricity use levels corresponding to the base load, while some instances of energy use exceeding base load consumption levels were noted in particular at KCH.

The electricity profile of the *RLH outpatient haemodialysis unit* during the week (Figure 4.9) showed distinct peaks at 6am, 12 noon and 5pm which were attributed to the heat disinfection of the approximately 30 haemodialysis machines<sup>13</sup>. The unit offered three dialysis shifts daily including a twilight shift from 5pm to 10pm on about half of the machines in order to meet the increasing demand for the service as well as accommodating renal patients who are still actively working. This is typical for renal units in urban centres where patient preference and local transport links for both patients and staff make such provision feasible (Department of Health, 2013).

Clinical staff worked 11.5 hour shifts, from either 7am to 6:30pm or from 11:30am to 11pm. During this time, dialysis machines were in constant use cycling between heat disinfection, preparation (also referred to as priming or lining), treatment and chemical disinfection. A number of different dialysis machine brands were found to be in use at the RLH (different models primarily by the manufacturers Gambro and Fresenius) of which newer types were reported by clinical staff and renal technicians to automatically power down after the last disinfection cycle while older machines had to be switched off manually. In the mornings, all machines were set to come on automatically and perform their first heat disinfection around 6:30am to be ready for preparation by health care assistants from 7am.

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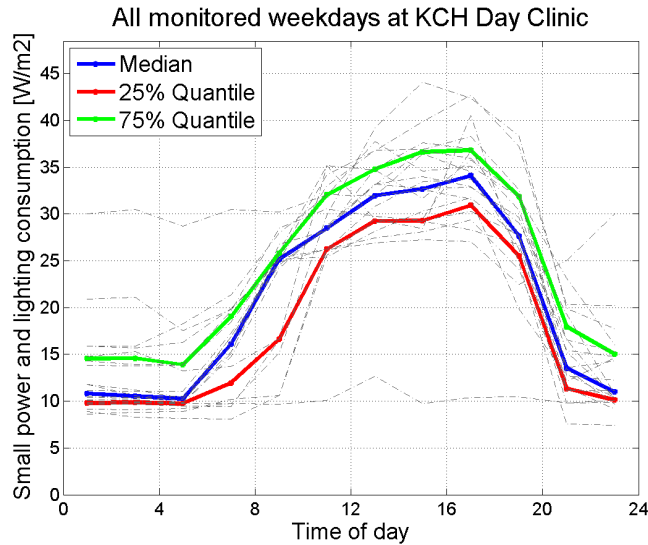
<sup>13</sup> According to Connor et al. (2011, and other unpublished data by the same author), dialysis machines use 0.6 - 1 kWh during 30 minutes of heat disinfection while the electricity use during the actual treatment was about half of that (1.5 - 2 kWh per four hours). This is in line with measurements by Jensen and Petersen (2011) (1.8 kW during heat disinfection, 0.6 kW during treatment) and taking into account some diversity in machine use as well as the expected electricity use for lighting and IT equipment explains the observed profile well. Understanding such characteristics of hospital departments can be important from an energy management perspective when making sense of the increasingly available smart and sub-meter data.



**Figure 4.9:** RLH Day unit weekday electricity consumption profile

The first set of haemodialysis patients was expected to arrive at 7:30am with subsequent sets scheduled at 12:30 and 5:30pm. On arrival, each patient was weighed and blood pressure and general health observations were taken. For this the department was equipped with a high capacity weighing scale (wheelchair compatible) and two blood pressure monitors, all constantly plugged in. Once sitting in their reclining chairs and connected to the machines, with an average treatment time of four hours, patients would ‘sleep, read, play on their phones or watch TV (G)’ if they got hold of one of the only two coin-operated and portable TVs provided in the department. Consultants and dieticians visited for consultations while the nurses, summonable through an electric nurse call system, attended to human needs for snack and beverages (as well as conversation if there was time).

In the *KCH Chemotherapy day unit*, patients started arriving from 9am while most staff got there by 8:45am to ensure smooth running. The patients reported to reception and were then escorted to their chairs for chemotherapy treatment. The department had space for up to 15 patients at a time while throughput varied depending on cancer type and administered drug. More patients awaited their turn in the department’s waiting room and - due to a lack of space - outside of the department on the corridor where additional chairs had been put up. In the waiting room, a TV provided some entertainment and drinks could be purchased from a vending machine, while the corridor held few amenities and was also reported to be somehow too cold during winter because no space heating was installed there.



**Figure 4.10:** KCH day unit weekday electricity consumption profile  
(includes lighting, small power and comprehensive split units for space conditioning.)

In both day units, the cleaning was reported to take place partly in the mornings (dusting, changing bin liners) but mainly in the evenings after the department closed. At KCH, this resulted in above base-line electricity use on weekdays past 5pm and up until 8pm due to continued lighting and split unit use (Figure 4.10). This corresponded to interviewed staff’s notion that domestic staff were coming in as they were leaving, meaning lights were mostly left on for them. At RLH, Carillion, the sub-contractor in charge of cleaning, confirmed that domestic staff would start in renal at 6am but do the mopping from 10pm to avoid accidents on slippery floors. Due to the longer operating hours, cleaner influence on electricity seemed overall less pronounced here than at KCH.

#### 4.5.2 Spatial arrangements

Although function and operating hours varied for the two investigated outpatient departments, the spatial configuration was found to be comparable. The main treatment took place in open plan bays in which views and natural daylight were important design considerations to ensure patient comfort and well-being. Curtains could be used as non-fixed partitions to flexibly separate spaces to ensure patient privacy as well as staff-to-patient and staff-to-staff confidentiality. Apart from the respective medical equipment (haemodialysis machines or chemotherapy infusion pumps), all patients had reading lights enabling them to control the lighting levels in their immediate environment.

While the patients were undergoing treatment, nursing staff and health care assistants monitored them while completing various administrative tasks. At RLH, computers, telephones and printers were provided in a number of nurse bases overseeing approximately 10 patients each. At KCH, laptop PCs on trolley were in use allowing for staff to take computerised notes while interacting with patients. Additional computers as well as printers could be found at reception and in the medication room. All PCs at KCH featured an automated PC shut-down at 7pm which had been set up centrally by the trust IT team. At RLH, computers were handled manually and supposedly switched off by staff members after the twilight shift.

Both day units featured storage space for consumables and equipment. At KCH, the medication room held the medical fridge for the storage of the hazardous cytotoxic drugs and therefore needed to be lockable and alarmed. The RLH haemodialysis unit mainly required storage space for sterile single use items such as dialysers and blood lines as well as sheets and blankets provided to all patients (Patients tend to feel cold during dialysis treatment for medical reasons). There was further an equipment store overseen by the renal technicians where additional dialysis machines were maintained or repaired. Both departments featured toilets for staff and patients but also operated bedpan washers to meet the needs of less mobile patients.

In addition to intravenous chemotherapy, the KCH day unit also offered intrathecal chemotherapy via lumbar puncture. In line with regulations, a separate room (7.6 m<sup>2</sup>) was available for this allowing for patients to be treated privately and while lying down. The room was served by a designated thermostat controlled split unit for ventilation and space conditioning, enabling a positive pressure to be maintained to preserve cleanliness. Cleanliness was generally a particularly important consideration in the chemotherapy unit because the treatment weakened the patients' immune systems and the department consequently featured a high number of clinic wash-hand basins and disinfectant dispensers.

Apart from specialist energy requirements for machines (RLH) and ventilation (KCH), the investigated treatment units required further engineering services: Haemodialysis creates considerable amounts of waste requiring strategic disposal as well as complex water services including water treatment. Chemotherapy also relies on specialist waste disposal arrangements due to the toxicity of the involved drugs. As for standard electricity uses, ceiling lights were controlled manually at KCH, while staff had full control over temperatures through room thermostats. In contrast, space heating and cooling were controlled centrally at RLH; corridor, store and utility room lights were sensor controlled and only the ceiling lights in the treatment bays could be influenced by clinical staff through conventional light switches.

## **4.6 Care: Inpatient accommodation on wards**

Historically, inpatient accommodation has been at the core of acute hospitals. Despite current trends aimed at shifting care into community settings, inpatient accommodation - in particular for complex cases or where major surgery requiring general anaesthesia is required - still accounts for a significant proportion of space in general acute hospitals (Department of Health, 2013). Wards, internationally sometimes referred to as 'inpatient units', are composed of patient bedrooms and the spaces that support them including utility rooms, nurse or touchdown bases, storage spaces and potentially food reheating facilities.

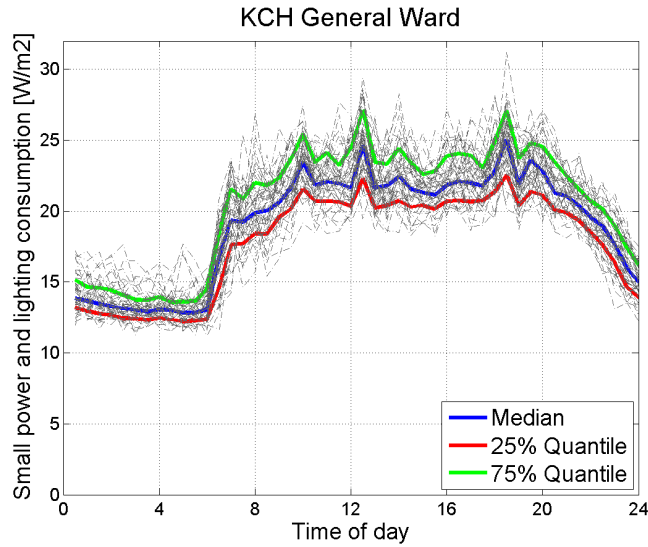
Some difference in electricity intensity can be expected between general wards, intermediate care or so-called step-down units and intensive care wards such as stroke or critical care units. In the latter, respiratory care services need to be available around the clock and monitoring is higher, with one trained critical care nurse in charge of only one or two patients as opposed to typically eight patients on general wards (RCN 2012). In this study, two general surgical wards were investigated at NUH and KCH, which - as opposed to more specialist wards associated with specific treatment centres - assume care for most post-surgical patients.



#### 4.6.1 Logistical arrangements

Wards are characterised by their continued occupation regardless of time of day, week or year providing continuous medical observation and care for patients before, during and after treatment. From an energy perspective week and weekend days were found to differ little on the investigated wards; the average electricity use on weekdays was 1.03 and 1.05 times that of weekend days at NUH and KCH respectively. Clinically, there were some difference in that less planned patient admissions and discharges took place over the weekend and fewer doctors as well as nurses were around. On both wards, the fieldwork for this study also took place during a weekend because staff nurses thought this more convenient.

The rhythm of ward activity was determined by the admitted patients who were often acutely ill and in need of observation. Each ward nevertheless had routines in place which were found to be both very comparable between the investigated wards and in line with available guidance (e.g. Department of Health, 2013). Clinical staff worked 13 hour shifts, starting at 7:30am to allow for a one hour overlap with the night shift to compare notes on patient status ('handover'). Patients needing medication were woken by the night staff from 6am while others might sleep until breakfast, at around 8am. Mornings were generally perceived by ward staff to be the busiest time due to many imminent tasks including washing, dressing and feeding incapacitated patients as well as preparing medications. Daily, all patients were also seen by their doctors during the mornings while visitors were welcome between 2pm and 8pm in the afternoons. In the evenings, patients were expected to sleep from 11pm the latest and this was promoted by a reduction in bay lighting to night levels (see Figure 4.11 for the KCH profile as one example).



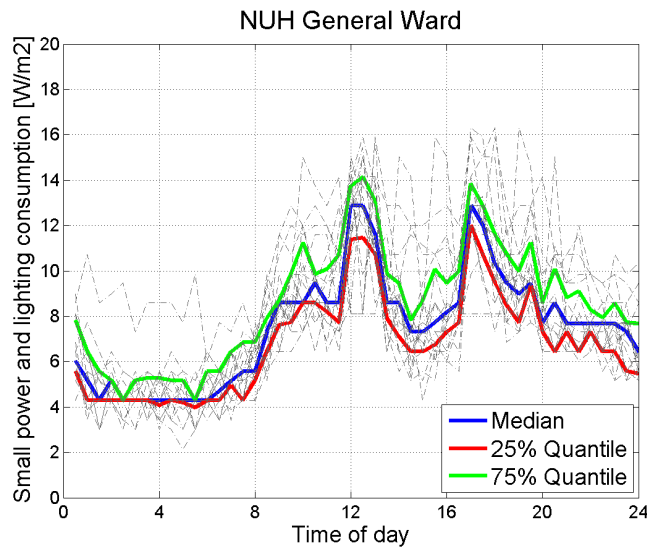
**Figure 4.11:** Electricity consumption profile of KCH general surgical ward (includes lighting, small power and comprehensive split units for space conditioning.)

**Table 4.3:** Mealtimes at investigated wards

Mealtimes	NUH	KCH
Breakfast	8am to 9am	7.45am to 8.45am
Lunch	12 to 1pm	12 to 1pm
Supper	5pm to 6pm	6pm to 7pm
Snacks & Hot drinks	10am, 3pm, 6:30pm & 7:30pm	Served all day on request

Meals were served three times a day (Table 4.3) by domestic staff who also helped patients to choose their daily meals taking into account medical diet restrictions. The energy use profiles of the investigated departments differed somehow due to differing means to re-heat patient meals locally after they had been prepared in central catering facilities. NUH used a regeneration kitchen, an equipment item previously identified to be comparatively energy intensive for a ward<sup>14</sup>. The NUH ward's electricity use profile (Figure 4.12) correspondingly showed a pronounced peak at lunch and dinner time, while at KCH less energy intensive commercial microwaves were used for food reheating and peaks hence less pronounced. After lunch, the NUH ward observed a period of quiet time dimming lights and switching off TVs to allow patients to get some rest which also resulted in lower electricity use.

<sup>14</sup> Building Research Energy Conservation Support Unit (BRECSU) (1996) for instance estimate an annual electricity use of 328 kWh/bed (equivalent to 8 - 10 kWh/(m<sup>2</sup> · yr)) while wards have small electricity requirements overall.



**Figure 4.12:** Electricity consumption profile of NUH general surgical ward

The central kitchen preparing and distributing patient meals across the hospital was only one of the central facilities maintaining logistical interactions with the wards. There were also frequent dealings with the central pharmacy department to stock up on medications and consumables such as syringes and needles as well as with laundry services and central stores to obtain clean supplies of linen and others. Bearing in mind the presence or visits of junior doctors, consultants and occupational or physiotherapists, wards seemed to have maintained their role as hub of hospital activity, further justifying their inclusion in this investigation despite comparatively low overall electricity intensities.

#### 4.6.2 Spatial arrangements

There are a number of important considerations for the design of ward spaces (Department of Health, 2013):

1. **Daylight:** It has been established that daylight has beneficial effects on patient recovery, so all patient spaces should receive natural daylight. At the same time, the efficient use of daylight (i.e. minimising the use of artificial lighting) seemed a promising energy savings strategy on wards.
2. **Observation:** The distance between patient rooms and staff workstations should be minimal to enable the observation of critically ill patients. Views into busy internal spaces such as circulation areas can further provide a distraction for patients in addition to views of the outside world.

3. **Single-bed rooms:** The provision of high-quality facilities, with the option of single-bed rooms with en-suite showers, is increasingly considered a factor influencing patients' choice of which hospital to stay in (Department of Health, 2013). The share of single bed-rooms in all general acute hospitals is recorded in ERIC since 2011 and has since grown by 9% a year within all NHS General Acute Hospitals. Room sizes of 23.5 m<sup>2</sup> are recommended to accommodate the increasing activity and amount of equipment and aids used in treatments around a patient's bedside.
4. **Same-sex accommodation:** If single-bed rooms are unavailable, same-sex accommodation is considered crucial in ensuring patients' privacy and dignity. It is one out of only five criteria for patient feedback on the NHS choices website (alongside with cleanliness, staff-cooperation, respect and involvement in decisions), reflecting the importance given to this provision. The health building notes recommend gender segregation to be guaranteed at all times, i.e patients should not have to pass through areas used by the opposite sex to reach their own facilities.

The above design considerations were found to be reflected on the investigated wards to differing extents (Table 4.4). Although small, the nucleus design of the NUH ward overall proved favourable by the above criteria while it experienced serious overheating problems which were found hard to mitigate in absence of suitable ventilation options (see also section 6.4.1). On the other hand, nightingale wards such as at KCH were previously shown to be more resilient in the face of a warming climate (Lomas et al., 2012) while mobile clinical workstations had been put in place to improve patient monitoring.

From an engineering and energy perspective, dirty utility or sluice rooms proved relevant because they contained bedpan washers requiring internal drainage and consuming moderate amounts of energy<sup>15</sup>. Further, medicine stores or preparation rooms held fridges and freezers for cold storage while reception and office spaces featured moderate amounts of standard office equipment. General medical equipment on wards consisted mainly of infusion pumps, patient monitors (for blood pressure, pulse, oxygen saturation and temperature) and basic equipment for resuscitation kept available on so-called 'resus trolleys'. Much of the medical equipment's electricity use was considered to be outside of clinical staff control because equipment manufacturers advised to keep items plugged in to ensure batteries were charged at all times.

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<sup>15</sup> 1 - 2 kWh/(m<sup>2</sup> · yr) according to the modelling undertaken for this project

**Table 4.4:** Comparison of spatial characteristics of investigated wards

Criteria	NUH (25 beds)	KCH (28 beds)
Bed density [m <sup>2</sup> per bed]	17	21
Daylight	All patient rooms with natural daylight	All patient rooms with natural daylight
Observation	Central nurse station with good access to all patient rooms	One nurse station in central part of corridor, use of mobile clinical workstations in rooms further away
Single bedrooms	4 single bed rooms (16% of total floor area, 13.8 m <sup>2</sup> each on average)	2 single bedrooms (7% of total floor area, 13.7 m <sup>2</sup> each on average), 3 double bedrooms (21%, 28.6 m <sup>2</sup> )
Same sex accommodation	Reasonable gender segregation possible	Separation in rooms, but patients have to pass through areas used by opposite gender
Heating control	Heating controlled centrally	TRVs on radiators, but reported by clinical staff to be dysfunctional
Ventilation	No cross ventilation possible	Cross-ventilation possible for multi-bed bays

Overall, ward local electricity use was expected to be dominated by lighting due to long operating hours and the need to keep corridor areas well lit also during the night. Patient bedrooms generally featured additional dimmer night lights to allow patients to sleep while still being observable to staff. In the investigated wards, main ceiling and night lights were mostly under the influence of clinical staff, with the exception of some toilets and shower rooms at NUH which had PIR sensors installed. Further, each bed had a patient lamp installed providing patients with some control over their immediate lighting levels. According to interviews and observations, the patients' use of these bed lamps varied hugely, but was overall expected to contribute little to total lighting use.

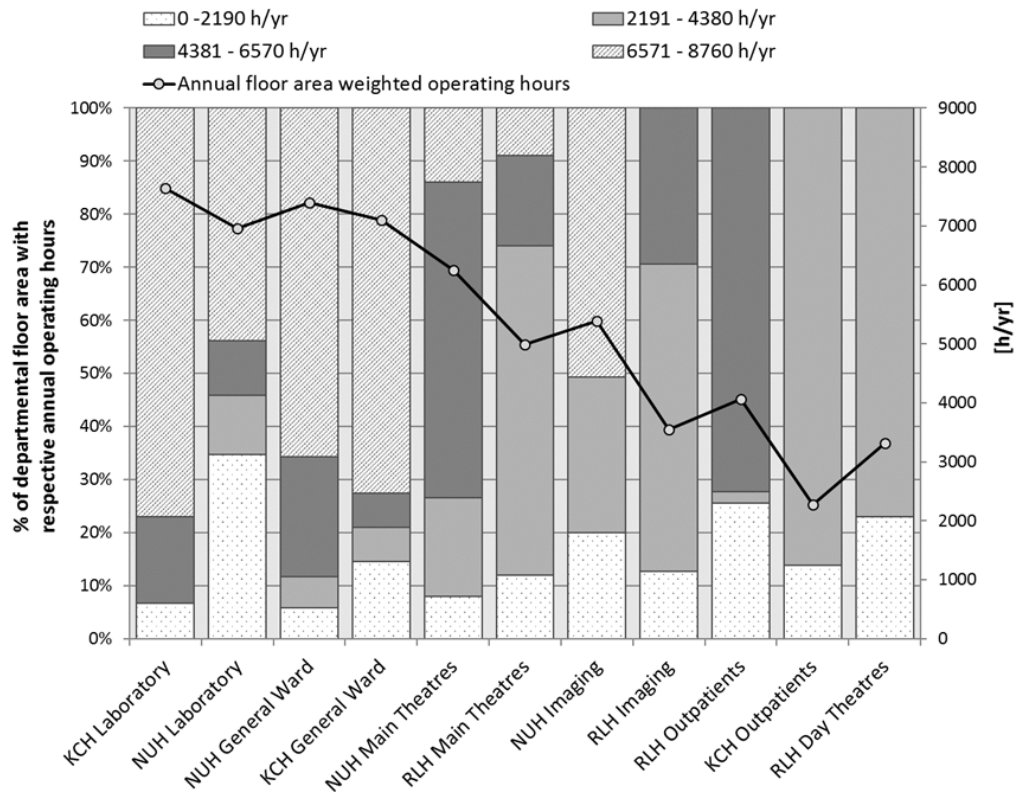
## 4.7 Summary of logistical and spatial arrangements

The above sections described in detail the different logistical and spatial arrangements of 11 hospital departments of five different types. Electricity requirements were linked clearly to the respective processes and provided services. It further became apparent during the fieldwork that defining departments and their boundaries could be complicated due to the interaction of three overlapping spheres which may or may not be aligned:

- **The functional sphere:** Primarily, departments were organisational units dividing the larger hospital into parts with specific responsibilities. They were defined by the structures of each NHS trust, but remained essentially virtual units open to re-organisation as seen for example at NUH after the hospital became part of the Barts Health NHS Trust.
- **The physical sphere:** Departments were also defined by their physical boundaries, i.e. the spaces they occupied. Such boundaries were found to be more pronounced in nucleus (NUH) and nightingale (KCH) designs where individual departments tended to occupy entire wings of the building, while the deep plan design of the RLH resulted in several departments overlapping in each building part. The electricity use and how well it could be measured also related to the physical sphere in so far that distribution boards did not always align with the organisational definition of departments, in particular at the RLH.
- **The social sphere:** Finally, the reality of hospitals as a workplace for clinical staff proved to not necessarily be bound to departments, neither as organisational nor as spatial units. While staff for example on wards tended to be quite firmly associated with their domain, those trained in certain imaging modalities or surgical specialities might work in different departments across the hospital or even across different hospitals depending on the rota.

To overcome the challenge of a fuzzy definition of departments, further analysis was guided by spatial arrangements focusing on core as opposed to support spaces while issues resulting in particular from the third of the above points ('the social sphere') are discussed in more detail in chapter 6.

As for core activity spaces, large variations were found between different department types. Within each department type, however, there was reasonable agreement across different hospitals since hospital spaces are coherently designed to be supportive of the logistics of health care processes. This suggested that, despite potential delimitation difficulties, departments rather than whole buildings posed a sensible unit for the analysis of hospitals (and potentially other heterogeneous and complex building types). Such choice of unit of analysis allowed for obtaining scalable but meaningful results and the identification of transferable factors for building operation and energy conservation.



**Figure 4.13:** Overview of use of space in all investigated departments<sup>16</sup>

Notable in most investigated departments, in particular those operating 24/7, was the heterogeneous use of space (Figure 4.13). All continuously operating department types such as theatres, laboratories and emergency imaging also contained spaces with more standard hours (e.g. between 9am and 5pm on weekdays only) resulting in floor area weighted opening hours well below 8760 h/yr (see also Table 4.1). This suggested that even those department types might include spaces and equipment items with some switch-off potential, as further discussed in the next chapter 5.

<sup>16</sup> This diagram type will be used extensively in the following chapter(s) to represent findings of the case study investigation. In all of them, two information items are presented for each case study department (x-axis), on the primary and secondary y-axes respectively depending on the leading narrative:

- **Stacked columns:** The contribution of different categories towards a total of 100% is presented for each department. In this figure (4.13), the primary axis shows how spaces with different annual operating hours build up the total floor space of each department.
- **Absolute value:** Here (Figure 4.13), the secondary y-axis shows the mean value for the entire department, allowing a comparison between departments on the whole.





# 5 Influence of clinical staff on hospital electricity use

This first findings chapter addresses the research objective *i*. It investigates the theoretical extent of clinical staff influence on departmental electricity use and estimates the theoretical maximum savings potential from simple changes in clinical operation for each department, identifying transferable drivers. The findings result primarily from quantitative analysis: As laid out in section 3.4.2, the understanding of local electricity use for each department was built from the top-down analysis of measured electricity use as well as a bottom-up end-use model based on a detailed audit of lighting and appliances use. For central energy requirements, it is drawn on literature and qualitative data as few quantitative data were collected as part of this study.

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## 5.1 Drivers of centralised and local electricity requirements

The electricity use associated with the provision of energy services to a hospital department occurs at two levels (see Table 5.1 for a general overview): through centralised plant for space conditioning, air handling and pumps; and through local distribution boards feeding lighting and power circuits (as well as fan coil units if applicable).

**Table 5.1:** Locally versus centrally provided main building services

**Typical systems:** Heat generation typically through gas boilers or combined heat and power plants (CHP).  
Cold generation typically through chillers.  
Fan coil units (FCUs) are simple devices consisting of a heating or cooling coil (connected to central generation) and a fan. In contrast, air handling units (AHUs) condition air centrally and discharge it through the entire building, normally through duct work.

**Typical fuel:** E - Electricity, G - Gas

User need	Building service	Systems	Fuel	Centrally	Locally
Winter thermal comfort	Space heating	Heat generation	G	O	
		Central Heating Pumps	E	O	
		FCUs or Fan heaters	E		O
Indoor air quality	Ventilation	AHUs <sup>1</sup>	E	O	
		Windows	-		O
Hot water	Domestic hot water	Heat generation	G	O	
		Hot water pumps	E	O	
Summer thermal comfort	Air conditioning <sup>2</sup>	Cold generation	E	O	
		Cold water pumps	E	O	
		FCUs, also desk fans	E		O
Circulation	Lifts		E	O	
Illumination	Lighting		E		O
Process	Medical equipment		E		O
	Servers		E	O	
	Office equipment		E		O
	Catering <sup>3</sup>		E		O

<sup>1</sup> In buildings where space heating and cooling are through air systems, the AHU blowers also contribute to providing thermally comfortable conditions.

<sup>2</sup> Centralised air conditioning systems serve multiple spaces from one location and typically use chilled water as a cooling medium and extensive ductwork for air distribution. In contrast, decentralized air conditioning systems typically serve single or small spaces from within or directly adjacent to the space. They include through-the-wall and window air conditioners or split systems and the cooled air exchanges heat directly with the refrigerant (direct expansion).

<sup>3</sup> Catering is a broad and hard to define category (see also Appendix A.2). It can include centralised or decentralised facilities fuelled by both gas or electricity. In this study, it is focused on locally used catering equipment powered by electricity such as microwaves or regeneration kitchens on wards.

As discussed in section 1.1, space heating, usually by fossil fuel, is the largest component of energy usage in hospitals. It is however very dependent on the building envelope and the system efficiency, which is largely dictated by hospital age plus any retrofit improvements. Electricity use for ventilation and cooling will very much depend on system design and space usage - in particular whether mechanical ventilation and air conditioning is used, which in turn relates partially to built form (narrow or deep plan). The need for vertical transportation is also primarily defined by the building design. The influence of clinical staff on central heat and electricity requirements is therefore expected to be somehow limited, while facilities management as well as strategic retrofit improvements seem crucial in achieving reductions in the energy used for centrally supplied building services.

In contrast, electrical energy use for lighting is thought to be much more independent of building design and system age. Window design will be important in areas with daylight and replacement cycles influence installed lighting technologies. But lighting requirements are additionally also influenced by lighting controls as well as their utilisation and other operational practices. Small power use may be largely independent of building age and form and therefore more consistent across hospitals, depending instead on department type, operational hours and intensity of use, such as bed density on wards.

The influence of clinical staff on local electricity requirements was therefore expected to be somehow more pronounced, and local rather than central electricity requirements were consequently the focus of this study. The following sections nevertheless provide a discussion of both categories for the investigated case study hospitals to provide some understanding of the complete picture, but the analysis of central requirements and clinical staff influence on them is kept brief. It will draw mainly on literature and qualitative data as few quantitative data on central energy requirements were collected as part of this study.

## 5.2 Clinical staff influence on central electricity requirements

**Space heating and domestic hot water** In all investigated case hospitals (section 3.3.2), space heating and domestic hot water was provided by gas fired boilers only (RLH, NUH) or in combination with a combined heat and power plant (KCH). This study focused on electricity use as large cost to NHS trusts. Although significant in terms of carbon emissions (see also Table 3.2), space heating therefore remained largely outside of the scope of this study.

**Air conditioning** In contrast, air conditioning was (at least partly) provided by central electric chillers in all case hospitals. At KCH, practical challenges during the retrofit of the oldest among the three case study hospitals had also resulted in the use of split units<sup>1</sup> for cooling in some spaces. According to statements by the facilities managers, the chillers constituted large - if not the largest - single loads in the investigated hospitals. Clinical staff control over central air conditioning was absent or severely restricted<sup>2</sup> in most investigated departments, with the exception of operating theatres. For air conditioning, as well as for heating, temperature set-points tended to be defined centrally by the building operators through the building management system. These findings were in line with reports from consultants and health engineers for other hospitals, suggesting limited occupant temperature control to be a characteristic feature of this building type.

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<sup>1</sup> See glossary.

<sup>2</sup> In the NUH laboratory, a room thermostat had initially been provided to control the air conditioning in the main lab. Following disputes over operation and temperature settings resulting in system problems, the thermostat was enclosed in a sealed plastic box by the estates department so that staff could no longer interact with it directly. Temperatures were now set centrally as common for the majority of other departments to begin with.

In theatres<sup>3</sup>, space conditioning requirements are known to be particularly strict (EnCO2de, 2006). The Carbon Trust recommends operating theatre temperatures between 17 and 19 °C while other hospital spaces may range between 19 and 24 °C (Carbon Trust, 2011). No temperatures could be measured in this study due to concerns about introducing data logging equipment in health critical environments. The qualitative data however also illustrated the narrow band of acceptable temperatures: when too cold, patients risked hypothermia and supplementary warming equipment had to be used extensively; when too warm, the concentration of the surgical team might be affected or, more dramatically, sweating could become problematic over open cases. According to theatre staff at RLH, theatre temperatures between 18 to 21 °C were considered acceptable and it was stressed that higher temperatures also increased infection risks. During the interviews, staff consistently reported frequent interactions with the theatre panel in order to adjust temperatures, while the effectiveness was sometimes questioned:

There is a control in the wall, but I don't think it works properly to make the temperature go down. (F)

Theatre staff at both RLH and NUH frequently called the estates team with heating or cooling (control) issues. In comparison, they did appear more content with the speed of response than staff in other departments, potentially indicating a prioritization process within the facilities team. In all other department types, the estates team was also the first port of call to adjust temperature set-points - either directly or through calling the helpdesk. Influence on energy requirements from space conditioning therefore lay with technical, but only very indirectly with clinical staff as the following discussion of the related issue of ventilation affirms.

**Ventilation** All investigated departments contained a number of mechanically ventilated spaces, while the RLH was fully mechanically ventilated. Windows could not be opened there at all - a situation two out of the eight RLH interviewees stated to dislike. At NUH and KCH, mechanical ventilation was concentrated in core rooms and those with specialist ventilation requirements (e.g. laboratory or treatment rooms using solvents or hazardous materials, sanitary facilities, etc.). Windows in peripheral rooms could mostly be opened subject to safety restrictions in patient-accessible areas (see Health Technical Memorandum 55 - 'Windows').

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<sup>3</sup> It may be noted that this was the case only for the actual theatres but not for the rest of the departments.

This study found clinical staff to have no influence on energy requirements for mechanical ventilation in the investigated hospitals generally. Air handling units (AHUs) were controlled by the building management systems (BMS) operated by the hospital's estates department. Technical staff reported that the AHUs were set to run continuously in 24 hour areas or on time schedules otherwise. In areas with windows, some influence of clinical staff on energy requirements for heating or cooling influence could be suspected. Reduced window opening while heating or cooling systems are in operation has previously been pointed out in employee awareness campaigns (see also Table 2.1 in section 2.1) while indoor air quality and smell issues need to be considered.

In contrast to other department types, a share of ventilation electricity use may be under end-user control in theatres<sup>4</sup>: all of the visited full and some of the day theatres visited featured *ultra-clean ventilation (UCV) canopies* above the operating zone inclosing patient, equipment and immediate surgery team. Ultra-clean ventilation canopies discharge large volumes of clean air filtered through a high-efficiency particulate air (HEPA) filter at vertical air velocities of  $0.3 \text{ m s}^{-1}$  to reduce airborne bacteria in the operating zone and reduce post-operative sepsis following certain orthopaedic procedures. At NUH, UCV canopy operation was controlled through a manual switch in the theatre panel while at the RLH, PIR sensors supposedly switched airflow and canopy lights from operational (100%) into stand-by mode (50%) 15 to 20 minutes after the last activity was detected in theatres.

Energy requirements for ultra-clean ventilation are twofold: increased loads on central air handling units and local electricity requirements for fans. While the electricity use for UCV fans could be measured locally (NUH) or estimated based on manufacturer specifications (RLH), the increased load on air handling units from ultra-clean ventilation is difficult to determine without full dynamic simulation. To get at least some understanding of theatre ventilation requirements, the electricity consumptions of the air handling units serving parts of the NUH theatre department (two theatre suites) as well as some utility spaces in the theatre department and an adjacent ward were measured as part of this study.

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<sup>4</sup> Theatres further feature specialist extract ventilation from theatre suites and anaesthetic rooms through anaesthetic gas scavenging systems (AGS). In all investigated theatres, the scavenging pumps were controllable locally through on-off switches in the theatre panels (section 4.4.2).

The AHUs were found to be operating continuously irrespective of demand. Assuming ventilation requirements were equal across theatre and ward spaces, AHU electricity use amounted to 146 kWh/(m<sup>2</sup> · yr) as opposed to 397 kWh/(m<sup>2</sup> · yr) for all local power and lighting. This number underestimates the energy required for the ventilation of theatres as air change rates there are with 25 AC/h much higher than on wards (5 AC/h, Department of Health, 2013a). Beier (2009) have previously measured much higher electricity usage for theatre ventilation (364 kWh/(m<sup>2</sup> · yr) on average), with extremes of up to 1275 kWh/(m<sup>2</sup> · yr) for continuously operating AHUs. One promising strategy for reducing ventilation energy use in hospitals hence consists in implementing demand driven operation of AHUs through good-practice facilities management (CIBSE, 2015), similarly as suggested for other non-domestic building types (e.g. Gul and Patidar, 2015).

Other hospital departments potentially featuring user-controlled specialist ventilation were laboratories and imaging departments. Keeping fume cupboards in laboratories closed is frequently discussed in the literature as one example of end-user influence on building electricity use (Dodd and Padley, 1992; Hart et al., 2011; Jensen and Petersen, 2011). However, none of the investigated laboratory spaces had fume cupboards which are more common in chemical and microbiological laboratories. Further, local exhaust ventilation was traditionally required to remove hazardous vapours from X-ray film processing units but has become obsolete in the age of digital imaging (DoH, HTM 03-01).

### **5.3 Clinical staff influence on local electricity requirements**

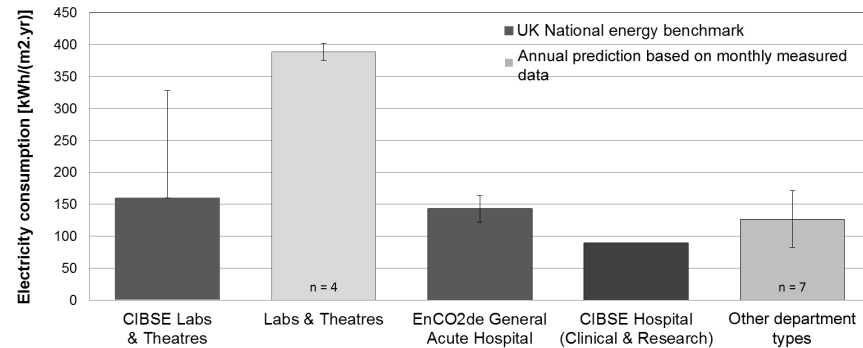
Establishing the extent of local electricity use in different hospital buildings and departments was one of the objectives of this study. As laid out in section 3.4.2, the understanding of local electricity use was built from the top-down analysis of measured departmental electricity usage in combination with a bottom-up end-use model based on a detailed audit of lighting and appliances use.

#### **5.3.1 Top-down analysis of departmental electricity use**

Some initial characteristics of departmental electricity consumption (Table 5.2) could be derived from the top-down analysis of the departmental electricity use profiles (see chapter 4 for selected plots). This sections restricts itself to summarizing a number of key points:

Department Type	Laboratory			Theatre			Day Theatre		Imaging		Ward			Day Unit		
	Hospital	KCH	NUH	Mean	RLH	NUH	Mean	RLH	NUH	RLH	Mean	KCH	NUH	Mean	RLH	KCH
Annual electricity use [kWh/(m <sup>2</sup> · yr)]	373	403	388	382	397	389	127	115	61	88	169	68	119	119	151	135
Average daily consumption on active days [kWh/(m <sup>2</sup> · d)]	1.05	1.13	1.09	1.06	1.07	1.07	0.35	0.32	0.17	0.25	0.47	0.19	0.33	0.37	0.45	0.41
Average daily consumption on closed days [kWh/(m <sup>2</sup> · d)]	0.94	1.05	0.99	1.02	1.16	1.09	0.33	0.27	0.16	0.21	0.45	0.18	0.32	0.22	0.22	0.22
Active/ Closed day factor	1.1	1.1	1.1	1.0	0.9	1.0	1.1	1.2	1.1	1.1	1.1	1.0	1.0	1.6	2.0	1.8
Base load [W m <sup>-2</sup> ]	29.7	40.7	35.2	37.8	32.3	35.0	10.4	8.3	5.3	6.8	11.7	3.6	7.6	4.4	9.4	6.9
Peak load [W m <sup>-2</sup> ]	59.5	53.5	56.5	48.3	68.9	58.6	18.8	20.0	9.3	14.7	29.8	14.5	22.2	25.0	26.5	25.8

**Table 5.2:** Measured power characteristics for all case departments (see section 3.5.1.1 for details on the analysis)



**Figure 5.1:** Measured departmental electricity consumptions in relation to established benchmarks (see section 3.5.1.1 for details on the analysis)



- Measured electricity consumption varied widely across different hospital departments (see also Figure 5.2), whereby intensive departments such as theatres and laboratory departments used on average roughly three times more electricity than wards, outpatient departments and imaging departments (excluding imaging equipment). In this the former group vastly exceeded the CIBSE TM 46 (2008) electricity benchmark<sup>5</sup>, while the latter was better aligned with general hospital electricity benchmarks (Figure 5.1).
- Theatres and laboratories were further characterised by rather continuous operation and high base loads. For some major equipment items, it remained unclear to users whether they could be switched off due to concerns about calibration needs and availability in case of emergency. Often, they therefore remained on continuously (see also section 6.1.1). Jensen and Petersen (2011) have made similar observations in a Danish hospital laboratory: while the research team concluded that many base load items could likely be switched off at night, lab staff were often uncertain about recalibration times and whether the equipment was affected by frequent on/off operations. For the theatres and laboratories in this study, some energy savings may hence result from similar clarifications.
- In departments with defined after hours (Outpatient departments, RLH Imaging, RLH Day theatres) differences between in use and not in use periods were more pronounced. Electricity saving potentials could be suspected out of hours at the RLH were closed day factors and average daily consumptions on closed days were measured only little below those of active days. It was further noted that night time loads tended to exceed base loads in particular on weekends suggesting differences in actors and routines contributed to poor energy efficiency. This observation will be followed up further in section 6.1.

A more detailed discussion of the measured electricity usage of the case study departments (amid a number of other departments monitored by collaboration partners) can be found in the paper Morgenstern et al. (2016a).

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<sup>5</sup> Please note that the measured values excluded electricity use by centralised plant while the benchmarks include all electricity use. Difference for operating theatres and laboratories were therefore even more pronounced suggesting benchmarking values for hospitals as well as benchmarking methodologies for complex non-domestic buildings might benefit from a revision.

**Table 5.3:** Definition of variables for model validity criteria

Variable	Definition
Base load (modelled)	Base loads were modelled as stand-by loads plus active loads with annual operating hours exceeding 6570 h/yr.
Base load (measured)	In measured data, base loads were defined as the mean of the minimum power readings recorded in each 24 hour period.
Total installed load (modelled)	Sum of average power consumption of all recorded installed loads
Peak load (Measured)	Mean of the maximum power readings recorded in each 24 hour period
Load diversity	Total modelled installed load over measured peak load

### 5.3.2 Validity of bottom-up representations of departmental electricity use

To further disaggregate the measured electricity use and understand the contribution of individual end-uses, representations of departmental electricity use were created based on detailed audits of lighting and appliance use as outlined in section 3.4.2.2. A number of criteria were defined to establish the validity of these electricity use model representations (see Table 5.3 for definitions):

1. Modelled **annual electricity intensities per floor area** were required to compare to measured values within the range of 20 to 30% as specified by Mortimer according to Liddiard (2012, p.44).
2. Modelled and measured **baseloads** were expected to compare within a similar range.
3. The interpretation of **load diversities** needed to be plausible with respect to the developed understanding of departmental processes: They were expected to be higher for departments with varied processes using much different equipment (in particular theatres) or equipment with a varied power output (haemodialysis) while departments with consistent equipment use such as laboratories or imaging departments (X-ray power use excluded) were expected to have diversity factors tending towards one.

In addition, lighting intensities were modelled based on the established lighting installations and compared to lux level measurements in some departments (see also section 6.4.2 for results and Table 3.4 for data collection per department). Detailed model results were further interpreted in comparison to departments of the same type and in the context of available literature (see chapter 4 on the analysis context). Table 5.4 provides an overview of the above listed characteristics for each department as well as a list of major uncertainties, which may be from either models or measurements.

Generally, the models complied well with the measured data according to the criteria listed above - with the exception of the KCH ward where some important base load components appeared to remain unaccounted for in the model (highlighted in grey in Table 5.4). This suggested that some savings potential from reducing base loads may be overlooked for this department while operating hours for other equipment are likely overestimated given the reasonable match of the annual energy use.

The load diversity of the KCH ward, at 1.4, also seemed rather low, providing further evidence that the model representation of this department should be used with caution only. A limited understanding of heating and cooling energy use by the installed split system was suspected to be the main reason for the modelling uncertainty. The load diversity of the NUH laboratory was also above expectations (1.7). This issue may however be explained by the fact that the laboratory model covered the whole of the pathology department showing a much higher diversity of use than the investigated area at KCH (see also Figure 4.13).

On the whole, the electricity models seemed to provide reasonable representations of departmental electricity usage. In combination with a robust methodology and some contextual understanding, some confidence could hence be had in end-use splits and saving potential estimates from operational changes on the basis of these models. The next section will present a comparative analysis of electricity end-uses in different department types.

**Table 5.4:** Validity of bottom-up representations of departmental electricity use

It is considered acceptable if the ratio of modelled over measured energy intensities and base loads falls in the range of  $100 \pm 20 - 30\%$  (following Liddiard, 2012, p.44) and interpretations of load diversity are plausible. Divergent cases are marked in grey. Major uncertainties are mostly from modelling (normal font), those related to measurement challenges are highlighted in italics.

Department	Modelled over measured		Load diversity	Key uncertainties (based on audit uncertainty codes)
	Annually [kWh/(m <sup>2</sup> · yr)]	Base load [W/m <sup>2</sup> ]		
NUH Imaging	101%	106%	1.9	<ul style="list-style-type: none"> <li>• <i>Uncertainties around which areas &amp; services were included in the measured data</i><sup>1</sup></li> <li>• Duration of use and power consumption of split units</li> <li>• Actual power consumption of analogue imaging processors</li> </ul>
RLH Imaging	118%	71%	2.4	<ul style="list-style-type: none"> <li>• Duration of use of reporting rooms which are shared with other departments</li> </ul>
KCH Laboratory	99%	110%	1.0	<ul style="list-style-type: none"> <li>• Power consumption of track system</li> <li>• (Stand-by) Consumption of automated analysers</li> <li>• Duration of use and power consumption of split units</li> </ul>
NUH Laboratory	88%	81%	1.7	<ul style="list-style-type: none"> <li>• Power consumption of cold room</li> <li>• (Stand-by) Consumption of automated analysers</li> <li>• Duration of use of IT equipment in specimen reception</li> </ul>
RLH Main Theatres	103%	92%	1.7	<ul style="list-style-type: none"> <li>• Actual operating hours at each theatre</li> <li>• Durations of use for medical equipment items generally</li> <li>• Actual loads from intensive medical equipment and those items hard to identify</li> </ul>
NUH Main Theatres	103%	96%	1.4	<ul style="list-style-type: none"> <li>• Actual loads of theatre panels and hard to identify medical equipment</li> </ul>

Table 5.4: (continued)

Department	Modelled over measured		Load diversity	Biggest uncertainties (based on codes & sensitivity analysis)
	Annually [kWh/(m <sup>2</sup> · yr)]	Base load [W/m <sup>2</sup> ]		
RLH Day Theatres	122%	84%	1.5	<ul style="list-style-type: none"> <li>• Actual loads from intensive medical equipment and those items hard to identify</li> <li>• Durations of use for medical equipment items generally</li> </ul>
RLH Outpatients	117%	72%	1.3	<ul style="list-style-type: none"> <li>• <i>Issues with metering suspected but could not be clarified despite collaboration with facilities management</i></li> </ul>
KCH Outpatients	99%	75%	1.9	<ul style="list-style-type: none"> <li>• Duration of use and power consumption of split units</li> </ul>
KCH General Ward	98%	61%	1.4	<ul style="list-style-type: none"> <li>• Duration of use and power consumption of split units</li> <li>• Operating hours for lighting in rooms where day light is available</li> <li>• Major unaccounted base load contribution and exaggerated installed load</li> </ul>
NUH General Ward	110%	94%	2.0	<ul style="list-style-type: none"> <li>• Operating hours for lighting in rooms where day light is available</li> <li>• Bedpan washer power consumption and duration of use</li> </ul>

<sup>1</sup> The whole of the NUH Radiology department (1320 m<sup>2</sup>, also including MRI, CT and nuclear medicine) was covered by 6 sub-meters, out of which one supposedly covered the X-ray area. The department had, however, been refurbished repeatedly over the last decades resulting in changes to circuit and distribution board layouts. According to the responsible electrician, some loads within the X-ray area now ran through other distribution boards while the X-ray board included lighting loads in other areas. The exact determination of which circuits were served by which board resulted impossible due to a lack of documentation and the continuous operation of the department preventing experimental determinations of attributions through powering down boards sequentially out of hours. The measured figures and profiles at NUH Imaging hence need to be understood as indicative only.

### 5.3.3 Local electricity use in different department types

Both annual electrical consumptions and the significance of different end-uses varied widely across different hospital department types (Figure 5.2). Energy intensive department types i.e. operating theatre departments and laboratories used most of their electricity for ultraclean ventilation (UCV) and medical equipment or automated analysers (also coded as medical equipment). Lower intensity department types were dominated by lighting energy consumption. The RLH haemodialysis department was an exception here due to the extensive use of the dialysis machines.

Notable was also the more pronounced electricity use for local heating and cooling at KCH as a result of split unit provision, prompting questions around the overall efficiencies of air conditioning provided through different technologies. Such questions remained largely outside the scope of this study. KCH technical personnel, however, pointed out that the central chillers could feed more spaces than they were currently being used for. This suggested challenges for the consistent implementation of energy efficient infrastructure strategies in budget constrained and fast changing environments such as hospitals.

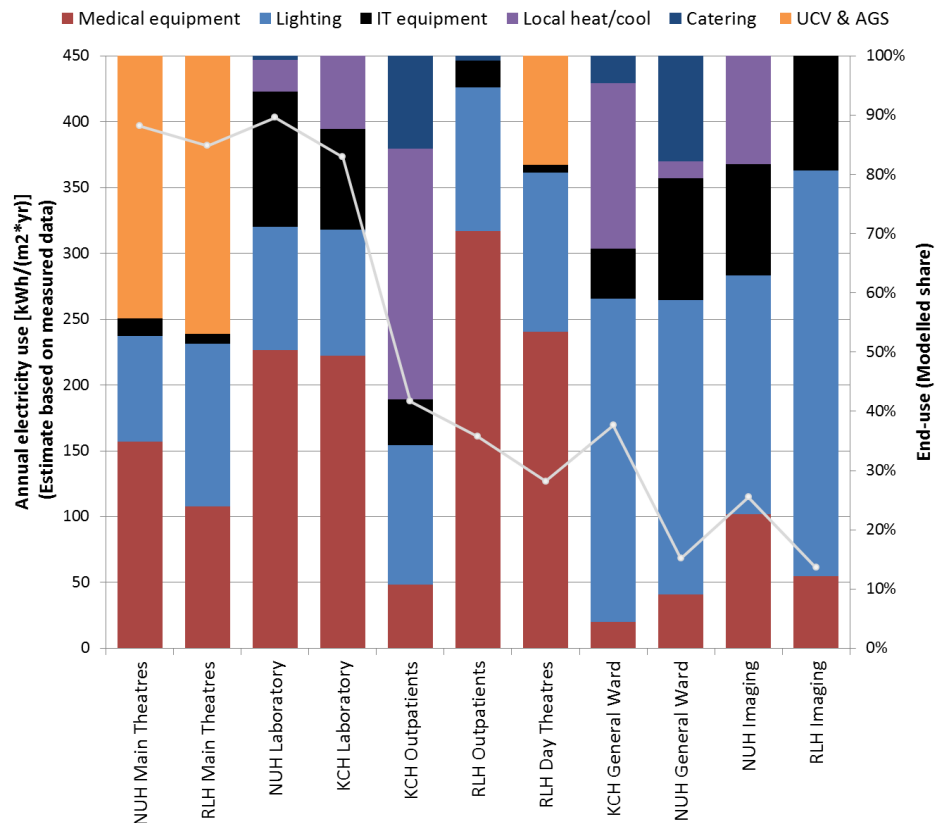
Overall, the findings were in fair agreement with the limited available evidence on end-uses for hospitals as a whole. Figure 1.2 showed that lighting loads were dominant over equipment loads in entire hospitals. This suggested that non-energy intensive department types played a major role within the make-up of a building's total energy performance, an interpretation that was substantiated by the fact that wards accounted for a significant proportion of space in general acute hospitals (Department of Health, 2013).

### 5.3.4 Means of clinical staff control over local electricity use

It was hypothesised in this study that control interfaces for building services as well as nature and type of departmental appliances were one factor<sup>6</sup> influencing the extent of clinical staff's influence on electricity use (section 3.1). This section will undertake an analysis of these control aspects, investigating in particular whether building services and appliances could theoretically be switched off by clinical staff. As laid out in section 2.2.2.1, the theoretical viability of switch-off is understood to be determined only by material configurations, ignoring all constraints effective in real-world situations. These constraints are in detail discussed in chapter 6.

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<sup>6</sup> The other one was departmental operating hours, i.e. the amount of time building and equipment were not in use. Findings for the latter are summarized in section 4.7.



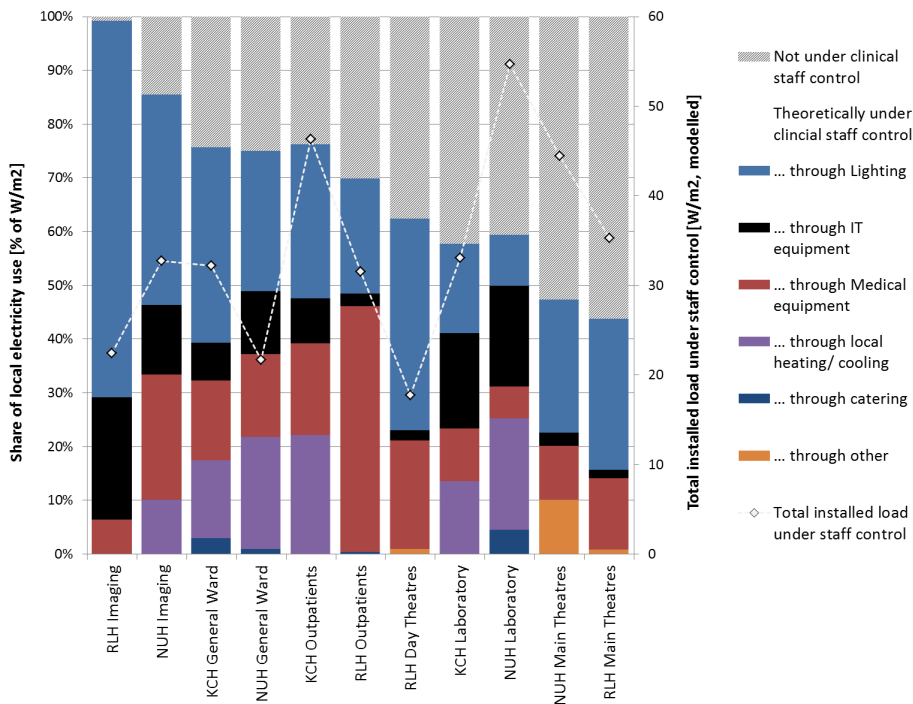
**Figure 5.2:** Overview of local departmental electricity consumption for all investigated departments

**Absolute values** (Left axis): Annual prediction for energy intensity extrapolated based on measured data (White line)

**Stacked column** (Right axis): Relevance of respective end-uses for each type (Absolute use represents 100% for each department.)  
UCV - Ultra-clean ventilation; AGS - Anaesthetic gas scavenging (see section 4.4.2)

See also Figure 4.13 for a description of the diagram type.

To allow for the comparison of the concept of control means across departments with different operating hours, an analysis was undertaken in the power dimension focusing on staff control over installed loads. All items within the bottom-up models were coded by the author according to the extent their electricity consumption was under clinical staff control following the equipment typology introduced in section 3.4.2.2. This included a differentiation according to whether equipment had to remain in stand-by or could be switched off completely (see also Figure 3.2). A list of equipment items encountered during the audits for this project can be found in Table D.1 in the appendix. For lighting, manual switches were understood as means of clinical staff control, while PIR sensors or lights under the control of patients were not.



**Figure 5.3:** Comparison of installed load (modelled) under clinical staff control  
**Stacked column (Left axis):** Breakdown of staff control according to end-use  
 Other - Ultra-Clean Ventilation (UCV) and Anaesthetic Gas Scavenging (AGS)  
**Absolute values (Right axis):** Total installed load under staff control (White line)  
 See also Figure 4.13 for a description of the diagram type.

As laid out in section 3.4.2.2, there could be considerable challenges to understanding the switch-off conditions for some hospital-specific equipment items. This was partly due to the background of the researcher in buildings rather than health care and partly due to uncertainty among clinical informants on this issue (see also section 6.2.2). It is acknowledged that such uncertainty was a major limitation of this research study, implications of which are discussed in the sections 3.6 and 8.2.3. In a conservative approach, items for which there were doubts as to whether they could be switched off, were coded as ‘not under clinical staff control’. Combining departmental bottom-up electricity model with these codes allowed for the share of the total installed load under clinical staff control to be identified (Figure 5.3).



Generally, energy intensive department types such as theatres and laboratories exhibited lower relative shares of clinical staff control over electricity use than other department types. Absolute loads under staff control may however be higher due to the higher energy intensities of these departments. In the laboratories, the low relative shares of clinical staff control were largely due to high cooling loads and automated analysers supposedly needing to remain in stand-by due to calibration issues. In the theatres, high loads were from equipment which manufacturers recommended to maintain in stand-by. At the RLH, the electricity intensive UCV canopies were automated through PIR sensors, further reducing clinical staff control. Among the less electricity intensive department types, imaging departments exhibited the greatest relative extent of clinical staff control. In day clinics and wards where staff consistently controlled around three quarters of the installed loads, patients featured as important actors accountable for some electricity use in particular from patient lamps and entertainment equipment.

The above analysis tentatively suggested that the largest theoretical extent of clinical staff control over installed loads in hospitals was found in low energy intensive departments with limited residence of the patient population. Apart from diagnosis-focused departments such as imaging, this will likely also apply to outpatient departments focused on consultations. At the same time, absolute loads and therefore also absolute loads under staff control may be comparatively small in these departments, reducing the ultimate scope for savings.

It was also observed that control shares were higher in departments where the energy-intensity of an end-use coincided with the available means of control. Figure 5.2 had shown the importance of lighting loads in most non-energy intensive department types. At the same time, much clinical influence was found to be through manual light switches (with the exception of haemodialysis and laboratories). A similar concurrence can be observed at the KCH day unit, where the installed split-units for air conditioning contributed significantly to the department's energy use. They were fully controllable through clinical staff boosting the extent of clinical staff influence on installed loads.

This finding suggested that addressing lighting use might be a crucial component of potential staff-centred energy conservation initiatives, also in hospitals. Bordass et al. (2007) however highlight that the presence of light switches alone will not result in energy efficiency; control design and usability are vitally important. In the light of the practical constraints in hospitals (chapter 6), automated lighting controls based on PIR sensors and/or timers may further represent an avenue worth exploring.

## 5.4 Theoretical electricity savings potentials of simple changes in clinical operation

This research further aimed at conceptualising potential operational changes in the way hospital departments are being used by occupants (principally clinical staff) and establishing the theoretical maximum electricity savings potential from simple operational changes for different departments types. Details on proposed simple changes for each case study department are shown in the appendix (Table E.1).

Conceptually, the proposed simple changes included both suggestions for more energy efficient standard procedures and the promotion of simple energy behaviours, i.e. an increased compliance of staff with existing procedures. Within the conceptual framework set out earlier (Figure 2.4), they corresponded to the levels I and II. More complex changes to service and service delivery, level III of the framework, were excluded in the quantitative analyse due to practical challenges for estimating their more complex impacts in energy terms.

In the investigated departments, simple changes in clinical operation included elements such as improved light switching or reducing equipment stand-by but also the introduction of quiet time on wards, a period in which lights and equipment are powered down after lunch to allow patients to rest better. Importantly, this may also include matching the operational state of spaces and equipment to staff availability and patient numbers, by for example switching off all but one X-ray room if only one radiographer was present during nights at NUH Radiology or switching off one of the three RLH X-ray rooms at 4pm rather than 5pm to match declining patient throughput. Most proposal for change were in line with low energy workplace behaviours suggested in the literature for other building types (see Table 2.1). Hospital specific energy behaviours were limited to operating theatres as very specialist areas, requiring the (manual) switch-off of specialist ventilation systems and anaesthetic gas scavenging pumps.

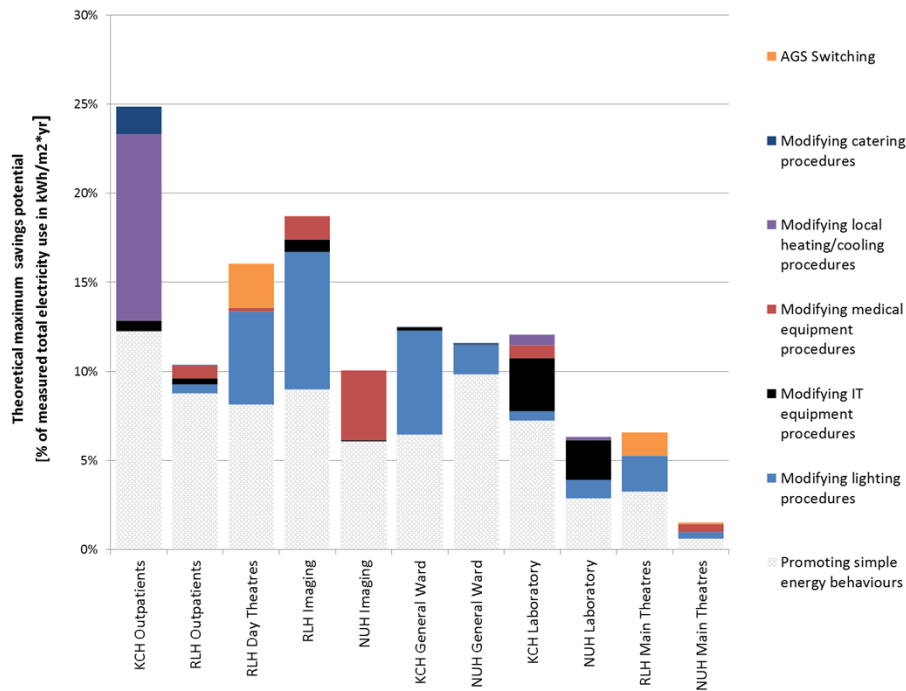
As laid out in section 2.2.2.1, there is no consensus in the literature on what is to be understood as theoretical potential in the context of energy conservation interventions involving humans. For the purpose of this thesis, the theoretical savings potential was equated with the difference between current local electricity use and the optimal efficient operation of the respective hospital department, based on an assessment as detailed in section 3.5.1.3.

The theoretical electricity savings potentials of simple changes in clinical operation across the 11 investigated hospital departments ranged between 2 and 25% of local electricity use (Figure 5.4), with a median value of 12%<sup>7</sup>. Importantly, these values represent a theoretical savings potential and could therefore not be directly compared to literature values for achieved savings from behaviour change campaigns as presented in section 2.2.1.2. The median did, however, exceed most reports of actual savings in line with expectations based in the nature of the different metrics (see Table 2.6 for an overview or section 2.2.1.2 for more details on savings reported in the literature).

As for potentials, Kattenstein et al. (2002) and Junnila (2007) reported theoretical savings potentials for university and office buildings based on simulation. At 20%, both estimates were higher than the median estimated in this study, suggesting savings potentials from simple operational changes may on the whole be lower in hospitals than in other building types. Benke (2012) further estimated a savings potential of 10-15% of the total fuel bill based on experiences in hospitals. In comparison with the findings of this study, this suggests that electricity and heating fuel savings might have comparable orders of magnitude.

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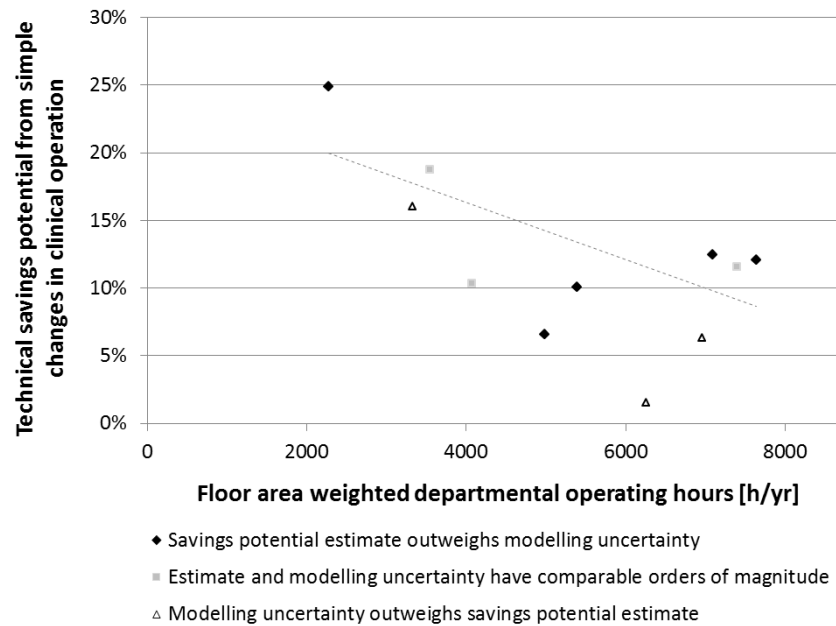
<sup>7</sup> If the potentials were assumed to be a normal distributed sample, which given the non-representative sampling strategy and the small sample size did not apply, then 95% of the population could be expected to achieve theoretical savings potentials between 8% and 15%.



**Figure 5.4:** Definition and theoretical savings potential of changes in departmental operation

On average, 57% of the estimated savings potentials were from promoting simple energy behaviours, with up to 85% in the RLH day unit and on the NUH ward (Figure 5.4)<sup>8</sup>. This finding highlighted that while setting standard procedures affecting energy use well mattered, motivating occupants to comply with them remained crucial. The following chapter 6 will discuss challenges associated with such attempts. In less energy intensive departments, savings were available from changes in lighting use and where applicable, addressing local heating and cooling use appeared to be important.

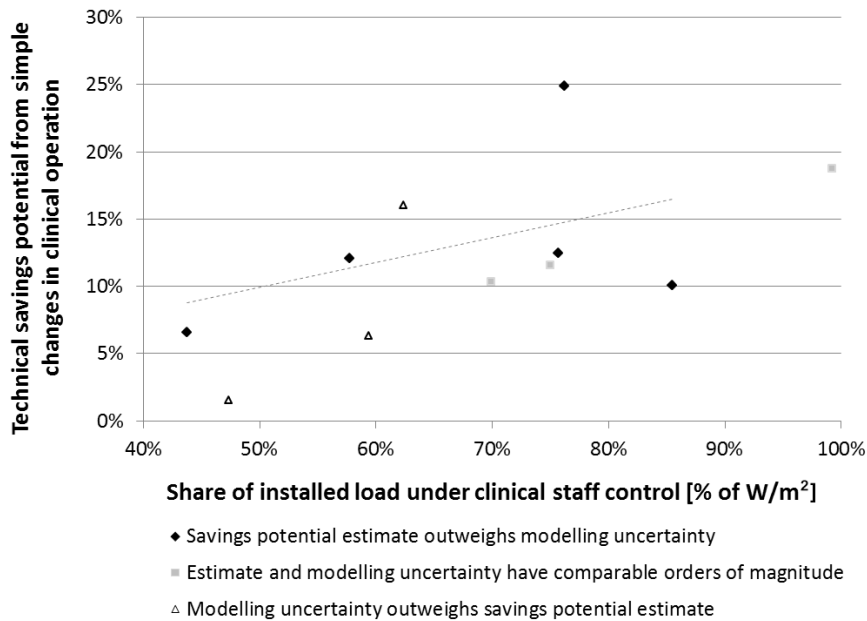
<sup>8</sup> There may be some bias in this analysis due to the differing methodologies applied to estimate the savings potentials from different types of changes. Savings from promoting standard procedures were based on a top down estimate (level I, see 3.5.1.3) while the effects of procedural modifications were estimated based on a bottom-up approach (level II). To mitigate potential differences from these complementary approaches, level II savings were implemented conservatively after a comparison of level I potentials according to both methodologies for three trial departments had shown that the audit based estimates resulted higher than those from top-down analysis.



**Figure 5.5:** Influence of departmental operating hours on theoretical savings potentials

It could further be confirmed that departments with shorter occupation - resulting in more down time - had higher savings potentials (Figure 5.5,  $R^2 = 0.4$ ). Savings could here be achievable through reducing the after-hour use of lighting, equipment and space conditioning systems. This suggested that energy conservation initiatives aimed at operational changes might want to focus on areas with less occupied hours in hospitals, and likely also in other complex building types. From an implementation perspective a further focus on areas where the boundaries between used and un-used periods were clear also appeared beneficial (see also section 6.4.1).

A relation between clinical staff control over installed loads and the theoretical savings potential could also be confirmed, although with less determination (Figure 5.6,  $R^2 = 0.2$ ). This may partly be due to the methodological limitations touched upon earlier: given the expertise of the author in buildings rather than in health care processes, some difficulties were encountered during the audits in identifying unknown specialist equipment and classifying the extent to which items could viably be controlled by clinical staff. This is an important limitation of the deployed study methodology, but nevertheless seemed preferable to not addressing the influence of control aspects on the research question at all in the absence of other available data (see section 3.4.2.2). The general tendency of the relation at least seemed meaningful in providing additional guidance on aspects worth thinking about during the design of end-user focused energy saving initiatives.



**Figure 5.6:** Influence of clinical staff control on theoretical savings potentials

## 5.5 Summary of quantitative findings

This first findings chapter investigated the departmental electricity use of different hospital departments and the extent to which it can theoretically be influenced by clinical staff. Departmental electricity use profiles were found to vary widely between department types: Out of those investigated in this study, theatres and laboratories may in line with previous research be classified as energy intensive departments with high base loads, while other department types showed lower consumption intensities and a higher relevance of lighting loads. The latter category appeared to be in reasonable agreement with current UK energy benchmarks while findings suggested that a revision of electricity benchmarks for energy intensive hospital areas may be worth considering given the increase in technology use over the last decade.

The influence of clinical staff on hospital electricity use was found to likewise vary between departments, but to overall be relatively small. Few hospital specific energy behaviours were identified and pathways of influence were mainly through reducing the after-hour use of lighting, equipment and space conditioning systems (see Appendix E.1 for details). In theory, the median electricity savings from simple changes in the way the eleven case study departments were used by their occupants amounted to 12%. Simple changes in clinical operation are hence likely insufficient to realize substantial carbon savings in hospitals and more complex changes taking into account central energy use as well as the nature of health care service delivery will have to be considered.

At a conceptual level, it could be shown that the theoretical savings potentials from simple operational changes were driven by at least two factors: Firstly, higher potentials were seen for departments with lower operating hours resulting in more down time for space and equipment. And secondly, savings potentials seemed higher for departments where substantial loads, for example from heating or cooling, were under clinical staff control as opposed to being either automated, centrally controlled or determined by equipment parameters. Floor area weighted opening hours and share of installed load under clinical staff control proved to be useful metrics allowing for a building and process independent assessment of organisational energy use. It is believed that such metrics may be helpful to facilities managers across the non-domestic building stock in easily identifying buildings or building parts where conservation initiatives focused on promoting simple energy behaviours or modifying operational standard procedures may be promising in reducing local electricity use.

It should be noted, however, that the concept of a theoretical savings potential is limited as it does not account for organisational, social or individual constraints on clinical operations and staff energy behaviours. So while technical saving potentials can be useful in prioritising and planning for energy conservation campaigns and in energy policy, they may not be confused with actual campaign effect sizes. The next chapter 6 will proceed to discuss some of the named constraints and reach out beyond the theoretical energy savings potential.





# 6 Socio-technical constraints on end-use energy savings

This second findings chapter analyses the semi-structured interviews with clinical staff in the context of information from the literature, the monitoring of environmental variables and further contextual evidence obtained during the site visits for audits and monitoring. In response to research objective *ii*, the findings aim to determine how the theoretical electricity saving potentials (chapter 5) in particular and attempts to achieve end-use energy savings in general are constrained in the complex socio-technical systems that real-world hospital departments constitute.

The presentation of these (primarily) qualitative findings is guided by Gram-Hanssen’s (2013a) empirical analysis framework for social practices, which has become widely used in built environment research (see section 2.3.2). Gram-Hanssen suggests that social practices can be operationalized for analysis through the four elements embodied habits, knowledge, meanings and technologies which mutually shape each other and the practice in question. A section is dedicated to each element in this chapter (6.1 - 6.4), briefly introducing each of them before themes from the empirical data are analysed and then related back to the theoretical concepts in section summaries.

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## 6.1 Embodied habits around energy saving

Embodied habits can be understood as often unconsciously performed routinised practices (Gram-Hanssen, 2013b). They encompass a practical and bodily understanding of actions by those engaged in them and are generally firmly rooted in every day activities. Previously, related concepts have been discussed using a varied terminology including habitus, practical understanding or know-how (see also section 2.3.2.1). Importantly, having the skills to carry out an action may in some situations not be the same as having the knowledge to evaluate the performance, with the latter being linked more explicitly to cognition and discussed in section 6.2. This section investigates a number of habitual actions which jointly may or may not contribute to a practice of saving energy being carried (out) by clinical staff in different hospital departments.

### 6.1.1 Temporal routines: Intermediate and after-hour switching

It was illustrated in chapter 5 that energy could potentially be saved locally in hospital departments through a number of simple operational changes which conceptually can be divided into the following categories:

- Changing the operational state of items from ‘on’ to ‘not in use’ when their service is not required. Importantly, this may include matching the operational state of spaces and equipment to staff availability and patient numbers.;
- Eliminating equipment ‘not in use’ energy consumption (stand-by) where possible; and

- Reducing the service delivery of items with a range of operational states to the lowest acceptable level (such as increasing thermostat set-points for split air-conditioning units or dimming corridor lights).

From an implementation perspective, the necessary actions could be further be differentiated according to when they needed to take place: during or after departmental operation. After-hours switch-off was shown to be more relevant for departments with defined operating hours, while all department types including those running 24 hour services featured spaces and functions relevant only during core hours (section 4.7). In contrast, intermediate switching to adapt levels of service delivery as well as to switch-off items not required could in theory apply in all department types.

The analysis of instances of switching by clinical staff reported in the interviews revealed an imbalance between the processes of switching-on and switching-off. For other building types, the low likelihood of intermediate switching despite the absence of a service demand is well documented in the literature, in particular for lighting (e.g. Lindelöf and Morel, 2006).

In this study, switching-on mostly followed routines such as the starting up of a department in the morning, but instances of switching-on driven by service demand were also reported in the interviews. They included the switching-on of the split air conditioning units in the KCH Day Unit once it was getting warm because many patients were around or switching on the computers to do documentation once the first cohort of patients had been put onto the haemodialysis machines in the RLH Day Unit.

In contrast, switching-off seemed to be driven purely by routines: mainly at closing time, but occasionally also during lunch breaks or associated with a prescribed ‘quiet time’<sup>1</sup> on NUH ward. All of the very few examples of demand-driven switch-offs reported during the interviews could be linked to clinical outcomes such as the adjusting of lighting levels in X-ray rooms or for endoscopic procedures in operating theatres. If sufficient day light was available on wards, reducing lighting levels was reportedly considered there, but had to be contrasted with safety considerations for patients who may be elderly, disorientated or had bad eyesight.

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<sup>1</sup> See also section 6.4.1 for a further explanation of the quiet time.

In many areas, lights stayed on throughout from ‘when we are in in the morning, that’s it until the end of the day (G)’ while intermediate light switching was often considered impractical due to the intermittent use of rooms. People would often walk in and out of rooms, carrying out tasks which might not take longer than a few minutes. This narrative was supported by the data from occupancy sensors which for example suggested that the occupation of the sister’s office on the NUH ward was for periods of 6 min on average. For many equipment items, intermediate switching reportedly was out of the question due to continued demand or the need to be ready if demand was to occur - in combination with long start-up times of equipment (see also section 6.4.1).

For after-hour switching, differences were noted between individual spaces such as permanent offices and communal spaces for instance corridors, utility rooms but also shared offices used in a hot-desking fashion. While staff permanently in an office or an individual treatment room (n=5) consistently expressed robust knowledge on switch-off procedures for their space, there was more uncertainty about what was happening to lights and computers in shared and communal areas:

I think often they are sort of left on, I think it is random whether workers working in the area will switch it off. [...] I don’t think anybody is keeping track of the lights and computers. (L)

Interviewees across all case hospitals, especially in departments with clear after-hours, had developed a personal perspective with regards to what was happening in their department at night. These narratives may or may not reflect actual operations. In that sense, it proved a central limitation to this project that interviews remained restricted to day-time clinical staff and excluded night staff and cleaners (section 8.2.1).

Switching-on and switching-off in mornings and evenings were further found to be routinised parts of daily tasks with lights being switched on by the first person in and off by the last person out of departments with clear operating hours. If it was believed that the space was or would soon be occupied by others colleagues including cleaners or colleagues from other teams, lights as well as air conditioning were often left on (section 6.3.1). Such practice was for example observable in the electricity profile of the KCH day unit where lights and split units remained on for the cleaners after the department’s official closing time at 5pm (see Figure 4.10).

The switching-on of equipment represented a particularly firm part of daily routines where extensive checks and quality controls on machinery formed part of the clinical protocol such as for automated analysers, anaesthetic machines or X-ray machinery. Switching-off was often associated with tidying and cleaning:

We try to kind of close here bang on five o'clock to shut the door. That involves turning and tidying, turning the machines off, making sure everything is switched off correctly, making sure all our patients are sorted out for the day which sometimes can take a bit more time than you expect. (K)

This suggested that saving energy through adjusting the operational states of lighting and appliances may currently be part of a set of other activities which clinical staff perform, rather than an integrated practice in its own right.

### 6.1.2 Saving energy at home

13 out of the 22 interviewees unprompted touched on the question how the practice of saving energy at work differed from doing so at home: To all of them it was clear that energy was not to be wasted at home. Different reasons were provided for this which apart from financial motives included that their up-bringing had emphasized the importance of not leaving things on unnecessarily or that not being wasteful was an important value to be passed on to their own children.

The extent to which interviewees aimed to be green at home varied<sup>2</sup>. When asked what they did at home to be green, some interviewees referred only to the electricity related actions which had been discussed extensively throughout the interview for the work place (lights, IT equipment). Others included actions to save heat (including retrofitting their homes if owner-occupiers), measures to reduce waste and water consumption, sustainable transport options or conscious purchasing of goods including food. Saving electricity at home did however appear relevant to all interviewees.

There is some debate within the academic community as to whether habits at home influence those at work. In an office study, Littleford et al. (2014) for example found little to no evidence to support the existence of spillover effects in the way energy services were being used across settings. Potentially the relationship is a negative one at best, as one of the interviewees in this project put it:

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<sup>2</sup> The variation may potentially also be related to their job roles and qualification levels, see also section 6.2.2 and Figure 6.1.

If you haven't got the habit of saving up from at home, then obviously you will not have that at work. (I)

So while possibly a prerequisite, saving energy at home must not necessarily result in a similar practice at work<sup>3</sup>.

Some interviewees did however point out that switching things off at home had become a more universal habit for them in a sense that 'for me, it's in me (N)'. Similarly, practices at home were referred to as guidance exemplifying best practice:

Because it is not your home, does it mean you have to waste it? I mean, I do try to think - it's not my home, but I do try to think what would I do there. (T)

Such notions may of course only apply to energy end-uses which are consistent across settings, while many hospital processes were extremely context dependent. Lighting use was however identified in the technical analysis to be both comparatively electricity intensive and under user control in many hospital departments, while closely matching a service also required in domestic settings. And while additional constraints from procedural know-how or social and organisational factors may apply in the work place, the embodiment of light switching in the home context could potentially be an important prerequisite for enacting such practice at work as well<sup>4</sup>.

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<sup>3</sup> Home habits of patients and their attitudes towards spaces which were not their homes also proved relevant on wards and in day units. Night lighting use on wards may for instance be defined by a patient's fear of the dark and a consequent habit from home to sleep with the lights on.

While in hospitals, patients would often feel poorly and concentrate primarily on getting better. In contrast to clinical staff, however, who will have somehow durable relationships to the hospital departments as their workplaces, patients may further feel little or no concern about the space and its resource use. One interviewee observed with regards to patients' consumable use:

And people take lots of blankets and sheets and sometimes for the wrong reason. You know, like they will have one for this arm, one for this arm, one for their back, one to put their feet (laughs) Unnecessary really. In my head, I do think - Would they do that at home? (T)

The influence of patients on hospital electricity use remains outside of the scope of this study, but the above argument as well as repeated reports by clinical staff that patient practices seemed to be linked to age (with older patients tending to be more modest) point towards potential areas for further research.

<sup>4</sup> In the terminology of formal logics, light switching could potentially be thought of as a necessary but not a sufficient condition for light switching at work.

### **6.1.3 Section summary: Energy saving in hospitals as proto-practice**

Embodied habits associated with low end-use energy demands in hospitals were found to primarily relate to instances of switching lighting and equipment off after-hours. Instances of demand driven switching were biased toward switching-on and intermediate switching was often considered out of the question due to a perceived need to have everything ready if demand was to occur in combination with long start-up times of equipment. Both of these constraints will be further analysed in the following sections.

It was further recognised that adjusting the operational states of lighting and appliances may currently be part of a set of other activities which clinical staff perform. This suggested that energy saving in hospitals may not currently be an integrated practice in its own right. Such finding stood in contrast to the domestic context: while encompassing a cluster of different activities and carried out by people to differing degrees, energy saving at home seemed to be more established as a coherent unit of practice. In contrast, energy saving at work could potentially be conceptualised as what Shove et al. (2012) refer to as a 'proto-practice', with respective implications for possible strategies to encourage the establishment of such a practice (section 7.2.1).

## **6.2 Knowledge constraints on end-use energy savings in hospitals**

This practice theory element refers to the level of general knowledge individuals hold with respect to electricity consuming technologies and their use (Gram-Hanssen, 2013b). This includes the available language (Schatzki, 2002) through which it can be thought and spoken about energy saving; as well as the pathways through which knowledge is established and disseminated 'including what rules [people] have been taught to follow by different types of intermediaries such as caretakers, energy advisors, craftsmen or sales persons' (Gram-Hanssen, 2013b, p.104). Goldkuhl and Braf (2002) further differentiate between individual knowledge and institutionalised (shared) knowledge, which has transcended individual subjects as a result of common working practices and plays a crucial role in enabling organised and coordinated action in an organisation. Importantly, practice theory discourages any interpretation which linearly links knowledge and practices while aligning itself with a language of systems, complexity and interactions (Cohn, 2014).

The following sections firstly analyse the level of knowledge held in different hospitals departments with respect to how low energy end-use is enabled (section 6.2.1). It is then uncovered how the knowledge on the control of most building services is shared among clinical staff (section 6.2.2). Finally, constraints on end-use energy savings are highlighted which result from the limited knowledge individual members of staff hold on who else may use shared spaces in many hospital departments (section 6.2.3). Conceptually, knowledge on end-use energy savings in hospitals is hence analysed at three levels (Table 6.1) for each of which Bernstein (1996) has identified viability conditions.

**Table 6.1:** Levels of knowledge required for low energy operations  
(Levels and conditions by Bernstein (1996))

Levels	Conditions	Application to hospitals	Section
Political	Discourse	What is required to locally use as little operational energy as possible?	Identifying the best-practice agenda
Social	Communitas	How would we act?	Shared knowledge on building services control
Individual	Confidence	Who needs to take action?	Individual action in an organisational setting

### 6.2.1 Identifying the best-practice agenda

The first step towards energy conservation in any given context constitutes in strategically identifying what would need to be done in order to be energy efficient (CIBSE, 2012). The interviews suggested that in the complex environment of some hospital departments this could prove quite difficult. Far from being relevant to everyone, this question was found to primarily be of importance for senior staff and those with health and safety responsibilities. On one occasion, a junior staff member with a personal interest in sustainability also commented on this challenge while stressing that their department nurtured a culture of openness allowing them to get involved with improving departmental runnings beyond their pay grade.

Generally, it seemed that especially in complex departments such as laboratories and theatres individuals found it hard to understand the interactions within and between processes and systems. In the absence of established knowledge, myths were generated for example on how the scavenging of anaesthetic gases was implemented on the building side or on centralised heating schedules as illustrated in the following quote:



In this theatre it [the heating] seems to work, but there seems to be... like at night-time it seems to automatically re-set itself to a very cold temperature. [...] I presume they automatically reduce temperatures because it seems to get cold sometimes. (X)

According to the facilities department no such night-time temperature set-back was operational in this particular theatre due to uncertainty about operating hours<sup>5</sup>. Certain knowledge about operations was particularly hard to obtain for clinical staff where processes were partly defined and/or controlled outside of the department<sup>6</sup>. Such challenges were even bigger if it was attempted to holistically understand a department's environmental impact and life-cycle emissions were also considered, as this quote by a senior laboratory staff with strong interest in sustainability indicated:

Of course, heat, light, electricity - if we could recycle all our waste, we might be using more electricity so it's a difficult balance. We might really be using more energy because our plastic boxes need to be incinerated, and then they need to be made again. (B)

Challenges in setting best-practice agenda arose in particular from hospital specific functions and building services. For lighting, environmental impact and control means were perceived as quite straightforward in comparison. Although issues around obstructed, hidden or unlabelled light switches were occasionally reported, it was generally clear to staff in all departments that switching lights off was associated with saving energy and lighting controls were often the way to effect this:

It's like any room you go into, they are not hidden so to say - light switches are placed basically in the same kind of areas everywhere, so you could go into a strange house and switch the lights on. (E)

---

<sup>5</sup> It is generally recommended for hospitals that heating systems should be controlled to a set-back temperature of 12 to 15 °C out of hours (Department of Health Estates and Facilities Division, 2007). For theatres in contrast, the system should ensure that temperatures do not fall below 15 °C to avoid lengthy temperature recovery periods. Full manual override permitting plant restoration to full operational status at short notice is recommended. The presented case, however, illustrated that facilities staff preferred to avoid conflict by not implementing night-time temperature set-backs in specialist areas. More collaboration between facilities and clinical staff to provide the former with insights on actual occupancy schedules may be beneficial here (section 7.3).

<sup>6</sup> In the quoted case, the impression also was that efforts applied in further investigation were limited because comfort levels were not seriously infringed on.

In all departments, staff did also display some awareness as to whether their department was a major energy user within the context of the entire hospital. Such judgements could be related to department size or the energy intensity of the departmental activity. For example in the KCH Day Unit which with 178 m<sup>2</sup> indeed was one of the smallest departments in the study, both interviewed staff suggested that little energy was wasted there in absolute terms because they had ‘less lights, less computers, less places to walk (M)’ and more energy could hence be saved elsewhere. An interviewee from a ward also explained:

My job and energy use are negatively correlated. [...] Nursing and electricity, I don’t think they have anything to do. If you are in ICU [Intensive Care Unit] they rely solely on electricity for the machines. If you are in CCU [Critical Care Unit], they rely on the machines. If you are in the birthing centre, they rely on the machines, incubators and all that. But here [on a general ward] - if nobody needs a machine, sometimes we go a whole week and nobody needs a machine that uses electricity. (R)

In contrast, all interviewed theatre and in particular laboratory staff (energy intensive department types) expressed concerns about energy costs. Setting the best-practice agenda consequently seemed to be of particular concern in energy intensive department types, which coincidentally also tended to be more specialist and complex.

### **6.2.2 Shared knowledge on building services control**

In a second step, local energy conservation requires the relevant occupants of a space to know both what constitutes the best-practice agenda and how it can be enacted. Hospitals were found to be a very hierarchical environment with strong division of labour where roles were clearly prescribed and every team member contributed specialist knowledge. It became clear in this study that labour division also extended to control over building services and - potentially somehow less surprisingly - equipment. As a result, not all members of staff possessed knowledge on how to adapt building services or influence the operational state of equipment items as illustrated by this junior doctor’s statement on heating control:

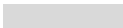
I... don’t know how to [control the heating]. But I am sure the nurse, the head nurse can. But I don’t know where the panel is. [...] But the doctors can say to the nurses ‘Can we change the temperature?’ It’s mainly that. (P1)

In this statement, the frequent use of the conjunction ‘but’ seemed to indicate that the described lack of knowledge was not considered problematic. Hospital work is team work and while the interviewee did not understand managing the thermal environment as part of her responsibility she could rely on her team members to know how to respond in the case of discomfort. From a management perspective such well-established collaborations will surely be welcomed given the cost of time of highly trained specialists (see Table 6.2).

**Table 6.2:** NHS job roles, Agenda for Change (AfC) pay grades<sup>7</sup> and likely local knowledge on controlling complex building services

AfC Pay Bands	Typical roles in this band	Basic annual pay rates (as of April 2015) *
1	Porters, Domestic support workers	£15 100 - £15 363
2	Typical clinical support worker, Security officers	£15 100 - £17 800
3	Linen/laundry supervisors, Estates maintenance workers	£16 633 - £19 461
4	Laboratory assistants, Maternity care assistants	£19 027 - £22 236
5	Fully qualified nurses, Doctors in training	£21 692 - £28 180
6	Nurse team leaders	£26 041 - £34 876
7	Estates managers, Advanced health care science staff	£31 072 - £40 964
8	Matrons, Nurse consultants, GPs, Specialist doctors	£39 632 - £81 618
9	Consultants, Surgeons	£77 850 - £98 453

Key:

 Likely to locally hold knowledge on the control of building services (beyond lighting)

\* [www.nhs Careers.nhs.uk/working-in-the-nhs/pay-and-benefits/agenda-for-change-pay-rates/](http://www.nhs Careers.nhs.uk/working-in-the-nhs/pay-and-benefits/agenda-for-change-pay-rates/)

Apart from the established labour division described above other reasons potentially resulting in a lack of knowledge on local best-practice were:

- **Specialist staff working across different hospitals:** Especially specialist staff such as surgeons or radiologists tended to work across different hospitals, sometimes spending as little as one day a week in each. When on-site, they would spend their time (which during the fieldwork was variously referred to as ‘precious’ by both themselves and others) in patient care and not with basic runnings of buildings or systems.

<sup>7</sup> Most jobs in the NHS except doctors, dentists and most senior managers are covered by the AfC pay scales. Doctor salaries were matched to pay grade based on expected ranges for this illustration.

- **Increasing number of temporary staff:** Due to staff shortages, especially in less centrally located or prestigious hospitals such as NUH, agency staff were frequently employed to temporarily fulfil the duties of absent others (Locum). Depending on local arrangements, time in post and personal abilities, locum staff may have a lower status and less rights than permanent staff in for example accessing computer systems, accompanying patients or being entitled to discounted canteen food. One interviewed nurse employed as agency staff observed:

And there is only one toilet. It's only a disabled toilet. And there is no toilet for the staff, there is no toilet for woman. Just one toilet - and this place is contagious, but everyone is using this toilet... But I don't know, I am just agency, but that is what I see (M).

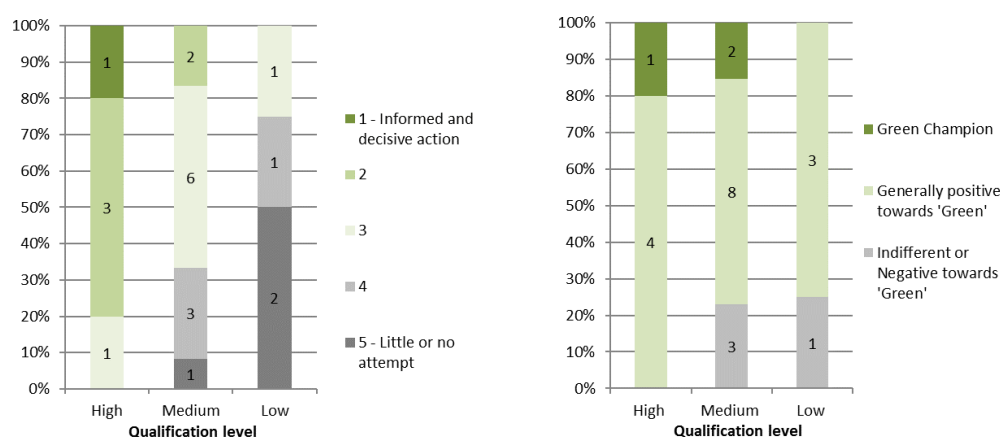
Despite making a valid point which her colleagues affirmed, the interviewee seemed less sure throughout the conversation of her right to voice an opinion due to her role as temporary staff. Such perceptions may have an important influence on knowledge of local best-practice, ownership of space and when aiming to establish a culture of change.

- **Limited agency in support staff:** Two out of the three interviewed health care assistants (HCA) agreed that as a support worker 'the most important is we got told what to do, so we do that, we follow that. Because it is what the management told us. (F)' Own initiative and independent knowledge were consequently limited, while the third HCA showed higher levels of agency and reported to commonly help the nurses out with tasks above her pay grade.
- **Uncertainty on equipment switch-off options:** Clinical staff were in some cases found to be unsure about the operating characteristics of specialist medical or laboratory equipment, making it hard for them to decide whether or not equipment could be switched-off or into stand-by. To give but one example, RLH radiology staff tended to work across different imaging departments including inpatient-, outpatient- and paediatric-X-ray. While in inpatient X-ray, the manufacturer (Siemens) specified that the X-ray generators may be switched off after-hours, the instruction manual in paediatrics (GE Medical) recommended keeping them on throughout. For staff working across departments, this proved somehow confusing 'with all these different things... With different companies, different equipment, there are different rules and regulations. (L)'. Such uncertainties pointed towards the role of equipment manufacturers and equipment technicians for low carbon clinical operations (section 7.2.2).

- **Contradictory instructions:** Similarly, uncertainty could extend to procedures for IT equipment. The green group of a hospital affiliated with but not directly participating in this study discussed sending an e-mail reminder to clinical staff asking them to shut down computers after work. They received the following response from the trust's IT department working on a business-critical software migration: 'We sent a message out to all trust staff last week that [...] they should leave their PCs on for us. A message asking users to turn them off would obviously directly contradict the first one and would leave users confused, leave us unable to complete the merge, and make the trust look like it didn't know what it was doing.' Apart from the confusion potential for end-users, this example also highlighted differences in priorities and little coordination between departments.
- **Little conversations about energy best practice:** All interviewees consistently reported that energy efficiency and sustainability were 'not really' issues discussed among colleagues, neither did they tend to be included in local staff inductions. The peer-to-peer diffusion of best practice procedures associated with energy and sustainability hence proved unlikely, unless someone in the team was actively pursuing the topic out of a personal interest. In the latter cases, e-mails and reminders during staff meetings for specific actions such as switching off the ultraclean ventilation canopy in theatres or recycling certain items were found to be most common.

On the whole, the available knowledge on the control of both building services (especially heating/cooling and specialist building services such as gas scavenging or ultra clean ventilation in theatres) and equipment seemed to be concentrated in the hand of intermediate level professionals, primarily nurses (see Table 6.2).

Nurses commonly hold medium level qualifications<sup>8</sup>. There has been some evidence for the general public that education was associated with pro-environmental attitudes (DEFRA 2008). More recent studies have however criticised the knowledge deficit interpretation for climate change action and shown mediating influences of the type of environmental-friendly actions (Lynn and Longhi, 2011) and political values (Whitmarsh, 2011). The interview data in this study did suggest that staff with high levels of qualification were more likely to take informed and decisive action to be green at home and generally champion green attitudes (see Figure 6.1). There was hence a potential disconnect between those in the know on how to control building and appliances and those interested in reducing energy use in favour of environment and planet. It may however be noted that this is a small study and qualification levels are only one factor among many which may potentially be associated with the uptake of environmentally-friendly practices.



**Figure 6.1:** Influence of qualification levels on: left) interviewee attitudes towards being green at home<sup>9</sup> ; and right) championing green issues more generally<sup>10</sup>

<sup>8</sup> Currently, nursing degree courses in any of the four branches of nursing (adult, mental health, learning disabilities and children's nursing) are three years full-time and are offered by universities across the country. They comprise 50% theory and 50% of supervised nursing practice taking place in both hospital and community settings and eventually lead to the registration with the Nursing and Midwifery Council (NMC) as registered nurses. Specialisations for employment in critical care or theatre departments as well as master degrees in nursing studies are also available.

<sup>9</sup> Numerical ratings assigned based on whether interviewees unpromptedly referred to actions on electricity, heat (including retrofitting), waste (including water and recycling), transport and conscious purchasing (including diet) when asked what they did to be green at home

<sup>10</sup> Categories attributed by the researcher based on the enthusiasms for sustainability expressed during the interviews. It is acknowledged that rating will be subject to interpretive bias.

### 6.2.3 Individual action in an organisational setting

A third knowledge constraint on energy saving in clinical workplaces seemed to result from difficulties for the individual in identifying situations in which it was specifically upon them to act. The interviews suggested that there was a strong social component to working in hospitals and friendly relations with colleagues were often stated as the most important reason for work place satisfaction. The team was also considered a strong power in solving problems and ensuring the smooth running of departments.

Aside from rigid hierarchical structures, hospitals proved to be rather dynamic with respect to teams. As one senior staff put it:

People off sick, annual leave, vacancies, locums we have to get in - you write a rota and then you re-write it on the day. (B)

In consequence, all employees were familiar to regularly working with different colleagues and based on a professional conduct this generally seemed to work well.

It did, however, seem that the perception of teams was restricted to direct colleagues based on time spent together. At NUH for example, some employees in the pathology lab and the radiology department only worked night shifts. Only to a very limited extent were they considered part of the team by their colleagues from the day shift. Similarly, the interviewees did not understand domestic staff such as cleaners or hostesses re-heating patient meals on wards as a part of their team. Such exclusion was reinforced because the latter tended to be employed through sub-contractors or agencies rather than the respective trust directly.

As a result of this narrow conceptualisation of teams, all departments were regularly frequented by 'outsiders' who intervened in the departmental runnings. In some departments at the RLH this was aggravated by the spatial arrangements requiring the shared use of office spaces, lockers or staff rooms with other departments with differing operating hours. Uncertainty could hence arise for staff as to whether energy services were still needed by someone or not. The implications of this uncertainty in combination with meanings relevant in hospitals are further discussed in section 6.3.1.

One way of clarifying who should be in charge of switching-off and the implementation of energy best practice more generally which was brought up in the interviews was the attribution of formal responsibilities, for example by integrating energy efficiency with health and safety roles. In hospitals, hierarchies and fixed job roles are generally well established (see also Tudor et al., 2008), suggesting such strategies might fit the organisational culture. In their work within the retail sector, Christina et al. (2015) have pointed out the importance of aligning organisational energy strategies with the prevailing organisational culture.

In this study, the interviewees' opinions on integrating energy issues into formal responsibilities were divided: Support staff but also those rather new to more responsible roles and hence feeling mentally occupied with their clinical responsibilities tended to like the idea, while others thought that flexibility in combination with good team work would be a strategy more adaptive to different situations. It also seemed that some individuals were already taking responsibility for sustainable operations according to their interests, a motivation which could be hampered by structuring existing working routines even more.

#### **6.2.4 Section summary: Levels of knowledge constraints**

This section presented a number of constraints on end-use energy savings from limits in knowledge at the managerial, team and individual level. It was shown for energy intensive department types such as operating theatres and laboratories that system complexities, multiple stakeholders and conflicting priorities complicated decisions on sustainability strategies. Bernstein (1996) identified 'discourse' as necessary condition to establish knowledge in such circumstances. This study however highlighted that conversations about energy issues were rare within clinical teams, but perhaps more importantly also between clinical staff and those in charge of facilities and energy management. This seemed to result in a lack of joined-up knowledge on how to locally define (energy) best practice, an important challenge in hospitals and likely other complex building types that will be further discussed in section 7.3.



This study further found that the control of HVAC systems and specialist building services constituted inter-subjective knowledge and tended to be shared between intermediate level professionals, primarily nurses. This may partly be due to the well established labour division in the hierarchical environment which hospitals constitute, while staff moving between hospitals as specialists or locums and contradictory instructions from equipment manufacturers and IT specialists appeared to further contribute to a lack of knowledge on local best-practice among individuals in other job roles. In line with Bernstein's proposition, the team, i.e. *communitas*, did consequently seem to represent a powerful player in the investigated hospital departments, as well as a significant resource for resilience in the face of obstacles.

Finally, challenges for low energy use in shared spaces may arise from uncertainty around whether space and equipment may still be needed by someone. Bernstein advocates confidence as one condition which allows individuals to know appropriate courses of action. Confidence building may hence be promising for some support staff which currently seemed to have limited agency. In line with previous research for example by Tudor et al. (2008), this study further highlighted the role of hierarchies and fixed job roles in hospitals. The attribution of formal responsibilities, for example through integrating energy efficiency with health and safety roles, may hence represent an additional strategy well suited to the organisational culture typical in health care settings.

### **6.3 Meanings associated with hospital energy usage**

Meanings and engagements are considered a further element holding practices together. There is however limited agreement among practice theorists on how to characterize meanings, emotions and motivations (Shove et al., 2012). Gram-Hanssen (2010) states that practitioners can be understood to connect with practices through individual and collective engagements while meanings accumulate through these actions. Other scholars, especially those more firmly rooted in sociology where the concept of meanings goes back as far as Max Weber, debate the extent to which engagements are at all individual. All interpretations and subsequent meanings are considered a result of collective processes.

This and other debates highlight that SPT is a theory in development rather than a finalized tool. The focus of this study meanwhile is on empirical data collection and analysis in a novel context rather than on theory development. The following section will orientate itself towards an interpretation of meanings following Gram-Hanssen, which grants individuals a limited amount of personnel motivations and engagements. For this study, this seemed appropriate for two main reasons: firstly, hospitals were found to be strictly hierarchical environments strongly shaped by job roles. This resulted in some differences between clinical staff which are thought to influence engagements. And secondly, there is an increasing amount of literature available on motivations for energy saving at the workplace, in particular within business research and social/environmental psychology (section 2.2.1) while social practice based studies are still few (section 2.3.2.2). At least reflecting on the collected data against the background of this literature therefore seemed beneficial.

A comparison of evidence from offices or manufacturing with accounts on the realities of working life collected in this study indicated that, from an employee perspective, hospitals were little different to other work places in many aspects. This finding contrasted the perception of many people encountered over the course of this research project, especially building professionals, and therefore seemed relevant in itself (see section 7.3). Two central meanings in the context of energy end-use which were particular to hospitals are further discussed below: the strong impetus to accommodate potential needs of others (section 6.3.1) and the place of saving energy in busy hospital environments (section 6.3.2).

### **6.3.1 Accommodating potentials needs of others**

In the hospital context, a number of engagements of clinical staff were identified, amongst which caring for others featured prominently. This included both a commitment to excellent patient care as well as more general social considerations aiming to accommodate the needs and wants of their colleagues, their families and also strangers such as the researcher of this project. Naturally, the degree to which interviewees appeared to be driven by motives of care varied between them and depending on their position and personality other engagements such as cost concerns, an impetus for compliance or a desire to learn were also important to them. All interviewed staff, however, expressed a concern for the well-being of others at some point, likely a characteristic somehow typical for the health care sector.

From an energy perspective, the kind concern for the well-being of others however often resulted in increased energy demand because it made ‘on’ the default mode of operation for equipment and lights. The interviews clearly highlighted the social motive behind the ‘defaulting to on’: it was considered important to leave a room or an equipment item ready for use in case colleagues or patients might need it, as illustrated by the following quote on keeping lights and equipment on during the day theatre lunch break:

Because maybe surgeons come in there, because we don’t know who might come in there while we are having lunch. (F)

Palm and Darby (2014) have previously uncovered a very similar notion among researchers in university laboratories, where lab machines were generally ‘left on around the clock largely because someone *might* want to use them (p.86, italics in the original)’. In the office context, it used to be custom to boil full kettles in case colleagues were also in need of cup of tea.

At the same time, hospitals seemed to be fundamentally risk-averse environments. Building systems were sized with generous safety margins (Bacon, 2014) and often held additional plant equipment (such as back-up gas boilers<sup>11</sup>), laboratories featured redundant analysers (B) and additional tests were prescribed in diagnosis to be on the safe side (P1). The fact that room lights were kept on in case someone may walk in (L) hence appeared to fit in well with the wider organisational culture.

The above quote also re-emphasized the important role of hierarchy in hospitals as previously discussed and also reported by Tudor et al. (2008). Certain professions, in particular surgeons, were regarded by their colleagues with much respect and it was attempted to shelter them from nuisance. In particular temperatures in operating theatres proved a contentious issue in this context (see also section 5.2): temperatures were often predetermined at 18 °C or below to ensure the surgeon would not sweat and concentrate well, while people at the periphery might well feel cold. It seemed to generally remain unquestioned whether the actual thermal comfort preferences of the surgeon or the nature of the clinical case required such low temperatures.

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<sup>11</sup> For instance, the RLH is equipped with six 3.5MW gas-fired combi boilers. During the technical site visit on a fairly cold day during March 2013, only one of the boilers was in use while according to the technician even on peak days no more than four out of the six boilers are ever in use.

Similarly, the interviews indicated that patient needs for environmental conditions such as temperature or lighting levels were often estimated based on experience and potentially personal preference rather than through interaction with the respective patient. In nursing, it certainly is crucial to emphatically accommodate the needs of others, especially those excluded from exercising control over their environment themselves due to vulnerability (Nightingale, 1860). These observations nevertheless suggested that there may be some scope to question default operational states with a view to reducing energy use to determine to what extent they meet actual needs as opposed to pre-empting ideas of clinical needs and comfort.

### 6.3.2 The place for energy saving in the clinical day-to-day

Not surprisingly, hospitals were found to be rather demanding workplaces. All interviewed staff reported to be very busy and the perceived lack of time seemed to spread fairly equally across different roles, despite differences in responsibilities. In line with official NHS communications (e.g NHS England, 2013), the interviewed staff expressed strong commitments to achieve excellent patient care. In this endeavour however they found themselves subject to many competing priorities, including:

- **Responsibility for human life:** Undoubtedly, responsibilities for clinical staff especially in senior positions are rather high compared to other professions as they are often required to take decisions affecting human life and death. Depending on staff experience and patient need this can be quite taxing as the following quote illustrates:

I think that A&E is very... stressful - not stressful, but you have to be alert all the time and you are constantly thinking about what you are going do with your patients, how are you not missing important things, how are you not missing life threatening stuff. That... like so much of my energy is focused on that. I have found that when I am in A&E, I am very focused and people think that I am quite serious, but it is just that I am trying to concentrate on not missing anything or that kind of stuff. (P1)

- **Budget constraints within the NHS:** Pressures to continue delivering value for money in the face of rising demands are high within the NHS (NHS England, 2013). On the ground, this resulted in some awareness of cost issues in all trusts but in particular at NUH where the funding situation had long been complicated and culminated in the trust being put into special measures<sup>12</sup> in March 2015.
- **Staffing pressures:** Partly a consequence of tight budgets, but also a result of planning issues and recruiting difficulties as well as staff illness, all visited departments suffered from more or less prolonged periods of under-staffing. The workload of present staff consequently often doubled resulting at least in overtime and no breaks but potentially more dramatically also in a lack of time for patient care as one interviewee pointed out:

There seemed to be a lot of shortages somehow and it's been looked into and hopefully the issues will be resolved eventually because we can't work under such conditions. It comprises patients and safety because right now there is so much work, you begin to lose your concentration and there may be a detrimental impact on service quality. (D)

- **Security concerns:** Hospitals are public spaces with largely uncontrolled access, meaning that security can be a concern. Interviewees related occurrences of equipment and drug theft as well as the use of sanitary facilities for substance abuse suggesting that a permanent state of alertness was indicated. At the same time, patients or visitors in need for directions may constantly approach any member of staff, especially at the difficult to navigate RLH.
- **Personal well-being:** Finally, staff also expressed concerns about their personal well-being, which from an organisational perspective will additionally be important in the light of productivity. As far as building services were concerned, this related in particular to thermal comfort preferences but also for example to the need for cold temperatures or very bright light to stay awake during night shifts as well as personal health issues such as hot flushes during the menopause influencing fan use, or poor levels of eyesight as well as spending extended periods in dim X-ray rooms marking lighting preferences.

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<sup>12</sup> When there are concerns about the quality of care that NHS hospitals are delivering, they can be put into special measures under the authority of three Department of Health funded bodies (Care Quality Commission, Monitor and the NHS Trust Development Authority). Special measures supposedly provide the hospitals with support to improve while giving the public the ability to hold them accountable.

Among these great many priorities, the profile of sustainability and energy efficiency proved comparatively low for the interviewed staff. It was, however, notable that issues of waste disposal and recycling were valued more highly, while especially switching-off lights held little importance to most. It was in consequence occasionally forgotten when it would have admittedly been appropriate to turn the lights off. Forgetting was in these situations understood as part of ‘being human’ (A), indicating that energy use was of little priority to staff in the face of the above engagements. In several departments, reminders were used to address forgetfulness, but most interviewees did not appear convinced of their sustained effectiveness because ‘it lasts for a few weeks and then it goes back to normal.’ (L)

A lack of leadership on sustainability, at times combined with a more general lack of leadership following staffing changes and under-staffing, was suspected to be a further reason for the low priority of energy efficiency in hospitals. Three out of the eleven investigated departments did not have on-site managers in charge of the departments at the time of the fieldwork while many managerial tasks had temporarily been taken over by other team members. Non-core activities had low priority as a consequence. Similar findings have previously been reported generally (Zibarras and Ballinger, 2011) and also for the NHS: Tudor et al. (2008) have undertaken a study of the waste management in the NHS Cornwall. Managers there likewise tended to prioritise health care related targets and showed a certain reluctance to spend money on non-core activities including sustainability, resulting in low motivation among all staff towards them.

All interviewed staff did show an awareness of the importance of budgeting for the NHS and saving energy was appreciated as a tool to cut overall costs. Benefits as well as difficulties were often interpreted in the light of immediate outcomes for oneself and each department:

If the bills go up, then they will cut on the staff, so effects do come to us. (R)

Saving energy therefore constituted an indirect tool for each employee to improve their work environment. The relevance of such financial motive however relied on a strong and trustful relationship between employer and employee forming the basis for engagement. One interviewee described how the absence of a positive employer-employee relationship impacted on work ethic and the consequent willingness to make an effort, be it for energy efficiency or service delivery more generally:

It's more to do with people's... what do you call it... see, with their enthusiasm to work in an environment where you feel like 'I could go the extra mile'. But under the circumstances, it's not just lighting, it impacts on other things. [...] I don't want to say problem because problem is too strong a word to use... But people don't have the morale. (D)

In this sense, operational energy efficiency could potentially be understood as additional indicator of a successful organisation, while in return contributing to making an organisation successful by delivering value for money.

To many interviewed staff, saving energy at the workplace further related to a notion of being prepared for the future; similar to the concerns about eventual staff reduction expressed in the above quote. Resourcefulness was seen as morally right by a majority of interviewees while any waste had to be avoided on principle. It is likely that cultural and socio-economic backgrounds will have contributed to this understanding as one staff member originally from India pointed out:

And I know this sounds crazy but a lot of people come from poor countries and that is what they do automatically - not waste things. (U)

According to NHS workforce statistics, 80% of all Hospital and Community Health Service staff were British in 2014 while the rest came from 212 other countries, most prominently India, Ireland and the Philippines (Health and Social Care Information Centre, 2014). It may be expected that diversity will be somehow higher for the case study hospitals due to their London location. Cultural differences may hence play a role with respect to what resources mean to individual members of hospital staff<sup>13</sup>. Avoiding waste, especially with respect to consumables and through recycling while potentially less so for electricity, was in any case a common theme across the interviews and seemed to reflect - possibly an extension of the notion of 'caring' to include future generations - a motive relevant to most clinical staff.

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<sup>13</sup> The facilities management at both RLH and NUH also commented on differing temperature preferences between cultures: according to them people from warmer countries tended to prefer (and demand) higher levels of space heating.

### 6.3.3 Section summary: A hierarchy of meanings

This section investigated a number of issues which collectively held meaning for clinical staff in hospitals. It was found that all interviewed staff expressed strong commitments to achieving excellent patient care. Similarly, it was collectively considered important to leave a room or an equipment item ready for use in case colleagues or patients might need it. Such kind concern for others often increased energy demand because it made ‘on’ the default mode of operation for equipment and lights. In a number of instances, the analysis questioned whether such pre-emptive approaches actually contributed to the well-being of those considered. This suggested that there may be scope for questioning default operational states with view to reducing hospital energy use, an issue further discussed in section 7.3.

On the other hand, it was found that saving energy in their workplace held little meaning for most clinical staff in the face of many competing priorities. A lack of leadership on sustainability, at times combined with a more general lack of leadership following staffing changes and under-staffing, further contributed to a low profile of energy efficiency in most hospital departments. Many staff nevertheless understood saving energy as tool to cut overall costs while appreciating the importance of budgeting for the NHS. The average rating across all interviewees with respect to the question ‘At your workplace, how important is saving energy for you?’ was 4.3<sup>14</sup> (n = 23) on a 5 point scale with 5 being ‘Very important’. Despite competing priorities, it hence seemed that (at least intellectually) saving energy had some relevance for clinical staff in hospitals as work places.

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<sup>14</sup> It is expected that there were methodological limitations associated with this question (including some social desirability bias) while interviewees sometimes found it hard to interpret the question on a numerical scale. Accordingly, some interviewees introduced qualifiers differentiating between the trust perspective and a personal perspective or between a theoretical importance and where the trust was currently in terms of practical implementations. If such comments as well as the unprompted provision of a rationale were considered a sign of reflection on the question while ratings by interviewees very immediately providing only a high score were excluded due to suspected bias, the average rating dropped to 3.8 (n = 17).

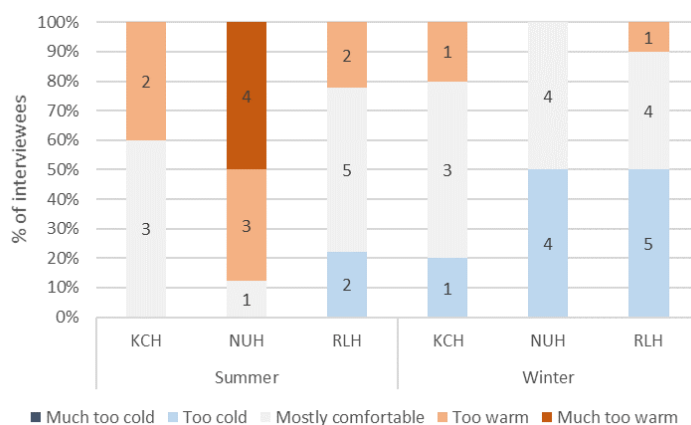


## 6.4 Technological constraints affecting energy end-use

As opposed to behavioural approaches focusing on the action of individuals, practice theory - in the tradition of sociology and science and technology studies - places a strong focus on the role of technologies and the material environment in shaping human action. With respect to energy saving practices, technologies may refer to the physical environment surrounding us including the buildings themselves, electrical devices but also other physical objects and infrastructures. In a wider sense, procedural items such as schedules may also be understood to form part of the material environment (following Latour, 1999).

Technology and infrastructure have been recognised to constrain and enable human activity at two levels: in the present and by channeling forthcoming activity in what Schatzki (2002, p.44) refers to as ‘prefiguration’. Likewise, current material arrangements have been shaped by past activities in a loop-like process. In the context of this research project, the current design of hospital buildings as well as the definition of clinical processes consequently needed to be understood as the outcome of past decisions in which sustainability and efficient resource use may have been a lesser concern than today given rising energy costs, threats from air pollution and a changing climate.

The following sections investigate how energy efficient local operations in different hospital departments may be constrained and enabled by technologies and material arrangements, building on interview data as well as evidence from monitoring and an analysis of the physical arrangements as described in chapter 4. Technological constraints on energy efficient hospital operation are discussed in the present (section 6.4.1), and as a result of prefiguration (section 6.4.2). Finally, possible contributions of technology and material helpers in achieving low end-use energy demand are also discussed (section 6.4.3).



**Figure 6.2:** Cross case comparison of reported thermal comfort levels

#### 6.4.1 Operational challenges to resource efficiency

Technology and the material environment can pose major challenges to the optimal running of departments, affecting both patient care and energy use. During the interviews, ‘insufficient working means’ were identified to be a central problem for clinical staff and accounted for 71% ( $n = 29$ ) of all coding references related to technological challenges during operation ( $n = 41$ ). Insufficient working means included lack of space (especially in NUH and KCH Outpatients) and affected building services and equipment corresponding to all electrical end-uses, while space cooling and heating proved most problematic (38% ( $n = 11$ ) and 24% ( $n = 7$ ) of coding references under the code ‘insufficient working means’ respectively). Frequently, staff had to develop workarounds to achieve viable solutions in the face of such obstacles which at times proved sub-optimal from an energy perspective but, perhaps more importantly, also resulted in a waste of ‘personal energy (X)’ while likely being associated with higher operational costs.

Space cooling was found to be especially problematic at NUH where two thirds of the mentions ( $n = 8$ ) of insufficient cooling means came from, and to a lesser extent at KCH ( $n = 3$ ), while the theme was not mentioned at the RLH. This was also reflected in the reported thermal comfort levels across the different hospitals (Figure 6.2) indicating serious overheating issues in NUH during the summer while overheating has previously been identified as an important challenge for hospitals in a changing climate (e.g. Lomas and Ji, 2009; Short et al., 2012).

From a clinician perspective, thermal discomfort affected both patient safety and work place satisfaction (see also section 5.2). If the implemented ventilation and space cooling strategies proved insufficient in achieving acceptable summer temperatures, supplementary space cooling equipment including portable air conditioning units and fans were brought in:

So every summer we end up using portable units because the air conditioning is not up to the standard it should be. (E)

This was extensively observed in NUH, in particular in the laboratory and on the ward, but also in the radiology department and resulted in 4 - 8% of local electricity use being employed for local space conditioning in addition to the energy requirements of central plant (not estimated in this study). In contrast, no heaters or fans were observed at RLH and only individual devices in air-conditioned spaces at KCH.

A detailed analysis of building physical parameters contributing to this problem was beyond the scope of this study, while previous research is available which investigates overheating in hospitals from a technical perspective (e.g. Lomas et al., 2012; Lomas and Ji, 2009). It was, however, felt that the between-case differences in ventilation and space cooling strategies (Table 6.3) implied challenges for mixed mode strategies in existing hospitals which tended to evolve situational and often with little strategic planning. NUH for example was originally built as mixed mode building where the building core and spaces with specialist loads were mechanically ventilated and space conditioned through the air handling units while the periphery was naturally ventilated and heated through a wet radiator system. With increasing heat loads from equipment and dense occupation as well as restrictions to window opening, mechanical ventilation arrangements were seen to expand to the building periphery while service delivery proved unsatisfactory.

Conflicts between energy conservation aims and nursing policies were also observed to aggravate overheating issues. On both investigated wards for example, the windowless and rather small treatment rooms (9 m<sup>2</sup> at NUH and 7.5 m<sup>2</sup> at KCH) in which medications were prepared, were reported to be prone to overheating. Nursing policies, however, indicated that the doors of these rooms had to be kept shut at all times for security reasons (drug storage). At the same time, opening the door could provide some relief as suggested by the drops in temperature of the NUH treatment room (for example at 10:30am) on the hottest day of the measurement period (Figure 6.3). With such low-energy means of ventilation and temperature control barred, other measures had to be found to improve thermal comfort and a tower fan (power rating 50 W) was used.

**Table 6.3:** Cross case comparison of primary ventilation and space cooling strategies

MV - Mechanical ventilation, NV - Natural ventilation, AHU - Air handling units

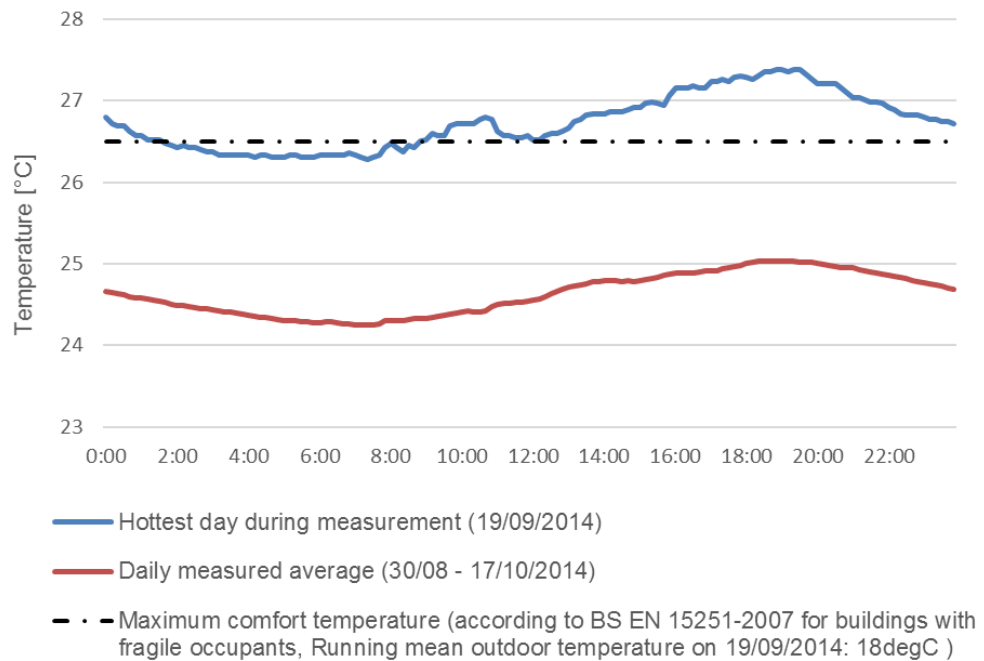
	NUH	KCH	RLH
Built form	Nucleus	Nightingale	Deep Plan
Ventilation	Mixed mode with expanding MV	Primarily NV with local extract ventilation <sup>1</sup>	MV throughout
Space cooling	Chiller serving AHUs; Some split units and local supplementary cooling	Split Units <sup>2</sup>	Chiller feeding chilled beams, Fan coil units in areas with special loads

<sup>1</sup> Laboratory spaces mechanically ventilated.

<sup>2</sup> In the laboratory (and other parts of the building not investigated in detail as part of this study), the split units were supported by a central chiller conditioning the MV incoming air.

At KCH, space heating proved challenging on the ward and in the outpatient department. Both were equipped with radiators controllable through thermostatic radiator valves (TRVs). But:

And the radiators seem to get stuck a lot of the time, there always seem to be... I have noticed in a couple of the bays, the radiators are on all the time. [...] Which is a bit of a waste because you have air conditioning at the same time. But there is nothing we can do because we don't have any control over the heating, only the air conditioning. (P)



**Figure 6.3:** Temperature profile of the NUH Ward treatment room

The quote from the ward illustrates how heating control was insufficient due to problems with the installed TRVs. In response, the split units were used to achieve comfortable conditions, resulting in energy wastage from simultaneous heating and cooling. Clinical staff had no means to reduce heating use while cooling loads were multiplied. To a lesser extent, further challenges to energy efficiency rooted in technology and the material environment resulted from poor access to infrastructure such as switches for ceiling or task lighting.

### 6.4.2 Energy intensive prefigurations in health care

Literature, interviews and the analysis of departmental set-ups provided evidence for prefigurations of hospital services, spaces and protocols affecting energy demand at two levels: firstly at a very fundamental level with respect to how a good as important as health could be provided to a population and secondly, how this service (however it may be defined) was delivered as efficiently as possible. The former question was ethically and politically complex and touched on big questions around prevention, care in the community, palliative care as well as on issues around the privatization of the NHS. More imminently, promoting all channels of health care delivery including pharmacies, the NHS 111 helpline and GPs to reduce the use of A&E for non-life-threatening injuries seemed important also from an energy perspective. Although certainly extremely crucial for resource use and carbon emissions within the health care sector, these questions remained large outside of the scope of this thesis.

In terms of the efficient delivery of a health service as currently defined, issues resulted from the over-specification of space and equipment in hospitals. When asked what they disliked about their buildings, almost two thirds ( $n = 8/14$ ) of the interviewed staff at NUH and KCH commented on a lack of space resulting in overcrowding and overheating. In contrast, interviewees at the RLH talked about a much higher variety of individual dislikes including slow lifts, heavy doors, bad food in the canteen, the location of the hospitals with few interesting shops around and a lack of fresh air due to windows not being operable. Three staff, however, also mentioned poor signage throughout the building in combination with the following:

The thing I don't like now is the distances we have to cover. [...] It makes you tired at the end of the day. (L)

Objectively, the RLH offered much more space than the older hospitals, an average theatre suite (104 m<sup>2</sup>) for example was 1.5 times as big as in NUH (69 m<sup>2</sup>). 24% of the building's total usable floor area was however comprised of corridors, lobbies and stairs compared to 3 - 5% on average in shops, offices or factory spaces (no details available for hospitals) (Liddiard, 2014). Investigating an outpatient department, Bacon (2014) argued that sizing hospitals with view to actual occupancy could substantially reduce energy use (see also Bacon, 2015, for a more general and somehow clearer presentation of the argument). It would seem that the large conditioned circulation spaces at the RLH contributed unfavourably to the hospital's absolute energy use, while floor area normalized demand as specified in benchmarks characterized the building as more efficient. This raised some methodological questions around the measurement of and accountability for energy use, further discussed in section 7.2.2.

Similarly, basic lux level estimates based on audited lighting installations in the theatre departments appeared high at the RLH while spot validations with lighting level measurements suggested they somehow overestimated actual lighting levels (Table 6.4)<sup>15</sup>. Especially in corridors, not atypically, the over-specification of lighting installations with respect to the relevant norm BS EN 12464-1 far exceeded the uncertainty of the estimate, suggesting energy savings from reducing lighting loads may be feasible in circulation areas across the hospital. At the same time, clinical staff voiced satisfaction with the quality of lighting in their normal work areas in all three hospitals. The RLH actually scored with 5.7 (n = 10) slightly lower on a 7 point scale (1 - Unsatisfactory, 7 - Satisfactory, see also Appendix C.2) than NUH (6.1, n = 7) and KCH (6.0, n = 6). Uniquely, one RLH staff criticised glare on computers screens indicating that potentially lighting installations across administrative spaces could also be reviewed there.

Equipment levels in hospitals have been growing constantly over the last decade, counteracting improvements in equipment efficiencies. A longitudinal analysis of ERIC data revealed that the share of inpatient occupied beds with a patient power service (comprised of television, radio and telephone) grew from 10.5% in 2001 to 60.5% in 2008<sup>16</sup> across all English general acute hospitals. Similarly, more electricity intensive medical equipment was in use (Black et al., 2013).

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<sup>15</sup> It is appreciated that this is an indicative comparison only and measured lux levels will amongst others be influenced by maintained illuminance requirements.

<sup>16</sup> After 2008 the figure was no longer reported in ERIC, likely because this was now considered standard.

**Table 6.4:** Lighting levels in theatres

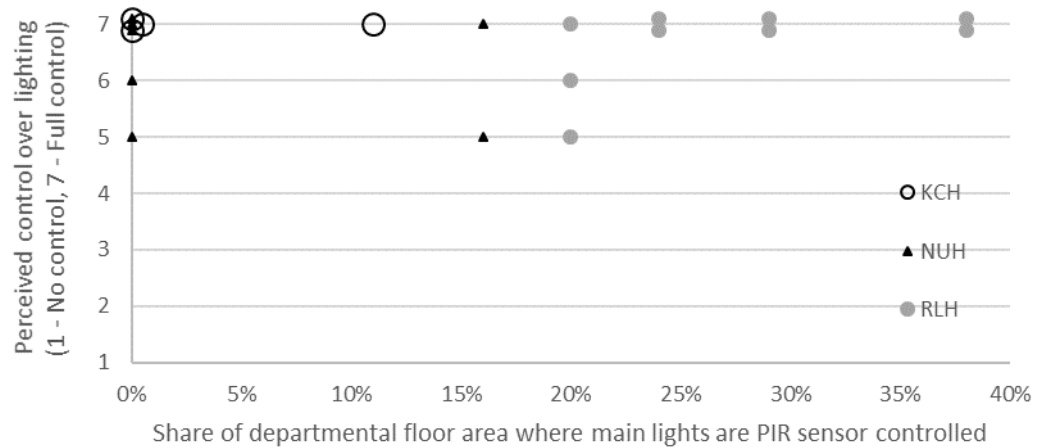
Lighting levels [lx]	Norm	Estimated			Measured
	BS EN 12464-1	RLH Main Theatres	NUH Main Theatres	RLH Day Theatres	RLH Day Theatres
Pre-op and recovery rooms (Anaesthetic room, Scrub room, Preparation room)	500	656	493	664	670
Theatres	1000	1653	1646	1394	1170
Corridors (Multi-purpose use)	200	502	180	356	450

In this context, NUH pathology staff described the shared use of medical fridges and centrifuges between haematology and biochemistry teams sharing a laboratory, after equipment had stopped working and not been replaced due to financial pressures. After an initial phase for customization, this arrangement worked fine for them while they made clear that they would use additional fridges and centrifuges if there were more. In the literature, Benke (2012) have previously reported similar examples of successful equipment sharing in hospitals. Although often out of necessity, this shared use of equipment between teams illustrates that current ways of doing things may be negotiable.

### 6.4.3 Technological helpers in saving energy

At the same time, technology may also help to deliver energy efficiency during departmental operation. In this, technology should be understood broadly specifying any arrangement or object that reduced resource use without the need for active involvement of staff (following Latour, 1999). When asked for ideas how their department could save energy, 7 out of the 22 interviewees suggested automatic sensors primarily for lighting and 6 favoured timers for lights, equipment and building services. On the whole, only taking responsibility individually (suggested by 10 interviewees) and doing something for your colleagues (9 mentioners) were believed to have more potential to save energy than these technological measures. Other suggestions for material helpers included for example lockers in the RLH dialysis unit allowing patients to store their own blankets there so that disposable blankets, excessive washing and high room temperatures could be avoided.





**Figure 6.4:** Perceived lighting control as rated by interviewees in relation to the share of departmental floor area controlled by PIR sensors

PIR sensors switching lights off after a certain time if no activity was detected were currently in use rather comprehensively at RLH and to a lesser extent in the other two hospitals. At NUH and KCH, a small number of PIR sensors had been retrofitted to public areas, some changing rooms and toilets while at RLH all public spaces including corridors were sensor-controlled. All out of the 10 interviewees referring to the PIR sensors evaluated them positively. Sensor control for the ultraclean ventilation canopy in the RLH theatres was also well received. This popularity of the automated lighting control seemed reflected in the interviewees' evaluation of their control over lighting which did not in any way seem to be diminished by the sensors (Figure 6.4). One interviewee related that the lights went out once while she was texting on a toilet but interpreted this as sign that the sensors were working really well.

The time between registered activity and switch-off did however seem to be a crucial criterion in evaluating energy saving potentials from PIR sensors. It is related by the RLH facilities team that it was initially tendered to purchase sensors for the new building which would switch the lights off 2 minutes after they had been triggered. During the value engineering process cheaper sensors were chosen waiting 20 minutes to go off, resulting in many lights being on almost continuously given hospital activity levels. One interviewee also observed that lights always seemed to be on in toilets, wondering whether the sensor might pick up on activity in the corridor through an open door - a known issue with many PIR sensors (BSI 2007). In combination, these challenges may seriously hamper the savings potential from PIR sensors and careful consideration during installation seems crucial.

Other technological helpers already in place across the case study hospitals included the sleep mode for PCs switching off monitors and sending PCs into energy saving mode after 30 minutes of inactivity. This feature was widely enabled in all hospitals and seemed to be perceived by occupants as so normal that it was rarely worth mentioning. All hospitals also featured an automated PC power down administered by the central IT departments which automatically switched off all workstations in non-clinical areas and some selected ones in clinical areas at 7 pm and re-started them at 7 am. Employees were further encouraged to communicate their actual working hours so that the power down software could be customized to maximise energy savings. The initiative appeared to be well received by staff across all hospitals, while few employees were aware of its existence and no-one was sure about details such as timings of the switch off.

In a wider sense, the 'quiet time' held on the NUH Ward (as well as on other wards within the Barts Health NHS Trust) could also be understood as technological helper as it introduced a schedule to be observed by both staff and patients. Between 12am and 2pm, lights were dimmed on the ward and TVs and other entertainment devices were switched off to allow for patients to get some rest. Additionally, this quiet time allowed staff to enjoy better defined lunch breaks. Staff reported that it was important for the quiet time to be institutionalised so that it could be argued to patients since on wards and in other care focused department types such as day units, control over lighting and equipment was shared between staff and patients.

Protocols were generally found to be crucial agents in achieving energy efficiency in situations where flexibility was required and full automation for example through timers was not adequate. Frequently it would seem that major saving potentials in particular in 24 hour areas with treatment functions resulted from matching room use to staff availability or activity levels, by for example switching off all but one X-ray room if only one radiographer was present during nights at NUH Radiology or switching off one of the three RLH X-ray rooms at 4pm rather than 5pm to match declining patient throughput (see also section 5.4). Desirable procedures were found to be more readily implemented if they offered non-energy benefits such as reducing stress at closing time at RLH X-ray or medical advantages such as more help at hand if night-time surgeries were concentrated in adjacent theatres in NUH.

Such protocols and ways of doing things were however often found to be in conflict with the notion of incessant availability in health care (see also section 7.3). But an anaesthetic nurse working amongst others in emergency theatres clarified:

One thing we tend to forget is that even in a dying emergency, you are being prompted. Let's say a head injury arrives at the A&E, and since this place is well developed, let's say in the UK we are well advanced, even before the patient comes here, we have a pre-information. Where I used to work, sometimes they would bring patients who have been involved in head injury, and the air ambulance normally brings them in, but before the air ambulance even lands on the hospital premises, we already have the pre-information. So by the time they land and transfer the patient, even if he goes straight into theatres, we should get ourselves sorted out. (A)

#### **6.4.4 Section summary: Implications of technological constraints**

This section uncovered a number of challenges for low carbon hospital operations from technology and the material environment. Insufficient working means, in particular heating and cooling systems, were identified to pose major challenges to resource efficient operations of hospitals. Problems with temperature control as well as simultaneous heating and cooling resulted in the waste of energy, but likely also affected clinical outcomes, staff morale and operational costs. Science and technology studies have long stressed the importance of artefact functionality in organisational ability (e.g. Goldkuhl and Braf, 2002). The findings of this study support the interpretation that in particular constraints from material problems need to urgently be addressed as well as taken into account in any attempt to affect organisational change. Protocols shaping the way things were done further had a huge role as flexible helpers to energy efficiency, while technological helpers could achieve savings in well defined and more rigid processes.

The presented analysis indicated a prefiguration of hospital services, spaces and protocols which affect energy demand at two levels: firstly with respect to how health is provided to a population and secondly, with respect to the resource use that was considered necessary and/or appropriate in this process. The former, very fundamental consideration remained largely outside the scope of this study. As for the latter, it was found that hospitals tended to be a risk-averse environment (see also section 6.3.1) in which there was a tendency to over-size systems and spaces in new designs. In existing hospitals, however, overcrowding and overheating was a problem, suggesting there was a fine balance to strike here. Section 7.3 will further address some of the resulting challenges, while this chapter highlighted the value of Schatzki's concept of prefiguration in uncovering the linkage between crisis response strategies in the past and their implications for the future.

### **6.5 Summary of qualitative findings**

This second findings chapter analysed how attempts to achieve end-use energy savings were constrained in the complex socio-technical systems that real-world hospital departments constitute. The presentation of the (primarily) qualitative findings is guided by Gram-Hanssen's (2013a) empirical analysis framework for social practices according to which the four elements embodied habits, knowledge, meanings and technologies mutually shape each other and the practice in question.

In the presented analysis, energy saving at work was initially conceptualised as a practice. But during the analysis it was found that adjusting the operational states of lighting and appliances tended to be part of a set of other activities which clinical staff performed, making energy saving in hospitals more akin to a ‘proto-practice’ (Shove et al., 2012, p.25) rather than a fully integrated practice in its own right. Proto-practices are characterised by no or only weak links between the different elements which mutually constitute a practice. Albeit hard to predict and difficult to enact, this finding implies that the making or strengthening of links between the analysed practice elements could be one possible strategy to reduce energy and resource use in hospitals.

The chapter further highlighted a lack of joined-up knowledge on how to locally define (energy) best practice, especially in complex and energy intensive department types such as laboratories and operating theatres. Neither local clinical staff nor facilities or energy personnel seemed to have full insight into departmental operations, which tended to be defined through both local and central processes. In contrast, the local knowledge on how to control specific building services seemed well established in most departments: it generally formed part of the institutionalised knowledge and was shared between intermediate level professionals, primarily nurses. In combination with strong core-teams, this arrangement seemed to work well for most building users, including those excluded from directly exercising control over their environment due to vulnerability or a focus on other responsibilities.

An efficient use of energy services was also limited by uncertainties as to whether spaces and equipments may still be needed by other building users after hours. Such uncertainties proved particularly relevant in health care where social considerations aimed at accommodating potential needs of others proved to have much meaning. This often resulted in increased energy use because ‘on’ was maintained as the default mode of operation for equipment and lights in case a colleague or a patient might require these services. At the same time, saving energy was found to hold little meaning for most clinical staff in the face of many competing priorities and a lack of leadership on sustainability issues. Saving energy was, if at all, considered a tool to avoid cuts in the departmental budget or proclaimed as the morally right thing to do to preserve resources for future generations. While clinical staff intellectually ascribed some importance to saving energy at work and thought much about recycling, it was in particular considered ‘normal’ and ‘human’ to engage little with lighting use, especially in shared spaces. These findings again emphasized that energy saving as such did hardly constitute a relevant practice in hospital departments.

The chapter finally uncovered significant challenges to satisfactory as well as resource efficient hospital operations from insufficient working means, in particular under-performing or malfunctioning heating and cooling systems in older hospitals. The new hospital investigated in this study achieved better thermal comfort levels, while there was some evidence for the over-sizing of spaces, in particular corridor spaces, and systems (including boiler and lighting installations) which negatively impacted on absolute energy use. Importantly, floor area normalised energy use, a metric typically used in energy performance benchmarking, appeared lower due to the larger dimensions, highlighting the need for additional energy performance metrics based on service delivery instead of floor area - a proposal further discussed in section 7.2.2.

More generally, the next chapter 7 will now proceed to discuss further strategies to achieve end-use energy savings in hospitals given the estimated savings potentials from simple operational changes (chapter 5) as well as the recognised constraints and enabling factors (this chapter 6).

# 7 Achieving end-use energy savings in real-world settings

The discussion chapter brings together findings from the quantitative and the qualitative findings chapters and jointly discusses their implications, thereby addressing the research objectives *iii* (7.1 - 7.2) and *iv* (7.3 - 7.4). The first section 7.1 proposes an assessment framework by which the relevance of simple operational changes to save energy can be gauged in different buildings and building parts. Some suggestions to reduce the end-use of energy in hospitals based on the empirical study findings are also made (section 7.2). The next section (7.3) investigates how clinical processes are conceptualised from a facilities management perspective, highlighting some limitations and room for improvement with a view to reducing hospital resource consumption. Section (7.4) finally suggests developments to the concept of an energy savings potential as metric for decision support in organisational carbon management processes.

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## 7.1 Assessing the relevance of simple operational changes to save energy

Various staff-centred energy conservation initiatives have previously been trialled in hospitals in the UK and worldwide, with varying success (section 2.2.1.2). The available evidence was however largely limited to hospitals as a whole and little information is available on scope and viability of interventions across different departments despite their very different occupational and procedural characteristics (section 2.4.2). Guidance documents on energy management however stress the need to break buildings down, for example into areas with different uses, operating hours and tenancy arrangements (CIBSE, 2012). This study consequently investigated the influence of clinical staff on electricity use across five hospital department types with differing operating hours, energy intensities and roles within clinical patient pathways (see chapter 4 for a description of the department types).

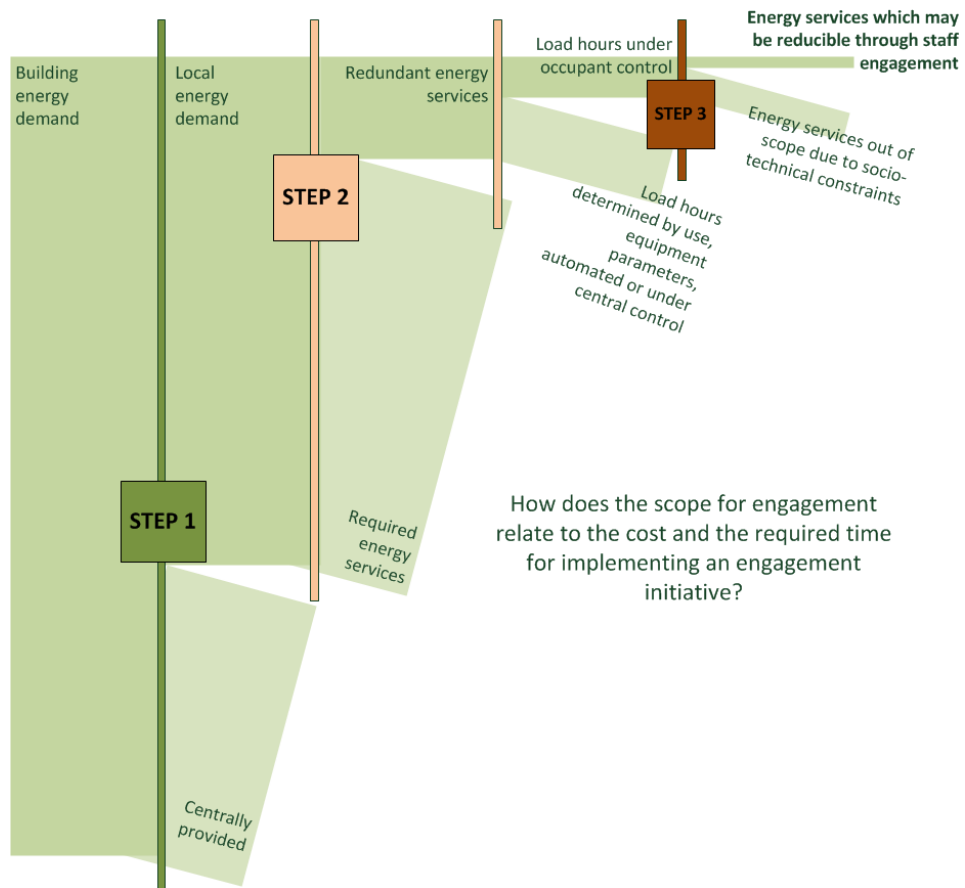
### 7.1.1 Proposed assessment framework

One objective of this study was to suggest a process by which the relevance of behaviour and other simple operational changes as tools for carbon mitigation in organisations can be assessed. Given its small scale, the study does not attempt to provide a blanket recommendation for the use (or not) of behaviour change initiatives to achieve energy savings in different hospital departments and buildings. Rather, it highlights the importance of a robust understanding of contextual variables in devising tailored organisational carbon management strategies. It is proposed that a three-tiered process may be appropriate in identifying parts of a building or estate where simple operational changes may be a viable tool for carbon mitigation (Figure 7.1):

1. In a first step, it is recommended to undertake an engineering analysis of the energy end-uses in the buildings and spaces in question, identifying significant loads at a local level. CIBSE TM22 (CIBSE, 2006) or other bottom-up energy assessment and audit methodologies provide guidance for this process.
2. Secondly, areas where energy services are provided but may not be required for service delivery (redundant energy services) and the extent to which such loads are influenced by the actions of occupants need to be determined. As discussed in the quantitative findings chapter 5, floor area weighted opening hours and staff control over energy-intensive end-uses may be helpful metrics to allow for a first order assessment.



3. If areas with significant load hours under occupant influence are identified, an analysis of socio-technical constraints could subsequently guide further efforts at strategy development. Gram-Hanssen's framework illustrating the nature of social practices based around the four interacting elements of embodied habits, knowledge, meanings and technology may be helpful here, while other theoretical propositions (see literature section 2.3.2.1) could be equally appropriate.



**Figure 7.1:** Sankey diagram illustrating the proposed assessment framework for staff engagement initiatives<sup>1</sup>

<sup>1</sup> The purpose of this diagram is to illustrate the assessment process while providing a sense for the orders of magnitude of energy flows. The presented flows are based on evidence for electricity gathered in this study as follows:

1. Roughly two thirds of hospital electricity use may occur in a decentralised fashion (see Figure 1.2).
2. The maximum theoretical savings potential was of 12% of local electricity use, albeit with some variation depending on department characteristics (see Figure 5.4).
3. Many departments were found to be rather constraint environments, suggesting that the actual savings potential is likely to be much lower than the theoretical one. An exact quantification of the socio-technical constraints was not attempted as part of this study.

Appropriate indicators for the assessment of socio-technical constraints are somehow harder to pin down than those relating to technical drivers of energy use only. The qualitative findings (chapter 6) of this study highlight a number of potential factors defining the viability of changes in local practices in hospitals, none of which have (as yet) been quantitatively assessed against their respective impact on savings potentials. Quantifying the impact of some of these diverse influences on building performance may hence represent a worthwhile area of future research (see section 8.4.2).

For the time being, four factors are selected for subsequent discussion due to their perceived importance in hospitals and their potential applicability in other non-domestic building types<sup>2</sup>: the local knowledge on building services and equipment, the shared use of space, the morale within the organisation and the suitability of working means.

1. Importantly, the need for **local knowledge** on operational characteristics of building services and equipment was identified to be a crucial pre-requisite for energy efficient runnings. This included certainty about whether process equipment could be switched off or into stand-by as well as an understanding of how building services such as heating or specialist ventilation were controlled. Out of the the presented factors, local knowledge is the least disputed - with both individualist and socially orientated scholars agreeing on its importance (see literature review chapter 2.1).

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<sup>2</sup> It is proposed that none of the identified factors stands in isolation and while the immediate impact of for example insufficient working means on energy use may be drastic, a resilient socio-technical system may be able to compensate for such a challenge. To illustrate this hypothesis for an empirical case: Excess energy use will be substantial if radiator valves are stuck and air conditioning needs to be used to combat overheating. But if staff are enthusiastic about their work, feel responsible for their space and further know who to call about this technical problem, chances are that it might get sorted reasonably fast.

2. In the hospital context, a number of engagements of clinical staff were identified, amongst which caring for others featured prominently. From an energy perspective, the kind concern for the well-being of others however often resulted in increased energy demand because it made ‘on’ the default mode of operation for equipment and lights. This was in particular the case in departments where the spatial arrangements required the shared use of office spaces, locker or staff rooms with other departments with differing operating hours. Uncertainty could arise there for staff as to whether energy services were still needed by someone or not. The **shared use of space** with strangers could reduce staff engagement with energy services, comparable to energy behaviours reported as typical for transient spaces (Cox et al., 2012).
  
3. A comparison of evidence from offices or manufacturing with accounts on the realities of working life collected in this study indicated that, from an employee perspective, hospitals were little different to other work places in many aspects (see section 6.3). Saving energy was perceived an indirect tool for employees to improve their work environment through reducing the organisation’s bills. The relevance of such financial motive however relied on a strong and trustful relationship between employer and employee forming the basis for engagement. Inspiring places to work may moreover not only boost people’s **morale** to engage with energy issues but to take responsibility for service quality and delivery more generally, a factor applicable in all workplaces (Lo et al., 2012; Pellegrini-Masini and Leishman, 2011).
  
4. And finally, **insufficient working means** (in particular heating and cooling systems) were identified to pose major challenges to resource efficient hospital operations in this study. Problems with temperature control as well as simultaneous heating and cooling resulted in the waste of energy, but likely also affected organisational outcomes, staff morale and operation costs. Science and technology studies have long stressed the importance of artefact functionality in organisational ability (e.g. Goldkuhl and Braf, 2002), highlighting the relevance of this aspect across building types.

### 7.1.2 Exemplary assessment for hospital buildings

The proposed assessment framework can be applied to the hospital departments analysed in this study, exemplifying its use while juxtaposing the findings of the different data collection methods employed.

**STEP 1:** Based on a review of the literature on hospital energy use, chapter 1.1.2 identified that about two thirds of a hospital's electricity consumption typically are from lighting or plug loads (such as IT or medical equipment and food preparation) and therefore occur in a decentralised fashion across the estate. Local as opposed to central energy demands can be difficult to address due to their fragmented nature and the multitude of actors involved in bringing them about, making staff engagement one possible carbon mitigation strategy worth exploring further.

**STEP 2:** Chapter 5 differentiated local electricity demands to show that lighting loads are typically dominant in low-intensity hospital departments such as wards or day clinics. High-intensity department types such as operating theatres and laboratories were dominated by specialist equipment loads (including theatre ventilation). For change initiatives, such **energy intensive departments** may offer large potentials for absolute savings due to the energy intensity of the departmental processes.

A subsequent analysis of the theoretical savings potential achievable through simple operational changes across different departments based on the identified metrics (chapter 5) suggested two departmental archetypes potentially holding relevant end-use energy savings from simple operational changes in hospitals. Firstly, **departments with defined after-hours** had substantial not-in-use periods. And secondly, **outpatient departments (ODPs) focused on consultations or diagnosis** seemed to exhibit high levels of clinical staff influence over installed electrical loads. Notably, they were often also defined by clear after-hours.

**STEP 3:** According to the qualitative findings (chapter 6), fewer constraints and therefore potentially higher savings potentials for initiatives aiming to engage clinical staff with energy issues were believed to prevail in:

- A) **Departments with many individual spaces:** due to less need for social considerations and clearer attributions of switch-off responsibilities;
- B) **Simple departments with well established switch-off protocols:** where energy and sustainability best-practice agendas could easily be established and were conveyed to relevant staff through the provision of appropriate and comprehensive training sessions;
- C) **Inspiring places to work:** where most employees were enthusiastic and prepared to go the extra mile while encouraged by the management to contribute ideas for improvements; and finally

**Table 7.1:** Simplified cross tabulation of departmental archetypes with relevant energy savings potentials according to different findings (quan + qual)  
Green cells represent circumstances where the quantitative and the qualitative conditions would likely occur in the same department, while for red cells the respective conditions exclude each other.

Department types with relevant energy savings potentials according to qualitative (right) and quantitative findings (below)	A) Many individual spaces	B) Simple departments	C) Inspiring workplaces	D) Functional & Efficient
1) Energy intensive		○		○
2) Defined operating hours		○		
3) OPDs with limited patient residence	○	○		

D) **Functional workplaces:** where both infrastructure and service definition were in excellent working order and optimised for low energy use, allowing employees to focus on their core activities.

A cross-tabulation of the departmental archetypes identified through quantitative and qualitative analysis respectively shows limited deterministic overlap between the categories (Table 7.1). Solely, arrangements tended to be more complex in energy intensive departments, complicating the identification of best practice procedures. At the same time, the cost of energy was more present to clinical and managerial staff there, potentially supporting the rollout of an energy efficient standard for working means. Due to the high patient throughput and in order to meet privacy and dignity standards, outpatient departments often held separate and clearly signposted facilities and responsibility conflicts resulting from the shared use of space were less common. Finally, department types with defined after-hours tended to have more established switch-off protocols, while the clear after-hours reduced social considerations according to which lights and equipment were left on in case someone might need them.

The limited overlap between departmental archetypes identified through quantitative and qualitative analysis suggested that both are important in order to identify relevant savings potentials. At a methodological level, the breadth and the range of the inquiry was therewith successfully expanded by the mixed-method deployment (see section 3.4.1).

Overall, the proposed assessment framework qualitatively outlined a process to select spaces within complex buildings where behaviour or other simple operational changes may represent viable tools for organisational carbon management. Field tests are recommended to establish whether the proposed framework is useful to practitioners in thinking about staff engagement initiatives in organisations.

## **7.2 Strategic suggestions for end-use energy savings in the hospital context**

In addition to proposing a procedural assessment framework, a number of suggestions to improve operational energy efficiency in existing hospital buildings can be derived from the presented empirical analysis of departmental energy use (chapter 5) and constraints on end-use energy savings (chapter 6). The suggestions are briefly outlined below and aim to improve on (7.2.1) or go beyond (7.2.2) simple staff engagement strategies.

### **7.2.1 Socio-technical suggestions for staff engagement in hospitals**

As pointed out in section 2.4, energy managers may resort to staff-centred energy conservation initiatives and other attempts at simple operational changes for a number of reasons, namely a lack of funding, time or control over infrastructural components. Despite debate about using socio-technical analysis in favour of individualist attempts at changing behaviours (section 2.1), it will hence seem to this author that there is value in taking account of a wider number of constraints and enabling factors also in the design of staff engagement campaigns.

Table 7.2 suggests a number of potential strategies corresponding primarily to the first level of the proposed conceptual framework (Figure 2.4), which will be discussed in more detail subsequently. Importantly, none of the proposed strategies has been tested within the remit of this study; they are hence to be understood as an invitation to think more broadly about staff-centred energy conservation initiatives in hospitals rather than as prescriptive recipes for success.

**Table 7.2:** Possible strategies to promote staff engagement with energy issues

Sphere	Improved staff engagement strategies in existing hospital buildings
Habits	Promoting lighting and equipment switch-off as part of a routine: ‘Time to go home’
Knowledge	Focusing engagement campaigns on intermediate level professionals taking into account their routines and motivations as well as tailoring communication means and messages to them
Meanings	Investment in job satisfaction through accountable local leadership, appropriate staffing levels as well as a culture of openness to ideas and feedback
Technology	‘Quick fixes’ for overheating issues where possible such as load re-distribution (Christiansen et al., 2015) and safety features for windows to make them operable

This study has highlighted that the switch-off of lights and equipment across all departments tended to be driven by routines, not by demands. Those switch-off actions that appeared habitual in character were found to be firm part of a temporal routine, in particular at closing time. In order to promote equipment and lighting switch-off, it consequently seemed important to acknowledge their place within a wider cluster of activities which people carried out to end their shifts. This may include activities such as cleaning or the hand-over of information which potentially are more closely associated with clinical outcomes and therefore of higher priority to staff. Promoting these combinations of activities, potentially with the positively connoted message ‘Time to go home’ after a long and busy working day, may be more promising than focusing on switch-off actions alone<sup>3</sup>.

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<sup>3</sup> Clinical staff were in some cases also found to be unsure about the operating characteristics of specialist medical equipment, making it impossible for them to decide whether or not equipment could be switched-off or into stand-by. In line with suggestions by others (Jensen and Petersen, 2011; Rohde and Martinez, 2015), it therefore appeared important to clarify options for the switch off of medical equipment.

It also seemed important to tailor engagement campaigns to reach out to the appropriate individuals, in particular in strictly hierarchical environments with strong labour division like hospitals. This study found that the knowledge on and the responsibility for controlling building services (potentially beyond lighting but often even including lighting) was concentrated in the hands of nurses and comparable intermediate level professionals such as operating department practitioners (ODPs) in theatres. Engagement campaigns in clinical areas of hospitals might hence want to concentrate on them by taking into account their routines and motivations as well as tailoring communication means<sup>4</sup>. This will also include ensuring good morale so people feel prepared to go the extra mile.

Finally, challenges that remain on the systems-side may not be overlooked when attempting to improve operational energy efficiency, in particular with respect to overheating issues. Ultimately, well-being and comfort needs of patients and staff take priority over energy issues as energy demand is essentially a by-product of service provision and not vice versa. Often, technological challenges will be substantial and require more fundamental investment and re-thinking, but at times easy and low-cost ‘quick fixes’ may be available to ensure that the comfort needs of all occupants are being met while eliminating energy inefficient work arounds.

### **7.2.2 Beyond behaviour and simple operational change**

Findings chapter 5 has shown that the theoretical influence of clinical staff on hospital electricity use was limited in most hospital departments, while chapter 6 hinted at the wide range of other stakeholders and processes involved in the resource efficient operation of a hospital. This section briefly outlines a number of avenues other than simple behaviour change which appeared beneficial throughout the case study investigation.

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<sup>4</sup> Nurses did for example spend limited time at a computer (as opposed to people in offices) and their day to day was determined by much moving around and face-to-face interaction with patients, colleagues and visitors. Engagement approaches meeting them directly in their department and inviting their input on the functionality of working means while discussing switch-off procedures consequently seemed most promising, despite the required investment of time.



In line with current practice in many hospitals, this study found it recommendable to make use of appropriately configured technological helpers (such as PIR sensors or timer settings for IT equipment) wherever possible as they proved popular with both clinical and technical staff (section 6.4.3). In particular for centrally controlled timer settings, manual override functionality appeared appropriate to customise technological helpers and enable them to flexibly meet the local demand. Timer settings could for example be implemented for anaesthetic gas scavenging systems in theatres based on planned operation (section 4.4.2) if effective options for override allowed staff to take the pumps in operation whenever necessary. In hospitals with powerful HVAC systems such as the new-built RLH, night-time temperature set-backs could also be implemented throughout as and when manual override functions allowed staff to adjust the temperatures locally in case of unplanned space utilisation, including for emergency surgery (section 6.2.1).

It also seemed that not only the use but also the purchasing of medical equipment deserved more attention. In tendering for any hospital equipment, clinical requirements are of course central. Cost savings from equipment sleep modes or quick re-calibrations allowing for complete switch-off after-hours would however seem a persuasive argument for including energy efficiency criteria in procurement specifications. Jensen and Petersen (2011) report that currently few tenders for energy intensive imaging equipment included energy use as criteria in Denmark. In the UK, the late NHS Purchasing and Supply agency published an assessment tool for energy efficiency requirements of electric medical devices (Centre for Evidence-based Purchasing, 2009), but its use (or lack of) remains in the hand of individual hospitals.

Against this background, it was felt that the hierarchical environment prevalent in hospitals subordinating other professions to doctors may be complicating it for equipment technicians to take a stand in procurement questions. Further research into the power dynamics of such relationships to clarify this notion is recommended (see also section 8.4). Collaborations with equipment manufacturers and vendors may also be a route to innovate towards a new product generation with lower electricity use (Rohde and Martinez, 2015).

Findings in this study have further suggested that the specification of energy benchmarks per floor space may benefit the over-sizing of new health care facilities<sup>5</sup>. Based on past experiences with overcrowded hospitals, a generous allocation of space is certainly desirable especially with respect to the future flexibility of a building. There may however be a danger of overshooting, with associated negative implications for energy and resource consumption, including construction materials.

Specifying additional energy targets on the basis of service delivery may consequently be one way forward, despite obvious complications with how service delivery should be specified. There is, however, a wealth of thinking available which has gone into clinical accountability and costing of treatments. It will seem to this author that increased collaboration between facilities managers and interested clinicians as well as administrators may be a way forward here to provide additional metrics for the energy performance benchmarking of hospitals.

The following section 7.3 now proceeds to reflect on some of these issues more abstractly, in order to contribute to the generation of theory.

### **7.3 The black-boxing of (clinical) processes**

Chiu et al. (2014) analyse the process of domestic retrofit from a socio-technical perspective. They reveal the existence of a dynamic and iterative adaptive process between technology, project teams and occupants, where retrofits have previously often been regarded as ‘black boxes’ (following Latour, 1999). This section uncovers parallels to such black boxes in the conceptualisation of clinical processes in hospitals from a facilities management perspective.

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<sup>5</sup> Somehow similarly, English (2014) suggests that air-changes-per-hour (ACH) are an unhelpful metric to specify required dilution ventilation rates in hospitals: Using ACH benefits the over-sizing of ventilation systems by not taking into account that contaminants naturally dilute in larger volumes.

### 7.3.1 The phenomenon of process black-boxing

Over the course of this research project, the author variously came across the notion that local operational energy savings were unlikely within hospitals due to the importance of the processes ongoing there, a suggestion repeatedly voiced by practitioners and academic experts in the buildings field. Reductions in hospital carbon emissions were considered feasible primarily through central changes to buildings and systems or supply-side initiatives such as combined heat and power plants or renewables (see chapter 1.1.3). During data collection on the ground, the only non-clinical interviewee, an IT expert responsible for the computer-based archiving of radiologic diagnosis results, also stressed the difficulties for energy saving attempts in clinical areas:

It is difficult. Because it is a clinical area. Because services are run and patients are in and out the trust at particular times. You know, it will be difficult. But I think it is achievable in areas that are not... in non-clinical areas, especially the offices having a note to switch off after for example 8 o'clock. (I)

The technical analysis in this study (see chapter 5) confirmed a higher energy savings potential from behaviour and simple operational changes in areas with defined operating hours. It did however seem notable that if clinical staff argued that more energy could be 'saved elsewhere', they did so on size and process grounds as part of the clinical work flow (see section 6.2.1). Non-clinical staff and building experts in contrast seemed to take an outside look and considered the clinical process sacrosanct, similar to the black box proposed by Latour. health care was conceptualised as non-stop and emergency driven while the impression on the ground taking a clinician perspective was quite different.

On the ground, established protocols were in place to manage in particular emergency situations and staff's designated roles and responsibilities helped to structure complex and potentially life-saving activities into manageable and almost routinised tasks. As one staff working amongst other in emergency theatres put it:

There can be no panic. Because if there is panic, there will be mistakes.  
(X)

Powell et al. (2014) concluded similarly from an interview study in an accident and emergency department where new nurses and doctors tended to find the environment stressful at first but then got used to it. health care became a job like many others - leaving little room for the argument that considering changes in clinical processes needed to remain out of bounds in attempts to develop strategies for reducing the resource consumption of hospitals.

Similar notions of ‘process black-boxing’ have also been identified in other contexts, albeit for different reasons:

- An expert discussion group between about 20 academics and practitioners experienced in consulting energy intensive industries concluded that the energy managers of manufacturing companies were often responsible for the building sided energy use only but had no control of or even insight in the production processes (ECEEE, Informal session 04/06/2015).
- Various energy managers of universities (UCL, Cambridge University, King’s College London) have also commented towards this author that they held no authority over energy-intensive research laboratories, including extensive plant growth facilities accountable for large shares of the fuel bill<sup>6</sup>.

### 7.3.2 The implications of process black-boxing

The interest in ensuring the quality of the respective process varies across the three contexts discussed above (ensuring human health, protecting commercial interests or guaranteeing sensitive research designs), but the outcome from an energy perspective seems comparable: the limited insight in and understanding of organisational processes leaves little scope for holistically identifying opportunities to reduce the associated energy use.

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<sup>6</sup> Often, the operation of HVAC systems in complex non-domestic buildings is also contracted out and no longer within the responsibility of building or energy managers (for example Palm and Darby, 2014, for hospitals common through public-private partnerships). It is believed that such increasing fragmentation of building management tasks complicates the holistic analysis and optimisation of building operations. Opportunities for energy demand reductions may hence be left out of consideration.

In hospitals, the disconnect between the clinical reality and its conceptualisation by non-clinicians (including facility managers and those developing carbon mitigation programmes for hospitals) pointed towards the important question of who, if anyone, did hold knowledge on reducing departmental electricity use. The dichotomy between clinical and energy knowledge was also evident in the conception of this research project, which for the generation of ideas on potential operational changes sought input from the interviewees as local experts, while interviewees interested in sustainability were found to frequently hope for input from the researcher. A risk of overlooking potential savings options seemed to result from this lack of joined-up knowledge on energy conservation pathways specific to the hospital setting.

Such detailed analysis will arguably take more time at the ‘energy planning stage (BS EN ISO 50001: 2011)’ and during implementation, while time is at a premium in hospitals and many other contexts. In many cases, however there seems to be scope for and mutual benefit from more collaborative attempts between core staff (i.e. clinical staff in hospitals, production engineers in the manufacturing industries or scientists in university laboratories) and those focused on cutting the organisation’s carbon emissions to explore and establish acceptable operational states associated with lower levels of service delivery. Notably, such attempts move the extent of operational changes more towards the third level depicted in the conceptual framework presented in section 2.4.1.

### **7.3.3 Suggestions for looking inside process black boxes**

Comprehensive operational changes require fundamental questions around how services in general as well as building services requirements are understood and defined. The following paragraphs place the findings of this study against the literature to highlight some scope for questioning established notions.

**Service understanding:** In their practice based study of four UK research laboratories, Palm and Darby (2014) question the notion of 24-hour buildings. They argue that ‘while the concept of a 24-hour building might sound flexible and empowering (p.82)’ and even represented an asset attracting academics to the university, the actual need for and use of the building between 11pm and 7am was minimal.

Similarly, this study found that even hospitals - where the need for some 24-hour provision to deal with emergencies is not subject to project deadlines, cultural interpretations of work ethics or personal ambitions - did not correspond to the notion of a 24-hour building. Parts of departments did of course operate on a 24 hour basis but this requirement would hardly extend to entire departments yet alone the entire building (chapter 4.7). Many hospitals nevertheless seemed to operate as continuously on, both from an employee and potentially more importantly also from a facilities management perspective. A higher resolution in the spatial understanding of operating characteristics may be an important step forward here (see section 8.3.1.1 on study implications for facilities professionals).

**Specifying requirements for building services:** This study further highlighted some of the difficulties associated with specifying the required levels of building service delivery in the sensitive context of hospitals (see for example section 6.3.1 on temperatures in operating theatres). Mathew et al. (2004) also address the tricky topic of health and safety in specialist buildings in their study on required ventilation rates in laboratories. They conclude that even in the health-critical context of labs ‘(t)he definition of what constitutes a requirement is often open to interpretation, and should not necessarily be taken at face value’ (Mathew et al., 2004, p.3-237). English (2014) seconds this call for ventilation rates in US hospitals more generally: Based on an informal and non-peer reviewed web survey, he finds that ‘some consulting engineers say they feel “handcuffed” by the ventilation standard (“We could achieve so much energy efficiency, if only we could change the ventilation rates”), while others believe the ventilation rates are akin to a moral imperative (“If the code says 6 ACH, anything less endangers patients”)’ (p.1).

The above quotes go a long way to illustrate that the stakes in all questions assessing actual service requirements in hospitals are high. It will nevertheless seem to this author, that given the urgency to reduce carbon emissions in all sectors of society, careful analysis and constructive debate should not remain out of bounds.

Consequently **three strategies** allowing facilities and energy managers to look into the black box of clinical requirements are proposed, based on an evaluation of the literature as well as the experience of this author acquired over the course of the project. It is thought that likely all of them will be needed, while the knowledge gap between the facilities and the clinical understanding may progressively decrease from 1 to 3:

1. **Seeking out process information in clinical reports:** Clinical reports on hospital operations could be regarded as tools to establish dialogue as they - although likely too complex in many aspects from a lay perspective - highlight priorities and workflows from a clinical perspective. Bacon (2015) argues that 'It is through such clinically led studies that the estates professional is able to find the clues to the evidence base that is required to enter into an informed dialogue with the clinical leadership teams' (p.46).
2. **Collaboration with interested clinicians:** Health professionals increasingly recognise air quality issues and climate change as threat to human health (Watts et al., 2015). Numerous organisations in the UK, such as the Oxford based Centre for Sustainable Health Care or the medicine student-led organisation Healthy Planet UK as well as many personally interested clinicians (for example Pierce et al., 2014, and many others met during the fieldwork) are actively engaged in moving the sustainability agenda forward from the clinical side. van Amstel et al. (2015) further give recommendations to encourage participatory design practice in health care projects.
3. **Novel methodologies for the assessment of service requirements:** Novel methodologies including modelling and simulations are needed to assess actual process requirements in detail. Mathew et al. (2004) for example propose computational fluid dynamics (CFD) simulations of different spill scenarios to determine safe ventilation rates in laboratories. System-dynamics based participatory and group modelling exercises also seem particularly rewarding in this sensitive context to capture demands and concerns of all involved stakeholders.

Albeit time consuming and potentially difficult, it seems that the proposed methods may contribute to opening the black box of clinical processes in different hospital departments and can therefore help to identify more fundamental end-use energy demand reduction strategies. Similarly, the next section (7.4) suggest developments to the concept of an energy savings potential as metric for decision support.

## 7.4 A real-world energy savings potential

Section 2.2.2.1 highlights the importance of ex-ante evaluations, i.e. attempts to forecast intended energy savings of future projects before an investment decision is made. Savings potentials are a commonly used metric in this context.

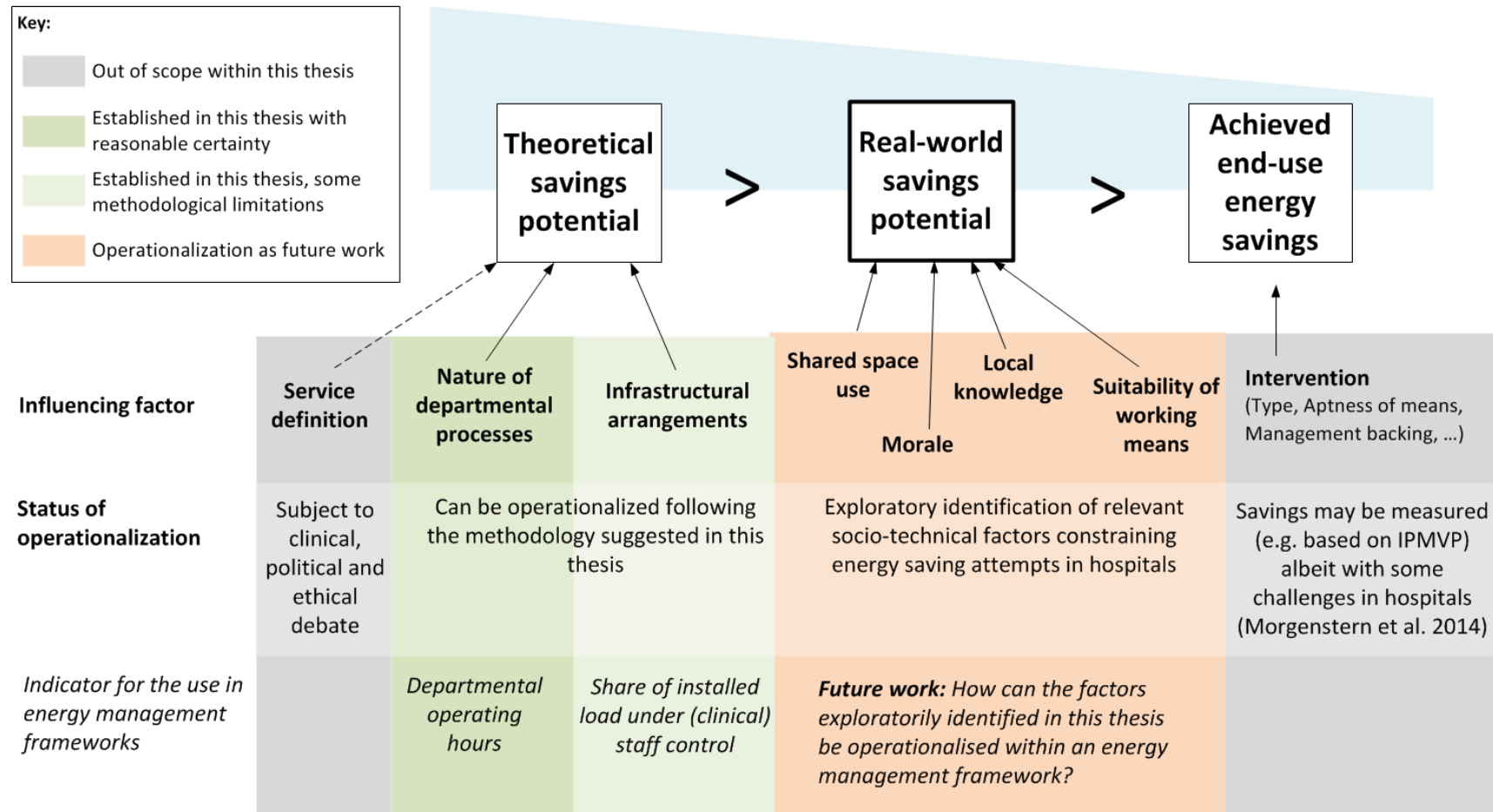
So far, potentials have been differentiated according to the type of change by which they might be achieved. Rather unanimously accepted, technological changes to buildings such as fabric or system upgrades are projected to obtain certain technical energy savings potentials. Some further expect that behavioural changes in the ways individuals interact with technologies may render behavioural savings potentials. And finally, Moezzi and Janda (2014) proposed the concept of a social potential as an emerging container aimed to shift the attention of the building energy efficiency industry away from a focus on individuals and towards a ‘more creative and contextual orientation that recognizes the importance of social relationships in creating use and in changing it’ (p.9).

It was one objective of this study to contribute to the concept of a socio-technical energy conservation potential. Rather than specifying the type of change by which energy savings may be achievable, it was felt that such a potential may be useful in highlighting an additional dimension which becomes relevant when the ‘potential’ concept originating in the field of engineering and its dealings with technology is applied to any aspect of change involving people: the analysis in this study exposed the need to move away from top-down imposed models of local change, taking a user-perspective instead. Inevitably, there will be differences between the perspectives of intervention designers or implementers on the one hand and the perspectives of those involved in bringing about the proposed changes on the other hand. Often, it appeared important to focus on changes that seemed ‘reasonably achievable (Dietz et al., 2009, see also section 2.2.2.1)’ to the occupants (rather than outsiders), giving appropriate consideration to operational, organisational as well as social constraints.

Aside from a theoretical savings potential, the concept of a real-world savings potential is hence proposed which takes an in-situ perspective and recognises the constraints applicable in real-world socio-technical systems (Figure 7.2). Regardless of whether the proposed intervention type is technical, behavioural or social, the real-world energy savings potential will be smaller than the theoretical potential. While such a gap can ideally be relatively minor for technical interventions, it may - subject to how well context and constraints were understood - be far bigger for all socio-technical interventions, i.e. those directly involving people.



## Overview of the thesis's contribution to knowledge



**Figure 7.2:** A real-world energy savings potential: overview of the thesis's contribution to knowledge

It is however increasingly recognised that even for primarily technological solutions, their implementation is crucial and people and their actions have an important role therein (e.g. Lowe et al., 2007). Assessing real-world energy savings potentials rather than theoretical potentials hence emphasizes the need to involve people as active participants in all transition processes in order to close this gap. For technical potentials, this will include focusing on how technologies work in practice rather than in tests and laboratory situations. For behavioural and social potentials, more attention needs to be on taking an end-user perspective in order to understand the complexity of reasons for the status quo and resulting consequences for change.

## 7.5 Summary of the discussion

This discussion chapter set out to evaluate the relevance of staff engagement and simple behaviour change as tools for carbon mitigation strategy in different hospital buildings and departments. A process is proposed by which buildings or building parts can be identified in which energy savings may be achievable through simple operational changes. The process combines an engineering analysis of local energy demands with an investigation into contextual factors which may constrain (or enable) changes in organisational practices. Such mixed use of both quantitative and qualitative as well as technical and social research methods enables an understanding of opportunities for change which could hardly be achieved using one type of methods alone.

It is further argued that in hospitals, which may be understood as one example of a complex socio-technical work environment, it is paramount to take a user-perspective when aiming to understand what constitutes a reasonably achievable change in the ways things are done. In return, this also means that standards and requirements are not beyond questioning. Instead, collaborative efforts between energy managers and interested clinicians as well as health administrators could help to demystify clinical processes and achieve a sound understanding of opportunities to reduce the energy use of the health service. There may also be an important role for equipment manufacturers and vendors to innovate towards new generation of specialist medical equipment with lower electricity use.

Methodologically, this same realisation may find reflection in the definition of savings potentials as tools to support strategic planning and decision making. When the engineering concept of a savings potential is applied to any aspect of change involving people, there will necessarily be a difference between the top-down perspectives of the intervention designers/implementers and the perspectives of those involved in bringing about the proposed changes. Aside from a theoretical savings potential, the concept of a real-world savings potential is hence proposed which takes an in-situ perspective and recognises the constraints applicable in real-world socio-technical systems. Assessing real-world energy savings potentials rather than theoretical potentials emphasizes the need to involve people as active participants in all transition processes in order to close this gap.



# 8 Conclusion and implications

The conclusion chapter briefly summarizes the key findings in relation to the research question. It further discusses the implications of the thesis findings for different stakeholders, taking into account the limitations of study design and methodology. Needs for future work, both academic and in practice, are highlighted.

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## 8.1 Key findings in relation to the research question

This multiple case mixed-method study exemplifies an unusual research approach which may contribute to an increased understanding of the interplay between building energy use, service delivery and occupant needs in non-domestic buildings. Immediate value also stems from its contribution to the evidence base on hospital electricity use at a sub-building level and its procedural proposal for the strategic development of carbon mitigation interventions taking account of both technical as well as organisational and social characteristics of distinct units (spaces, departments) within the wider context of an organisation. The following sections will briefly lay out how the respective study objectives presented in section 1.2 were addressed.

**i) Establish the theoretical maximum electricity savings potential from simple changes in the way different hospital departments are being used by occupants, principally clinical staff.** The influence of clinical staff on hospital electricity use was found to vary between departments, while hospital specific energy behaviours were limited to operating theatres as specialist areas which may require the manual switch-off of specialist ventilation systems and anaesthetic gas scavenging pumps. In other department types, clinical staff mainly impacted on departmental electricity use through reducing the after-hour use of lighting, equipment and space conditioning systems, similar to actions which have been described for other building types. Additional pathways of influence included the review of protocols to achieve a better match between the provision of building services and actual clinical needs. As opposed to somehow rigid technological helpers such as automation and sensors, protocols fit the dynamic context of hospitals in less defined situations which may require some improvisation.

The theoretical electricity savings potentials from simple operational changes were relatively small across the 11 investigated hospital departments. They ranged between 2 and 25% of local electricity use with a median value of 12%, which corroborated previous evidence from hospitals and suggested the savings potentials in hospitals are lower than in other non-domestic building types. It should further be noted that the concept of a theoretical savings potential is limited as it does not account for organisational, social or individual constraints on clinical operations and staff energy behaviours.

**ii) Unpick the governing constraints on energy demand reduction in the complex socio-technical systems that hospital departments constitute.**

The study highlighted a lack of joined-up knowledge on the optimal use of energy services, especially in complex and energy intensive department types such as laboratories and operating theatres. Neither local clinical staff nor facilities or energy personnel seemed to have full insight into departmental operations, which tended to be defined through both local and central processes and systems. There was further uncertainty for important pieces of medical equipment as to whether or not they could be switched-off or into stand-by, a question that could potentially be clarified through closer collaboration with equipment technicians and vendors. Challenges for efficient energy use in shared spaces could further arise from uncertainties as to whether spaces and equipment may still be needed by other building users after hours. At the same time, saving energy was found to hold little meaning for most clinical staff in the face of many competing priorities and a lack of leadership on sustainability issues. A general lack of leadership, typically a consequence of understaffing or staffing changes, could further impair employee morale and reduce initiative where applicable. Last but not least, significant challenges to satisfactory as well as resource efficient hospital operations arose from insufficient working means, in particular under-performing or malfunctioning heating and cooling systems in older hospitals as well as old IT infrastructure.

**iii) Suggest a process to evaluate the relevance of behaviour and other simple operational changes as tools for carbon mitigation in hospitals.**

Given its small scale, the study does not attempt to provide a blanket recommendation for the use (or not) of behaviour change initiatives to achieve energy savings in different hospital departments and buildings. Rather, it highlights the importance of a robust understanding of contextual variables and operational constraints in devising tailored organisational carbon management strategies.

It is proposed that a three-tiered process may be appropriate in identifying parts of a building or estate where simple operational changes could be a viable tool for carbon mitigation: it is recommended to, firstly, undertake an engineering analysis of the energy end-uses in the spaces in question, identifying significant loads at a local level. Floor area weighted operating hours and shares of installed loads under (clinical) staff control may then be helpful metrics to approximate the extent to which these loads are influenced by the actions of occupants. Finally, socio-technical constraints on departmental workings should be analysed taking into account at least aspects around the shared use of spaces between teams, the available local knowledge on the control of building services and equipment, the morale within the organisation as well as the suitability of the working means.

Generally, the need to move away from top-down imposed models of change is recognised, instead taking a user-perspective when aiming to understand what may constitute a reasonably achievable transformation in the ways things are done. This does also mean that standards and requirements are not beyond questioning, even in sensitive environments such as hospitals. Instead, collaborative efforts between energy managers and interested clinicians as well as health administrators and equipment technicians could help to demystify clinical processes and achieve a sound understanding of opportunities to reduce the energy use of the health service.

**iv) Contribute to the concept of a socio-technical energy conservation potential while discussing scope and limitations of socio-technical methods for research in the built environment.** The concept of a real-world energy savings potential is proposed as decision support tool, representing a metric which takes an in-situ perspective and recognises the constraints applicable in real-world socio-technical systems. Assessing real-world energy savings potentials rather than theoretical potentials emphasizes the need to involve people as active participants in all transition processes in order to obtain meaningful ex-ante expectations of effect sizes. For technical potentials, this will include focusing on how technologies work in practice rather than in tests and laboratory situations. For behavioural and social potentials, more attention needs to be on taking an end-user perspective in order to understand the complexity of reasons for the status-quo and resulting consequences for change.



The study has highlighted the value of small scale case study investigations in addressing the complexity arising from the interaction between buildings, organisations and their functions as well as their people. Quantitative conclusions for example on departmental electricity intensities are limited by the study's small scale (see limitations section 8.2.2), while the study represents a substantial advance on the available evidence in a context where primary data collection efforts are hindered by complexity and access issues. The theoretical development of the assessment framework for the viability of simple operational changes as well as the real-world energy savings potential were crucially dependent on the use of both quantitative and qualitative, of both technical and social research methods and further scope is expected for such approaches in the built environment.

## **8.2 Limitations of the study**

The present study has a number of contextual and methodological limitations highlighting the need for further research on reducing hospital electricity use. Table 8.2 provides an overview of the major study limitations and how they were dealt with. They are further briefly outlined below for each aspect of the study. Despite these limitations, this study offers some valuable insights into an area where comparatively little research was done so far and has significantly advanced the available evidence.

### **8.2.1 Delimitations of the study**

The scope of the study is necessarily limited. Firstly, it focuses exclusively on electricity as major cost to hospitals while energy use is often associated with both electricity and heat or cold use: internal gains from laboratory equipment decisively increase cooling loads, and electric fan heaters ('convective warmers') are used to maintain patient body temperatures during surgery. Further research is hence needed to clarify how for example central changes in room temperatures would impact on warmer use in theatres as well as on the use of desk fans in other departments.

Secondly, the study does not include electricity use for cooling or central ventilation systems, pumping and medical gas services, which as central services are only with difficulty attributable to separate spaces within a building. It is believed that this challenge contributes hugely to the performance gap in non-domestic buildings, with design simulations frequently misrepresenting the energy use of centralised plant feeding a multitude of different activity spaces. Further research clarifying the energy use for varying levels of service delivery across complex buildings is therefore recommended.

**Table 8.2:** Impact of and mitigation strategies for major study limitations

Aspect of study	Definition of limitation	Impact on findings	Mitigation
Delimitations	Focus on local electricity use	Carbon emissions from fossil fuels not addressed Interactions between electric loads and cooling loads not investigated	Review of the literature on hospital energy use Recommendation for future research provided
	Focus on clinical staff	Influence of other staff groups overlooked, in particular cleaning and security staff who work after-hours	Future research recommended (in hospitals, but also the wider non-domestic context)
Research design	Small, UK based sample	Quantitative results are indicative only	Collaboration with others working on hospital energy use (see Morgenstern et al., 2016a) Future research recommended for benchmark development
	Defining departmental functions and boundaries	Challenge for inter-hospital comparisons	Activity based approach Analysis of spatial arrangements because hospital spaces are coherently designed to be supportive to the logistics of health care processes
	Current levels of energy management and staff engagement assumed to be comparable across all departments and typical for the stock	Savings potentials may be underestimated in the wider population because participating trusts might be more engaged with sustainability issues already (self-selection bias)	Multiple case design: Selection of trusts and case study hospitals with different characteristics Qualitative findings used to contextualise levels of engagement.

Aspect of study	Definition of limitation	Impact on findings	Mitigation
Data collection	Data collection carried out when convenient for department	Spot checks in time, somehow limiting the comparability of findings between departments	Short term monitoring of environmental variables in some departments Night time audits and interviews with staff working outside of typical operating hours recommended in future projects
	Expertise of author in buildings rather than health care processes	Difficulties in identifying unknown specialist equipment and understanding processes and switch off options	Discussions with multiple informants on the ground Extensive literature research on hospital equipment Collaborations with clinical staff recommended for future projects
	Motivating interview participation in a time constrained environment	Potential bias towards interviewees with an interest in sustainability (self-selection bias) or those in support roles (participation mandated by line manager)	Consideration of unusual interview formats, such as in operating theatres while patients were undergoing surgery Contextualisation of recruitment circumstances during interview analysis
Data analysis	Epistemological incompatibility of different data strands in mixed-methods analysis	Low accuracy of qualitative data for quantitative modelling	Uncertainty coding for all data inputs into quantitative representation Sensitivity analysis for most uncertain inputs
		Loss of richness of qualitative data when reduced to quantitative dimensions	Focus on quantifying suggestions for change that could be represented in the model Qualitative representation of the others, while highlighting the need for novel methodologies to quantify complex and often intangible issues

**Table 8.2:** Impact of and mitigation strategies for major study limitations

Thirdly, it is focused on clinical staff as opposed to other occupants of hospital buildings such as domestic staff in charge of cleaning and maintenance or security staff. While in departments occupied around the clock, clinical staff contributing to this study were able to provide sound insight into the local use of the hospital building, this proved challenging in the 12-hour areas. There, clinical staff would commonly be succeeded by cleaners or others during after-hours; including the actions and views of this occupant group would therefore be crucial in order to obtain a comprehensive picture of local hospital electricity use. It will seem that this is a worthy area of further research, while limited evidence appears to currently be available.

### **8.2.2 Research design**

This was a small, UK based study with very limited sample sizes for hospital buildings and departments of each type. Especially quantitative results indicating mean departmental consumption intensities may hence be understood as indicative only. The three case study hospitals represented only a small selection of ages, built forms and infrastructural arrangements given the large variety between hospitals within the NHS.

Further issues complicating departmental comparison arose from structural differences between departments. While core functions might be clearly defined for each department type, additional service and infrastructural arrangements may vary widely. In addition, the electrical layout determining which circuits and areas are served by set distribution boards and can therefore be monitored will often not correspond to the spaces constituting a clinical function or department. Especially in older buildings, spaces may have undergone various changes of use resulting in distribution boards with undocumented service provision or serving several departments.

Similarly, differences in the current level of energy management as well as in current levels of staff engagement with energy issues across different hospitals and departments were disregarded in the technical analysis of savings potentials. The subsequent qualitative analysis did, however, partly address this limitation through an extensive analysis of contextual factors. Other limitations in the research design were met by the replication of factors thought influential across the multiple case study design (infrastructural and process elements). A protocol explicitly outlining fieldwork procedures was put in place to ensure reliability and discussions with experts from various disciplines were sought to ensure methodological soundness in the face of the mixed use of approaches in this study.

### 8.2.3 Data collection

Research, especially in the real-world context, is an iterative process (Robson, 2011). The data collection methods employed in this study hence evolved over time, resulting in differences in available evidence across departments. The fieldwork for this PhD thesis was undertaken between January 2013 and June 2015, providing a snapshot of activity and energy use for each department. Meanwhile, the data collection spanned summer and winter periods, with consequences for energy use especially from local heating and cooling. Additionally, both energy audits and interviews were arranged when convenient for the respective department in an attempt to minimize disruption and increase research participation. Consequently, data collection took place at different times during weekdays or weekends, mornings or afternoons, somehow restricting the replicability of audit results. The opportunistic auditing further resulted especially limiting for the understanding of after-hour energy usage which in the future should be assessed through night time audits (Morgenstern et al., 2014) and interviews with support staff frequenting hospital areas outside opening hours.

As to challenges for **electricity use measurement** practicalities, the use of different equipment with varying accuracies influenced result comparability. More fundamentally, however, there was a systematic error from measuring currents only instead of all power characteristics while the use of comprehensive energy analysers was not possible due to funding constraints. Similarly, it was not possible to monitor departments for a full year to fully understand the implications of seasonal variations in weather and clinical activity.

The reliability of the **lighting and appliance audits** was limited by their character as spot-checks in time, while repeated audits would also contribute to understanding changes within environments as dynamic as hospitals. There were further some difficulties in identifying processes and equipment items given that the expertise of this author was in buildings rather than in health-care processes. For future projects in health care, it is recommended to form interdisciplinary teams including both interested clinicians and technical personnel to fully embrace the variety of available options for reducing hospital electricity use during operation. Such a course of action would further allow for expanding the scope of initiatives to include demand flexibility with view to reducing peak power, an increasingly important concern for grid stability given high renewable penetration.

A major challenge for the **interviews** was for interviewees to make time for participation. Their speaking to the researcher often resulted in an absence which had to be covered for by other members of their team. On three occasions, staff had to be interviewed in the presence of others because no separate facilities were available to carry out the interview in private. Staff were explicitly asked whether they felt comfortable carrying out the interview under these circumstances or whether they preferred to rearrange which they did not wish to do. It is appreciated that this may not be ideal neither from an ethical nor from an analytical perspective but could - given the constraints on NHS staff and facilities - not be avoided. Such practical challenges also biased the sampling for interviewees, potentially favouring those interested in sustainability (self-selection bias) or those in support roles asked by their line managers to participate. It can further be expected that interviewees were to a certain extent affected by social desirability bias although it was aimed to avoid framing the research as a mere energy conservation project.

#### 8.2.4 Data analysis

Challenges during the data analysis stage resulted primarily from the integration of the many different types of data, an issue common in case study research (Yin, 2003). The mixed-method approach yielding both quantitative as well as qualitative data strands based on different epistemological assumptions added additional complications. ‘Spatio-temporal issues’ (Love and Cooper, 2015, p.987) arose from utilizing interview data on durations of space and equipment use within the quantitative context of the bottom-up electricity models following the concurrent mixed analysis of both data sets. Using *quantitized* qualitative data inputs (Tashakkori and Teddlie, 1998) was here the result of practical challenges in collecting actual quantitative data, therefore somewhat limiting model validity while nevertheless allowing for some process understanding.

Conversely, the qualitative data was rich in ideas occupants expressed for potential changes at their workplace (which may or may not contribute to energy savings). In order to estimate potential energy savings from them, they had to be broken down to the two dimensions of average power consumptions and durations of use. While this approach worked reasonably well for some ideas, others could only poorly be represented in such terms. It was nevertheless felt that even providing a rough estimate of potential impacts from different operational strategies would help the discussion on carbon mitigation in the hospital context, similarly as suggested by Gatersleben et al. (2002) in the consumer context.

### 8.3 Implications of this thesis for different stakeholders

Despite the limitations outlined above, this study represents a significant advance on the available evidence in a complex and ‘hard to research’ environment. It has shed light on a number of avenues worthwhile exploring to holistically address the energy use of hospitals and has contributed to an increased understanding of the interplay between building energy use, service delivery and occupant needs. Some implications of the research findings for the different stakeholder groups presented in section 1.2.1 are outlined subsequently.

### 8.3.1 Practitioners

#### 8.3.1.1 Energy managers and facilities professionals

- This study stresses the need to understand differing characteristics of processes and occupation as well as contextual variables in heterogeneous mixed-use buildings in order to develop effective strategies to reduce the end-use of energy. Previous guidance documents on energy management have also emphasized this need to break buildings down, for example into areas with different uses, operating hours and tenancy arrangements (CIBSE, 2012). Such detailed understanding will allow for targeted energy management, in particular with respect to HVAC set points and timings.
- Processes in hospitals, but also other building types, were sometimes ‘black-boxed’ and treated as beyond questioning in attempts to reduce building energy use. Such approaches overlook the connections between function and form of a building as well as between different energy services, most prominently the influence of electrical loads on cooling demands. Albeit time consuming and potentially difficult, it seems that opening the black boxes of clinical processes in different hospital departments can contribute to identifying end-use energy demand reduction strategies which go beyond simple operational changes. Section 7.3.3 proposes a number of strategies which may be helpful in the process, out of which strategic collaborations between facilities personnel and interested clinicians seems of most importance in hospitals.
- If staff engagement is considered as a carbon mitigation strategy in a hospital (be it due to a lack of funding or time for other measures), a three-tiered process may be appropriate to identify parts of a building or estate where simple operational changes could be a viable tool. It is recommended to undertake an engineering analysis of the energy end-uses in the buildings and spaces in question, identifying significant loads at a local level and the extent to which they are influenced by the actions of occupants. Floor area weighted operating hours and shares of installed loads under clinical staff control may be helpful metrics to allow for a first order assessment of the latter. In addition, socio-technical constraints on departmental workings should be analysed aiming to understand what may constitute a reasonably achievable transformation in the ways things are done from an occupant perspective.



### 8.3.1.2 Architects and Designers

- The research has presented a wealth of details on hospital operations and clinical processes understood from an energy perspective. The evidence exemplifies the links between spatial and logistical arrangements in relation to patient flows and may assist architects and designers interested in low carbon hospital design in exploring how different configurations can enable low carbon health care. A better understanding of clinical processes (and expectations for their future development) will be required to address the difficult issue of sizing hospital buildings, while it seems that a happy middle ground is yet to be found between spaciousness, adaptability and resource efficiency.
- This case study investigation has further highlighted that overheating can be a serious concern in many hospitals, both in summer and in winter. In summer, this seemed to be largely due to reactive rather than proactive cooling strategies which had evolved in a piecemeal fashion in response to growing heat loads from equipment and overcrowding. In winter, malfunctioning radiator systems and a lack of localised temperature control could be problematic, albeit in fewer cases. This study therefore follows previous studies (e.g Lomas et al., 2012; Short et al., 2012) in pointing out the urgent need to incorporate comprehensive and forward thinking ventilation and cooling strategies into new designs and retrofits to ensure comfort levels can be maintained without extensive work-arounds which often result sub-optimal from an energy perspective.

### 8.3.1.3 NHS Management

- The resource use of hospitals is defined by a large number of stakeholders. An essential problem for holistic energy demand reduction consequently seemed to arise from the fragmentation of the task. Opportunities, in particular for structural re-arrangements, could easily be overlooked if they fell between the spheres of responsibility of different stakeholder groups. The role of the energy manager, potentially once created to fill this very gap, was in many trusts seen bogged down with compliance and reporting responsibilities, leaving little capacity for the creation of context dependent and innovative carbon management strategies. To raise the profile of energy managers within NHS Trusts and make more resources available for their work, it could potentially be effective to emphasize the benefits of their activities for comfort and indoor air quality, maybe even renaming them as ‘indoor environment specialists’ or similar.

- Time pressure was a central concern for all NHS staff involved in this study. At the same time, a lack of leadership on sustainability issues was widespread. Given that one of the key recommendations of this study is for an increased collaboration between facilities, clinical and administrative staff - which inevitably will require further resources - it seems important that senior management within NHS Trusts and beyond develop a clear stand on the importance of sustainability for health, the aspect at the very core of the organisation's existence. Energy policy may be able to support such endeavours by supporting sector carbon targets as well as action-orientated benchmarks, while NHS funding remains a crucial matter of a wider political debate.

#### **8.3.1.4 Clinicians**

- Clinical staff were in some cases found to be unsure about the operating characteristics of specialist medical equipment, making it hard for them to decide whether or not the equipment could be switched-off or into stand-by. Equipment technicians could be an important port of call here to clarify options for the switch-off of medical equipment.
- A good working relationship between clinical staff and the hospital's facilities management (FM) team was further recognised as mutually beneficial in this study. The FM teams of large hospitals are in charge of a huge number of different spaces and areas, with differing operating hours, temperature requirements and special needs. As technical experts, their knowledge on clinical processes is necessarily limited. A close working relationship between the clinical management of each department and the FM team may therefore help to ensure that the departmental needs and requirements are met, while avoiding a somehow wasteful blanket provision of services 'just in case'. Clarifying actual operating hours may for example contribute to maximising the energy savings from a customized IT power down or enable heating and cooling energy savings by allowing for night-time temperature set-backs.

- More fundamentally, an increased clinician input into the detailed specification of building services required to ensure optimal patient outcomes could be beneficial. This may range from the required colour rendering properties of lighting installations to help diagnosis over the need for ventilation to reduce infection rates to future scenarios of health care provision and how hospital building may best support these. Naturally, such collaborations take time, a commodity traditionally sparse within health care organisations. Mutual benefits at the local level as well as the input of professional organisation such as medical associations and long-term planning more generally may be helpful here.

### 8.3.2 Research communities

- This study highlights the value of small scale case study investigations in a field that has traditionally been dominated by survey work and quantitative methods. Especially when aiming to address the complexity arising from the interaction between buildings, systems, organisations and their functions as well as occupants the explorative and open-ended nature of case studies was shown to have much value.
- It was further found that a healthy scepticism is appropriate in the analysis and interpretation of automatic meter readings. It is paramount to know what areas and services are located downstream of a meter in order to make sense of the generated data, an issue previously also highlighted by Janda et al. (2015). Especially in environments evolving adaptively and with little strategic planning, such as hospitals, this can be difficult. Such findings highlight that some caution may also be appropriate in the increasing use of smart meter data in energy research, given the limited value of the data without an appropriate contextualisation of what it represents.
- The pragmatic approach taken in this study has highlighted the potential contributions of several different disciplines to the real-world problem of reducing energy use in hospitals. Within the academic discourse, however, such appreciation of each others contributions does not always seem to be found. It will appear to this author that more value-neutral debates about the strength and limitations of different approaches would be beneficial, respecting that each can bring interesting aspects to a complex and multi-faceted problem but none holds the holy grail.

- The study further suggests that more attention should be paid to the link between occupant comfort/well-being/productivity and building energy performance. Energy use is not an end in itself but a means to an end, with associated consequences for pathways to change. This also points towards the rhetorical value of cost-effectiveness as central argument for explorations of energy demand.
- Finally, primary data is and will remain important as input in and for the validation of energy models, on which policy decisions are increasingly based. The collection of primary data is however resource intensive and time consuming, while these efforts do not always seem to be appropriately recognised. Research communities and funders may have a role in ensuring that the necessary means for primary data collection are made available. The further development of open-source data repositories and intellectual property licenses also seems important in this context, so that data can be shared and the efforts going into primary data collection can be credited as required.

### 8.3.3 Department of Health

- This study has exposed the variability between different hospital departments and clinical processes from an estates perspective. Like for the resource-efficient energy management of hospitals (section 8.3.1.1), an understanding of the differing characteristics of processes and contextual variables is also required from a policy perspective. Department of Health policies and recommendations, for example on but not restricted to staff awareness campaigns, do currently hardly differentiate between different spaces in hospitals. Going forward it is recommended that a more granular and process focussed strategy is adopted to make the most of efficiency opportunities within the estate as recommended by the 2016 Carter review.
- The Department of Health further has a role in advancing the energy benchmarking of hospital buildings. Findings in this study have suggested that the specification of energy benchmarks per floor space may benefit the over-sizing of new (health care) facilities. Additionally specifying energy usage on the basis of service delivery may consequently be one way forward, despite obvious complications with how service delivery should be specified. There is, however, a wealth of thinking available which has gone into clinical accountability and the costing of treatments. The Department of Health may have a role in providing a framework within which to bring facilities managers, clinicians and health administrators together to improve the available metrics for the energy performance benchmarking of hospitals.

- Specifying energy use per treatment (as attempted for example by the NHS Sustainable Development Unit through their Sustainable Care Pathways) will also be crucial in exploring the carbon impact of future healthcare pathways. A more continuous operation of imaging and laboratory facilities (as implied by the conservative government under their seven-day NHS plan to extend the weekend access to diagnostics) would for example increase the current metric of energy use per floor area while energy use per treatment would likely decrease, especially in laboratories due to their high base loads. The present study does at the same time highlight the need for government to specify more clearly what, above and beyond higher consultant cover on weekends, is meant by a seven-day service as the space-use data (see Figure 4.13) clearly indicate that services are already being provided around the clock in many hospital departments.
- Further challenges for the energy benchmarking of complex buildings (including hospitals) are associated with the definition of the standards against which to compare the actual performance of a building. If statistical rather than simulated standards are to be used, this author proposes that composite energy benchmarks taking into account differing energy intensities at a departmental level may be beneficial in hospitals (Morgenstern et al., 2016a). Such an approach may increase the meaningfulness of energy benchmarks by tailoring them to the service configuration of a respective hospital, accommodating the large heterogeneity between buildings of this category.
- It finally seemed that not only the use, but also the purchasing of medical equipment deserved more attention. EnCO2de (2015), Part B provides suggestions on the inclusion of energy and environmental criteria in tender documents. More impact may however be achievable given the collaborative purchasing power of the NHS from more stringent requirements while collaborations with equipment manufacturers and vendors may help to drive innovation towards new product generations with lower carbon impact.

## 8.4 Future work

The implications of this study for research communities (section 8.3.2) have already highlighted the need for future work, in particular to advance socio-technical methodologies and put them on equal grounds with other, more established approaches. A range of other areas considered worthy of further investigation are listed below.

### 8.4.1 Complex buildings

Energy research needs to extend its focus beyond dwellings to capture the carbon emissions from non-domestic buildings. Within the non-domestic sector, a shift of focus away from office and educational buildings is required to investigate the energy use in industry, retail and health care buildings and address the significant process loads in these building types. At the moment, there is much uncertainty about such process loads while they are often arranged outside of the responsibilities of energy managers. A better understanding and an integration of responsibilities may lead to the identification of new pathways to holistically reduce energy use.

Further research is also recommended to clarify how the energy use of central plant results from and is attributable to the delivery of energy services across complex buildings, where different areas can have varying occupational characteristics and differing service requirements. This challenge is increasingly addressed with regards to the after-hour use of HVAC systems in multi-tenanted office buildings, but little research is currently available for more complex mixed-use buildings. Field studies applying heat and cold metering at a sub-building level as well as the metering of fan coil units may help to minimise the performance gap in non-domestic buildings and provide input into energy simulations of centralised plant feeding a multitude of different activity spaces.

It was further pointed out that all non-domestic buildings are occupied by multiple groups of people. This study focused on clinical staff as core occupants of hospitals, but it proved a major limitation to the project that other staff groups had not been included in the analysis. Future research is therefore recommended to investigate the influence of cleaners and other domestic staff on building energy use. Given their likelihood to occupy buildings after-hours, their impact may be substantial while they will be subject to their own particular set of constraints.

### 8.4.2 Quantifying diverse influences on building performance

This case study investigation developed a qualitative understanding of a wide range of factors influencing the energy end-use in hospitals, including aspects of knowledge and motivation in building occupants and spatial and technological constraints. The impact of different factors on the energy savings potential of carbon management strategies has however not been quantitatively assessed as part of this study. Further research aiming to assess the relative importance of different factors against each other in energy terms therefore seems one possible next step.

In a similar vein, the development of novel methodologies to assess the level of space and building services requirements (such as ventilation rates), which are actually needed to ensure health and safety in hospitals, is recommended. This may also include a more fundamental assessment of how service is defined in hospitals themselves and in the wider health care sector. Participatory and group modelling exercises may be rewarding in this sensitive context to capture demands and concerns of all involved stakeholders.

### **8.4.3 Social and power dynamics within work places**

It was felt that the hierarchical environment prevalent in hospitals, which seemed to subordinate all other professions to doctors, complicated it for non-clinical staff including equipment technicians as well as energy managers to input in decision making processes. Further research clarifying this notion is recommended and may offer insights into barriers to collaboration across the NHS workforce, given that collaboration was concluded to be an important factor in reducing hospital emissions.

This study further produced an interesting anomaly: Much literature indicates that more control over building services at the workplace reduces sick building syndrome and lets occupants be more comfortable (e.g. Bordass et al., 2007). In most departments of this study, occupants had no control over the heating system. But while teams would establish ‘running gags’ on temperatures being too high or too low, they generally seemed to adapt to this situation reasonably well and the blame was placed outside of the team. Other departments, in contrast, had some means to control the temperature, and in those departments tension about temperature issues and thermostat settings could arise within the team. It may consequently be valuable to explore how HVAC control related to comfort in dynamic environments where spaces are always shared and the team is an important asset to the work-flow.

## **8.5 Outputs associated with this research**

This research was made possible by support from the EPSRC Centre for Doctoral Training in Energy Demand, grant numbers EP/L01517X/1 and EP/H009612/1. The following section lists the main outputs associated with the research. Outputs marked with an asterisks (\*) cover material included directly in this thesis, while other outputs address associated topics.

## Journal papers

Morgenstern, P., Li, M., Raslan, R., Ruyssevelt, P., & Wright, A. (2016). Benchmarking acute hospitals: Composite electricity targets based on departmental consumption intensities?. *Energy & Buildings*. doi:10.1016/j.enbuild.2016.02.052

- This paper presents departmental electricity intensities measured by this PhD project as well as by collaboration partners and discusses implications for the energy benchmarking of complex buildings.
- The data set underlying the publication has been published as:  
Morgenstern, P., Li, M., Raslan, R., Ruyssevelt, P., & Wright, A. (2016b). Small power and lighting load time series for 27 departments across 8 UK hospitals. *Data in Brief*. doi:10.1016/j.dib.2016.03.076

Morgenstern, P., Raslan, R., & Huebner, G. (2015). Applicability, potential and limitations of staff-centred energy conservation initiatives in English hospitals. *Energy Efficiency*. doi:10.1007/s12053-015-9346-2

- This paper reviews the literature on staff-centred energy conservation initiatives in hospitals and presents a survey study among NHS energy managers which was undertaken as scoping exercise for this PhD. The findings of the survey study are not directly included in this PhD thesis, but rather used to explore the context and define the research question. A brief summary of highlights has been included in the literature review in section 2.2.1.2.

## Peer reviewed conference papers

\* Morgenstern, P., Raslan, R., & Ruyssevelt, P. (2015). Assessing savings potentials from changes in energy behaviours of hospital staff: benefits and challenges of energy audits. In: *eceee2015 Summer Study on energy efficiency*. Belambra Les Criques, Toulon/Hyeres, France.

- This paper details the methodology of energy audits applied in this PhD study and illustrates their use for the assessment of energy savings potentials from simple operational changes.

\* Morgenstern, P., Raslan, R., & Ruyssevelt, P. (2016). Reducing hospital electricity use: an end-use perspective. In: *9<sup>th</sup> International Conference on Improving Energy Efficiency in Commercial Buildings and Smart Communities (IEECB&SC16)*. Light+Building trade fair, Frankfurt, Germany.

- This paper presents the quantitative findings on end-use splits across different hospital departments as described in section 5.3.3 of this thesis and discusses implications, in particular for lighting energy use.



### Other international conference papers and posters

Morgenstern, P., Raslan, R. M., & Ruyssevelt, P. (2014). Measuring changes in energy behaviours in complex non-domestic buildings. Paper. In: *BEHAVE Energy Conference 2014*. Saïd Business School, Oxford University, UK.

- This paper reflects the experience of the author during a scoping study, in which she assisted with the implementation and evaluation of a behaviour change campaign in a UK acute hospital.

\* Morgenstern, P., Raslan, R. M., & Lowe, R. (2013). Evaluating energy efficiency behaviour change interventions in hospitals. Poster. In: *10th Biennial Conference on Environmental Psychology*. Otto von Guericke Universitaet, Magdeburg, Germany.

- This poster reviews the literature on methodologies and challenges associated with the evaluation of behaviour change interventions, as presented in section 2.2.2.2 of the literature review.

### Other publications

Morgenstern, P. (2016). Energy saving in health care: why, who, how?. In: *Hospital health care Europe 2016*. European Hospitals and health care Federation. London, UK.

- This is an overview article highlighting the need to save energy in hospitals in a medical publication targetting health care professionals throughout Europe.

### Key presentations

\* Morgenstern, P. (2015). Understanding hospital electricity use: an end-use(r) perspective. In: *MSc Facility and Carbon Management*, University College London, London, UK.

Morgenstern, P. (2014). Practical challenges for energy audits in specialist buildings. In: *CBxchange*. London, UK.

Morgenstern, P. (2014). 'Helping patients' and/or/vs. 'Helping the planet': Pro-environmental behaviours and professional identities. In: *British Environmental Psychology Symposium*. Sheffield, UK.

Morgenstern, P. & Stancliffe, R. (2014). Grassroots action for a sustainable health care system: the Sustainable Specialities network and the NUS Green Impact scheme as case studies. In: *Healthy Planet Conference*. London, UK.

\* Morgenstern, P. (2013). How to measure the impact of energy efficiency behaviour change interventions in hospitals? In: *IHEEM Health Care Estates Conference*. Manchester, UK.

\* Morgenstern, P. (2013). How to evaluate energy efficiency behaviour change interventions in hospitals? In: *YoungOR Conference*. Exeter, UK.

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# A Hospital energy use

This appendix provides additional detail on the available evidence on hospital energy demand, in particular:

- A.1 Evidence on hospital energy performance: Measured consumption levels as well as best-practice targets at building level
- A.2 Evidence on the relevance of different energy end-uses in hospitals
- A.3 A graphic overview of UK guidance documents on energy efficiency in hospitals

## A.1 Evidence from the literature on hospital energy performance: Measured consumption levels as well as best-practice targets

The following table presents measured energy performance figures from various sources within the academic and the grey literature. Publications are ordered according to their purpose, i.e. with a view to which outcome was the energy performance of the respective hospital building(s) assessed? :

- >> **Academic publication:** Academic analysis focussed on specific aspects with view to driving innovation; often of individual hospitals or with low sample sizes
- >> **Industry Guidance:** Information on best practice energy performance to provide building operators with a context against which to evaluate their building
- >> **Certification:** Building certification under schemes such as BREEAM, LEED or Energy Star can increase the value of a building in the marketplace or attract tenants interested in sustainability
- >> **Mandatory disclosure:** This policy instrument requires the disclosure of building performance as soft incentive for its improvement.
- >> **Building Code:** Eventually, operational building performance might become part of building codes. Currently, building codes tend to mandate asset performance (calculated), likely due to the complexities of assessing operational performance and the confounded influence of building and occupants.

The comparison of consumption levels suggests that climate is an important driver of energy use, resulting for example in elevated electrical cooling loads in hospitals in tropical and sub-tropical climates. Within temperate climates such as in Europe, it is noted in comparison that there may be potential for improved energy performance in British hospitals.

Publication	Year of data	Country	Energy data source	Floor area definition	Approach for target development	Category	Number of data points	Current consumption (kWh/m <sup>2</sup> *yr)			Target (kWh/m <sup>2</sup> *yr)			Comment
								Electric	Thermal	Total	Electric	Thermal	Total	
Academic														
Beier 2009	2006 - 2009	Germany	On-site measurements	Likely GIA	Out of scope	Hospitals with 300 to 600 beds	20		110					Beier argues that current energy benchmarks based on total hospital floor area are of limited use due to the complexity and the big structural differences between hospitals. In consequence, he presents detailed consumption measurements for heating, cooling and hot water use as well as for ventilation in operating theatres and intensive care.
Bjerknes (2010) according to Harsem (2014)	2009	Norway	On-site measurements	Unclear	Out of scope	University Hospital, Nordic	1	206	77	283				As secondary data: yearly measurements of different end-uses
Bujak 2010	2010	Poland	On-site measurements	Usable floor area	Out of scope	Hospitals with over 600 beds	2		268					Bujak focuses on determining the domestic hot water use in hospitals with more than 600beds as basis for design recommendations.
Burpee & McDade 2014	2014	US	On-site measurements	Unclear	Out of scope	Hospitals with up to 500 beds	4			624				The Scandinavian hospitals use on average 40% less than their US counterparts (Pacific Northwest, similar climate) due to specific architectural, mechanical, and plant systems. Synergistic systems integration was identified as important enabler for reductions in energy consumption.
		Norway	On-site measurements	Unclear	Out of scope		3			386				
		Denmark	On-site measurements	Unclear	Out of scope		1			362				
D'Alessandro et al. 2007	2006	Italy	Postal survey	Unclear	Out of scope	Unclear	14	102	163	265				Consumption given on a per bed basis, net floor area assumed as 83m <sup>2</sup> /bed as in Heyne
Hu et al. 2004	2002	Taipeh	On-site measurements	Unclear	Out of scope	Large Acute Hospital, Sub-tropical	1	277						The paper presents measured electricity consumption and cost in a large acute hospital in a subtropical area. Air-conditioning is found to be the major electricity end use, accounting for more than 50% of the total building energy use.
Moghimi et al 2014	2012	Malaysia	On-site measurements	Unclear, likely gross	Out of scope	Large, Tropical climate	1	288	96	384				Detailed case study of a large hospital estate
Saidur et al 2010	2008	Malaysia	On-site measurements	Unclear	Out of scope	Public hospital in tropical climate	1	234						Walk-through energy audit in single hospital in tropical climate. It is suspected that the electricity use for building-sided demands is underestimated in the end-use split presented in this study. They state that labs are air conditioned and mechanically ventilated but no account is taken of this.
Santamouris et al. 1994	1993	Greece	On-site measurements	Unclear, likely net internal (heated)	Out of scope	Hospitals	33	108	299	407				Government funded energy audit programme in hospitals and clinics in Hellas. An energy conservation potential of 20% is identified overall, primarily through insulation and reducing heat loss during distribution as well as passive cooling techniques. 50% of lighting electricity use can be avoided through new lamps (This was in 1993 though!)
						Clinics		95	180	275				

- continued on the next page -

Publication	Year of data	Country	Energy data source	Floor area definition	Approach for target development	Category	Number of data points	Current consumption (kWh/m <sup>2</sup> ·yr)			Target (kWh/m <sup>2</sup> ·yr)			Comment
								Electric	Thermal	Total	Electric	Thermal	Total	
<b>Industry Guidance</b>														
BRECSU (Published unchanged in 2012 in CIBSE Guide F)	Pre 1996	UK	Unclear	Unclear	1st quartile	Acute Hospital	Unclear, but many	108	510	618	74	422	496	Assumed ceiling height 2.9m
EnCO2de	2006	UK	Mandatory reporting	GIA	1st quartile	General Acute Hospital	Many	143	373	516	122	317	439	Assumed ceiling height 2.7m
'Das energieeffiziente Krankenhaus' (Benke et al 2009)	2007	Austria	Mandatory reporting	GIA	Out of scope	Nieder-österreich	Unclear	108	203	311				In 2009, the authors assume an average actual use of 200kWh/m <sup>2</sup> ·yr for heat and 110kWh/m <sup>2</sup> ·yr for the rest for the whole of Austria (apparently based on this data)
	2006			GIA	Out of scope	Vorarlberg	Unclear	58	104	162				
ECObench	2010	India	Online platform	Unclear	Out of scope	Multi-Speciality Hospitals	129			307				US Aid have run a hospital benchmarking programme in India. They differentiated between small and large multi-speciality hospitals as well as public and private clinics, but there seem to be some issues with the numbers in the presentation I have.
IEA - CADDET: 'Saving energy with Energy Efficiency in Hospitals'	Pre 1997	Worldwide	Unclear	Gross floor area	Out of scope	Different countries		145	350	495				High-level world wide comparison, Large variation in electricity consumption noted, Averages presented here
VDI 3807	1999	Germany	On-site measurements	GIA	Pass definition: Mean of the 1st Quartile	Hospital with up to 250 beds	102	53	289	343	32	170	203	Consumption given on a per bed basis, net floor area given as 83m <sup>2</sup> /bed
						Hospital with 251 to 450 beds	76	67	243	309	45	172	217	
						Hospital with 451 to 650 beds	46	77	314	390	48	204	251	
						Hospitals with 651 - 1000 beds	27	78	308	386	36	230	266	
						More than 1000 beds	31	164	446	610	47	270	317	
Herbst (after Tippkötter & Schüwer)	1996	Germany	On-site measurements	GIA	Out of scope	Hospitals with 100 - 350 beds	Unclear	60	225	285				
Heyne (after Tippkötter & Schüwer)	1998	Germany	On-site measurements	Net internal floor area	Out of scope	Hospital (no further details)	Unclear	95	298	393				Consumption given on a per bed basis, net floor area given as 83m <sup>2</sup> /bed
<b>Industry Guidance based on simulation</b>														
ASHRAE 2010 - New built hospitals (Large Acute)	2000 - 2004	US	Various	Unclear	Pass definition: 50% reduction based on modelled data	Climate Zone 4B	Proto-typical model						334	Design guidance for new large acute hospitals. Develops energy performance targets based on simulation. The simulation is calibrated using data collected through various means, including a large scale survey and on-site measurements.
						Climate Zone 8						441		
<b>Certification</b>														
Energy Star	2003	US	Large scale survey	GIA	Regression		191			620	Based on multivariate regression		Actual performance data from Portfolio Manager	
Targeting 100! (Burpee et al. 2014 ACEEE)	2014	US	Large scale survey	GIA	Pass-Definition: 60% reduction by 2030	Hospitals (General Medical and Surgical)	191			784			315	Targeting 100! is a US based programme to identify low cost design principles specific to acute hospitals. It is concluded from a simulation based analysis of two hospital schemes that an efficient handling of solar gains and HVAC issues generally is more important than hospital specific issues.
Energy Star	2009	Canada	Large scale survey	GIA	Regression		150			653	Based on multivariate regression		Actual performance data from Portfolio Manager	
<b>Mandatory Disclosure</b>														
CIBSE TM46 as basis for DECs	?	UK	?	Usable floor area	?	Hospital (Clinical and Research)	Unclear	90	420	510	90	420	510	
Benchmarks for "Energieausweis" as prescribed by EnEV2007 and EnEV2009	2007	Germany	Large Scale Survey	Net floor area	Pass-Definition: 30%	Hospital with up to 250 beds	111	120	205	325	84	145	229	
						251 to 1000 beds	104	115	250	365	80	175	255	
						More than 1000 beds	33	115	285	400	80	200	280	
<b>Mandatory sector targets</b>														
Government targets for the NHS	2006	UK											413 - 488	Converted from GJ/100m <sup>3</sup> ; Assumed ceiling height 2.7m

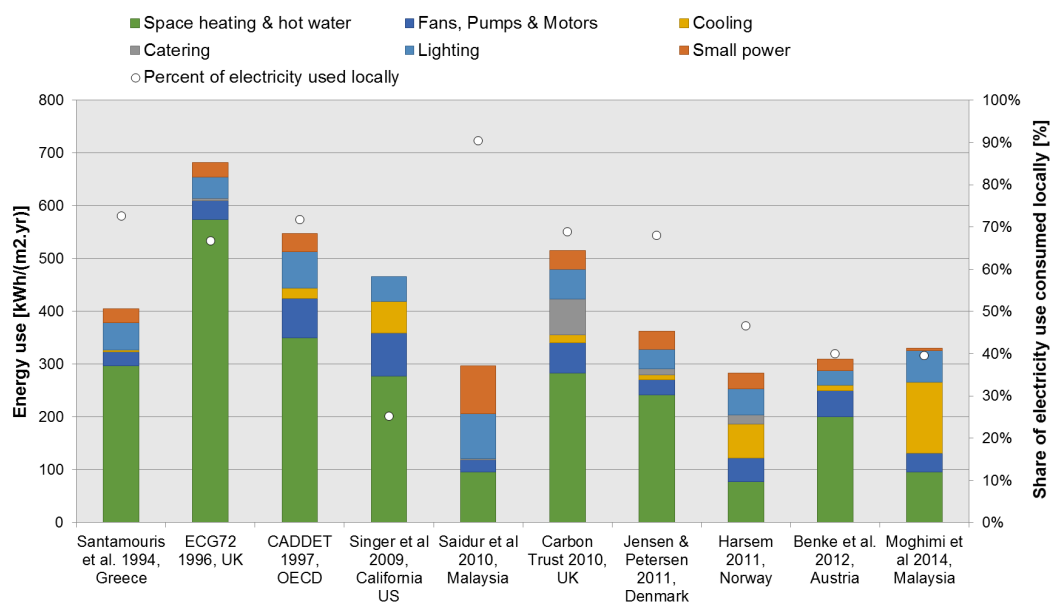
## A.2 Evidence on the relevance of different energy end-uses in hospitals

A number of single case as well as programme based audits aiming to identify energy conservation opportunities in hospitals are reported in the academic and practical literature. Scope, employed methodologies and quality of the reporting vary widely; presenting some challenges for systematic meta-analysis. Frequently, there are differences between the reported end-uses and what is encompassed within each term (CIBSE, 2006; Field et al., 1997, see example).

This study was interested in identifying electricity used locally as opposed to demands for heat (often from fossil fuel) or electricity used centrally for the provision of building services, i.e. ventilation, cooling and pumps (e.g. for hot water). End-uses categories were therefore defined rather broad:

- **Space heating and hot water:** Contains all energy use for space heating (incl. air heating) as well as the provision of both domestic hot water and hot water used in processes such as sterilisation. In the majority of hospitals, heat demand is met by fossil fuels rather than electricity.
- **Fans, Pumps & Motors:** Building-sided electricity use for ventilation fans, compressors and pumps moving domestic hot water as well as space conditioning fluids. If specified, electricity use of lifts was also included in this category.
- **Cooling:** Electricity use for cold generation, typically through electric chillers.
- **Catering:** May includes kitchen appliances as well as equipment for commercial food preparation (This category was found to often be poorly defined in the primary sources, major uncertainty hence remains to what is actually included. It was often also unclear which fuel was used in food preparation, all was attributed to electricity in this study.)
- **Lighting:** All ceiling as well as task lighting.
- **Small power:** This category includes all plug loads, i.e. IT equipment, medical equipment, supplementary heating and cooling through fans or electric radiators. Some medical equipment, in particular major imaging and laboratory equipment, operates on three phase supply. For the sake of this analysis, those are presumably also included as small power, while the analysed primary sources (depending on focus) hardly differentiated which medical equipment items were included in this category.





**Figure A.2:** Studies specifying energy end-uses in hospitals (Moghimi et al., 2013; Saidur et al., 2010; Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), 1997; Santamouris et al., 1994; Singer et al., 2009; Jensen and Petersen, 2011; Harsem, 2011; Benke, 2012; Building Research Energy Conservation Support Unit (BRECSU), 1996; Carbon Trust, 2010)

It is generally assumed that cooling as well as fans, pumps and motors operate from within centralised plant rooms and are run and maintained by facilities staff. In contrast, catering, lighting and small power loads were classified as localised process loads and their running is assumed to be associated with a building's end-users.

### A.3 A graphic overview of UK guidance documents on energy efficiency in hospitals

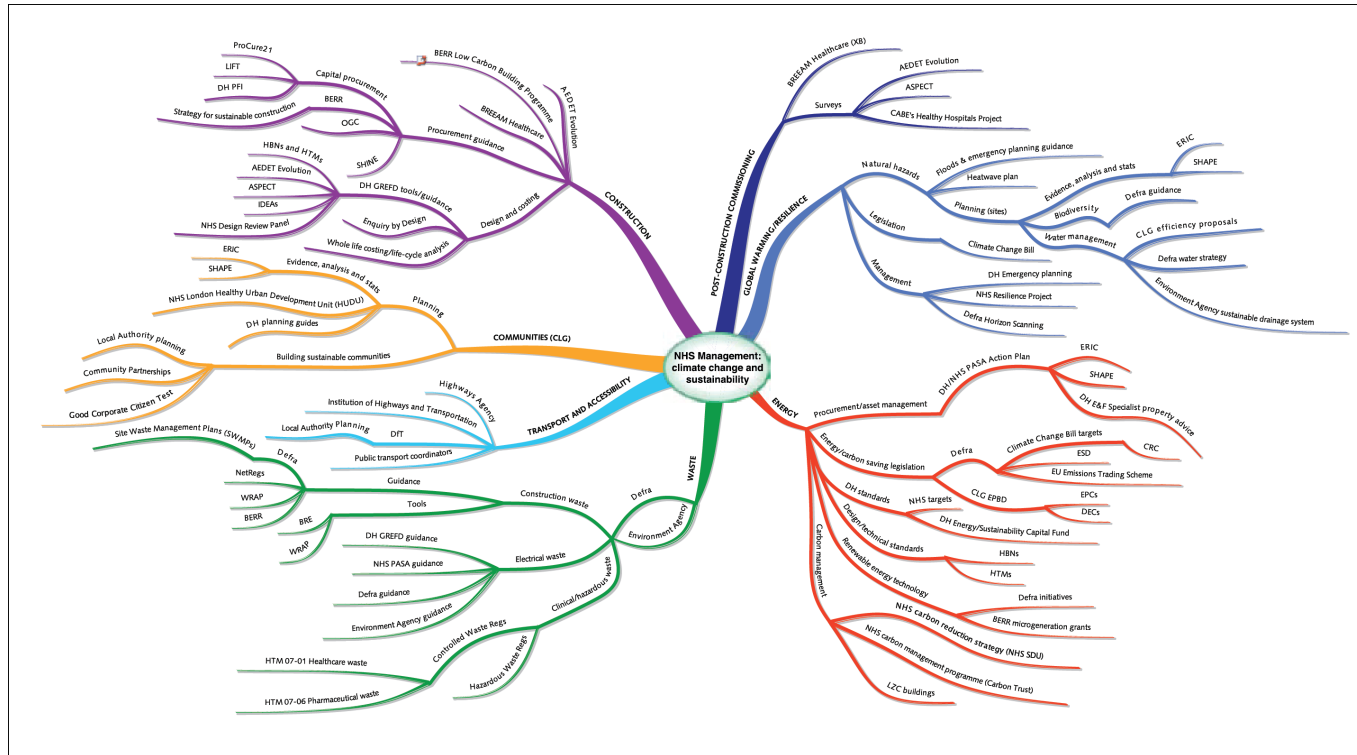


Figure A.3: Mind map exemplifying available NHS guidance documents on sustainability (incl. energy and construction) (Department of Health, 2013b, p.xii)

# B Supporting evidence based on a review of the literature

This appendix provides additional detail on the available evidence literature, in particular:

B.1 Details on a number of empirical social practices studies of non-domestic building energy use

B.2 Strategies to ensure quality in case study research and how they were applied in this study

## B.1 Empirical social practices studies of non-domestic building energy use

Most studies within *non-domestic buildings* were undertaken within the context of behaviour change interventions of some form, identifying what had worked and what not and providing suggestions on or even assisting with the implementation of improvements. It seemed overall that researching energy practices in a work context adds additional complexity as opposed to studies looking at dwellings. The time and effort required to carry out such studies is one likely reason why they have so far primarily been restricted to PhD projects which tend to operate on longer time frames than many other research projects within current funding arrangements. The following paragraphs each briefly describe one relevant study.

Based on her EngD project at Loughborough University, Christina presents a longitudinal case analysis of a UK retailer's organisational behavioural strategy for energy demand reduction (Christina et al., 2015). The extensive work (131 interviews in total) is based on a systems approach and stands out due to the comprehensive involvement of staff at all organisational levels over the course of two years. Based on initial findings on challenges associated with an energy champion system previously in place in the shops, the project proposed a behavioural intervention which incorporates energy management firmly into departmental job roles instead of relying on voluntary engagement and lays out specific energy tasks rather than abstract energy performance goals for all staff. While energy management remains a secondary goal to the organisation and its employees, it is now seen to be aligned with the primary organisational goals and included in the processes and practices used to manage those primary goals. Managers further feel more comfortable talking about how to get specific tasks completed rather than controlling energy budgets, while other staff approve of no longer being held accountable for systemic problems outside their control. The study stresses that this intervention 'fits into the culture of the stores (Christina et al., 2015, p.332)', indicating the importance of contextual factors.

During his PhD at the University of East Anglia, Hargreaves investigated an environmental champion campaign in the head offices of a UK construction company based on an ethnographic case. In Hargreaves (2011), he offers a re-interpretation of his data through a social practices lens. Data was collected through nine months of participant observation including the attendance of all environmental champions meetings and events, as well as through 38 semi-structured interviews with all champions, management and technical staff and several employees whom the initiative was seeking to influence. Hargreaves concludes that the ability of a well-informed team 'to challenge, let alone replace, existing and taken-for-granted practices (Hargreaves, 2011, p.93)' was rather limited as well as initially socially awkward. Much discussion hence centred on how 'stuff' associated with working practices might be replaced with more pro-environmental alternatives. Over time and as it were 'from the inside out (p.94)', the initiatives did however give rise to a new identity of an 'environmental employee' in making low carbon routines part of the organisation's unwritten set of rules. This suggested that social modelling campaigns may be related in particular to the 'institutionalised knowledge' element of the practices framework.

A third PhD project, by Dantsiou at Cambridge University, explores the effects of energy feedback in university offices on comfort seeking practices (Dantsiou and Sunikka-Blank, 2015). An environmental consultancy had organised a behavioural intervention displaying the sub-metered electricity consumption of different office spaces in real-time and encouraged the employees to compete for energy savings. Dantsiou collates semi-structured interviews with, and comfort diaries of the workplace users, while quantitatively measuring temperature and humidity in seven offices. Similarly to Hargreaves (2011), Dantsiou and Sunikka-Blank (2015) are sceptical about the potential of the feedback intervention in changing energy use and comfort practices. They conclude that in the absence of financial incentives to save energy (typical for work as opposed to home environments) and in the face of technological challenges resulting in limited cooling control, seeking comfort was a priority for employees. In shared offices, thermal comfort preferences are however found to be collectively shaped in order to avoid conflicts with colleagues. Social dynamics proved important, suggesting that collective pro-environmental attitudes based on a green organisational identity may be more effective in reducing energy use than energy competitions.

## **B.2 Strategies to ensure quality in case study research**

Case study research has in the past often been criticised for a lack of analytical rigour (Gray, 2004). A number of strategies are hence applied in this study to ensure quality, as conceptualised through the four elements external, measurement and internal validity as well as reliability (Bryman, 2012, p.47):

- **External validity during the research design phase:** External validity (i.e. the relevance of findings beyond the specific research context) can in multiple case study designs be shown through the replication of findings across different cases. In this study, it is hypothesised on the basis of literature review and scoping activities that the extent of clinical staff's influence on electricity use will depend on infrastructural arrangements, in particular control interfaces for building services, and the nature of departmental processes defining electricity requirements and operating hours. Each of these factors is replicated in the study design as basis for a potential replication of findings: infrastructural features across different departments within the same hospital and process elements within the same department type across different hospitals (see Figure 3.1).

- **Reliability during data collection:** Reliability refers to the consistency with which a concept is measured. To ensure reliability during data collection, a protocol outlining fieldwork procedures is put in place. It encompasses the following elements:
  - Obtain authorisation for fieldwork through facilities management of each hospital
  - Acquire hospital wide policy documents, information on IT procedures, etc.
  - Collect electricity consumption data for departments of interest (see section 3.4.2.1)
  - Establish contact with departmental manager to obtain authorisation for fieldwork
  - Guided walk through to understand departmental process and boundaries
  - Inform the team about upcoming visit of the researcher (through clinical lead, bulletin)
  - Data collection using quantitative and qualitative data as detailed in section 3.4
  - Data analysis as detailed in section 3.5

Research, especially in the real-world context, is an iterative process (Gray, 2004) and despite the initial pilot testing of data collection instruments some improvements to the protocol could be incorporated during the fieldwork phase. Such changes included for instance the additional measurement of lighting levels to obtain more detailed duration of use information for lighting in some departments, or the tightening of the interview guide for the third hospital by removing lines of enquiry which had not proved productive. With any iteration, great care is taken not to introduce bias into the collected data.

- **Measurement or construct validity during data collection and analysis:** Construct validity refers to the degree to which a measure of a concept really does reflect the concept. Mono-method bias has been described as a major threat to measurement validity (Tashakkori and Teddlie, 1998, p.40); avoided in this study through the triangulation of various sources of evidence describing for example the duration of use of building services and appliances. Details on the mixed methods approach are described in section 3.4. The concepts of a theoretical and an actual energy savings potential is developed based on established methods in the field and discussed with experts from various disciplines to ensure methodological soundness.

- **Internal validity during data analysis:** Internal validity relating mainly to the correct attribution of causality was in this study primarily ensured through pattern matching across different departments. Potential rival explanations for observed differences in savings potentials across different departments were also addressed through contextualising them within building and department type.





## C Data collection instruments

This appendix provides additional detail on the data collection instruments employed throughout this study:

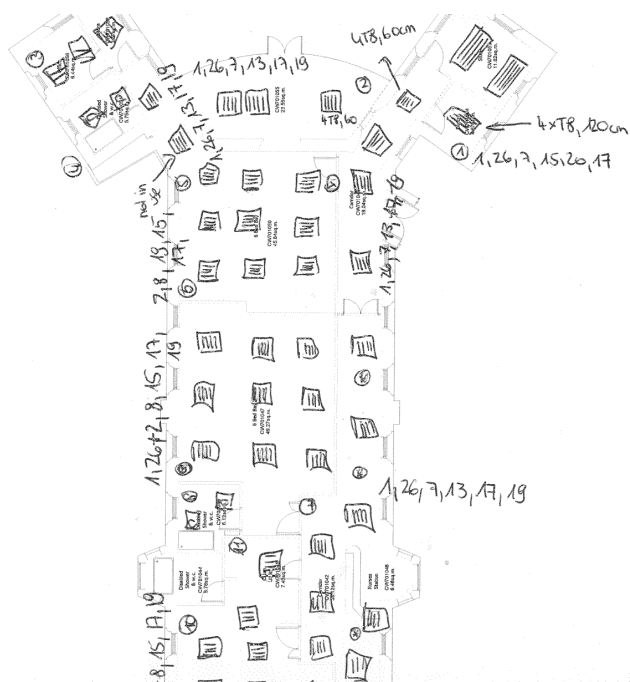
C.1 Tools used and records kept during the lighting and appliance audits on the ground

C.2 Interview guide for semi-structured interviews with clinical staff (including scales used as prompt)

C.3 Study information sheet and informed consent form utilized during interviewing

### C.1 Lighting and appliance audit

Figure C.1 shows a completed example of how data was recorded during the room to room inspection of hospital departments. Floor plans obtained from the hospital facility department were used to reflect the spatial distribution of lighting installations and record building services and control infrastructures for each room (Table C.1). Equipment items and their reported durations of use were noted as separate lists in the fieldwork book.



**Figure C.1:** Example of how data was recorded during the room to room inspection of hospital departments

	1 - Wet system
	2 - Air system
Space heating	3 - Underfloor
	4 - Local FCU
	5 - Local electric
	6 - None
	7 - None
Space cooling	8 - Air through wall
	9 - Air Split System
	10 - Chilled beams
	11 - Individual fans
	12 - Other
	13 - Natural Ventilation
Ventilation	14 - Local MV
	15 - Central MV
	16 - None
Windows	17 - Operable
	18 - Locked
	19 - Manual
Lighting control	20 - PIR
	21 - Daylight
	22 - Manual + PIR
	23 - Central
	24 - Other
HVAC control	25 - Room thermostat
	26 - TRV
	27 - At Split Unit
	28 - Central
	29 - None

**Table C.1:** Site visit codes describing building systems and controls

## C.2 Interview guide

Please find below the interview guide as utilised for the semi-structured interviews with clinical staff. During the second phase of the fieldwork, namely the investigation at KCH, questions which had so far not resulted productive with respect to the research question were removed from the interview guide in order to not take up too much of the participant's time given its shortage in hospitals. Such questions are marked here with (\*). The scales used as visual prompts to elicit numerical ratings are shown in Figure C.2.

### Briefing

- 'The aim of my research is to get a better idea of what energy is used for in different hospital areas and why.'
- Confirm information on interviewee (Position)
- Let them sign the **informed consent form** (see Figure C.4).

### Personal experience in the department/on the ward

- How long have you been working in this department?
  - Have you worked here in winter/summer?
- Could you please describe to me how a typical day looks here for you?
  - What do you spend most of your time doing?
  - How long do you spend directly in contact with your patients?
  - How much administrative work do you have to do?
- Could you tell me a bit about your experience of working here?
  - (\*) What do you like/dislike about the department / work environment?
  - Are there any particular aspects of the building you like or dislike? Maybe you can tell me a bit more about them.

### Area description

- Overall, how could the function of the department best be described?
  - Clarify whether the previous understanding was correct
  - Establish what the interviewee regards as their normal work area
- What are the operating hours of this department?

- During the week? On a weekend?
- Are there any days when the area is used less than usual?
- Are there any days when areas that are normally not used are used for something?
- Are there any times during the day, when there is more activity in the department / it tends to be quieter?
- (Do you know) When is the area being cleaned?
  - Is that every day?

### Lighting

- Let's talk a little bit about the lighting in your normal work area. I brought a scale in order to help us do that. [Show scale C.2a] Which number on this scale describes best how you feel about the lighting in your normal work area? Do you think it is 1 - 'Unsatisfactory'? Or 7 - 'Satisfactory'? Or somewhere in between?
  - Can you briefly explain to me why you chose this rating?
    - \* Too little / too much artificial light?
    - \* Too dark / bright in some areas? Glare from lights?
- Thank you for that. I have brought a second scale here. [Show scale C.2b] This one asks: How much control do you personally have over the lighting in your normal work area? And by control I mean, can you influence the state of the lights? Do you have 1 - 'No control' or up to 7 - 'Full control'?
  - Again, why did you choose this rating?
  - How are the lights controlled? / I understand that the main ceiling lights in this area are controlled <so-and-so>. Is that correct?
    - \* Is that the case for all rooms in this department?
  - *If manual light switches:*
    - \* How often do you operate the switches of the main lights?
    - \* If never or very seldom, why not?
    - \* When you begin/end work/your shift is the light normally on / off?
  - *If occupancy sensors:*
    - \* How well do you feel the automatic sensors control the lights?

A)	Unsatisfactory	1	2	3	4	5	6	7	Satisfactory
B)	No control	1	2	3	4	5	6	7	Full control
C)	Not at all important	1	2	3	4	5			Very important

**Figure C.2:** Scales shown to interviewees; a) Quality of lighting, b) Lighting / Heating / Cooling control, c) Importance of saving energy at work

- \* Are there any problems? / In certain rooms? / Have you ever been left in the dark somewhere?
- \* Do you have the ability to manually override the automatic light switches? Do you sometimes do that? Why?
- Are there additional lamps (for example at desks)?
  - Do you sometimes switch them on / off? Why?
- (\*) Have you ever made requests for changes to the lighting?
  - If yes:
    - \* How satisfied in general were you with the speed of the response?
    - \* ... the effectiveness of the response?

### Medical/Point of care equipment

- What is the piece of medical equipment you utilise most often?
  - Equipment that uses electricity?
- *If patient-related functions:*
  - How intensely are patients monitored in this department?
- *If treatment-related functions:*
  - How many <treatments> do you perform on a typical day?
  - Are you required to perform a certain number of <treatments>?
- Is there any equipment in this department that cannot be switched off?

- Why not? (Policy, Calibration, ...)
- Is someone responsible for switching off all other equipment when it is not in use? At the end of the day?

### **IT equipment**

- You mentioned that you spend <so and so long> doing administrative work.  
/ Do you spend much of your time doing administrative work?
- Do you have your own computer? / Between how many staff do you share a computer?
- Do you usually power down the computer after you finish using it?
  - If not, why not?
  - What happens at the end of the day?
  - Are / Could the computers be powered-down automatically?
- *If the department has other IT equipment:*
  - Explore the use of printers, fax, etc.
  - Investigate whether the equipment has sleep mode / is being switched off
  - Is someone responsible for powering down equipment?

### **Supplementary heating/cooling**

- How well do you feel is the heating working in this department generally?
- During winter, do you ever feel 'Too cold' or 'Much too cold' here?
  - *If yes:*
    - \* What do you do to get warmer?
    - \* Are any supplementary heaters used in the department?
    - \* If not, why not? (Policy?)
  - Do you sometimes feel 'Too warm' or 'Much too warm' in winter?
  - Could it be cooler? / Would it bother (you or) the patients if it were cooler?
  - Is it too hot now?
- In summer, do you ever feel 'Too warm' or 'Much too warm'?
  - *If too warm/much too warm:*

- \* How do you cool it down?
  - \* Explore use of fans, opening windows, portable air conditioning.
- How much control do you personally have over the heating?
  - 1 - 'No control', 7 - 'Full control' [Show scale C.2b]
  - !!! Check & if necessary prompt if answers refer to temperature control rather than heating control
- How much control do you personally have over the air conditioning?
  - 1 - 'No control', 7 - 'Full control' [Show scale C.2b]
- (\*) Have you ever made requests for changes to the heating (and/or air-conditioning/cooling)?
  - *If yes:*
    - \* How satisfied in general were you with the speed of the response?
    - \* ... the effectiveness of the response?

**(\*) Abnormalities in the electricity use profile**

*This section will only be asked if particularities were found in the profile and was omitted entirely during the second phase of the investigation.*

- This is the profile of how electricity is being used in this department. The use has been averaged across all days / weekdays / weekend days during the last month.
  - I was just wondering, whether you had any idea what could be going on...
  - I also noticed that...

**Ecological values (also compared to others)**

- What are your views in general about being green and saving energy?
  - What do you do to be green?
  - How do you save energy?
  - Explore actions at home
- At your workplace, how important is saving energy for you, on a scale of 1 to 5, with 1 being 'Not at all important' and 5 being 'Very important?' [Show scale C.2c)]
  - Can you briefly explain to me why you chose this rating?

- Do you think your colleagues and other people around here would say the same?
  - Are they more/less keen on sustainability?
  - Is being green something that comes up much in conversation? Why (not)?

### **Ideas on how to save energy**

*The questions in and the structure of this section are fairly open and the interviewer needs to respond flexibly to informant and prior information.*

- What do you think, could the department reduce its power use? How?
  - Explore ideas for change, what could be done differently
  - What are trade-offs, reasons for current ways of doing things
  - What would need to happen for you to take these actions?
- Explore issues of constrains and enablement, prefiguration
  - Does the set-up of the department help you not to waste energy?
  - Does anything in the physical arrangements of this department keep you from saving energy / being green?

### **Close**

- Explain when we might next be in touch and leave contact details for them.
- Thank them for their time and help.

## **C.3 Informed consent form**

Obtaining written informed consent from research participants is good practice and ensures that the rights of participants are respected throughout the research process. This project has been approved by the UCL Research Ethics Committee (Project ID: 5434/001). In accordance with the Data Protection Act 1998, this study is further registered with UCL Data Protection (Z6364106/2013/05/59). Please see below for the project information sheet (Figure C.3) and the consent form (Figure C.4) used in this study. The filled consent forms from all research participants are kept in a locked drawer. The following final report on the project was submitted to the UCL Research Ethics Committee:



### **Final project report to ethics committee**

For my PhD project entitled ‘Understanding hospital electricity use: an end-use(r) perspective’ I have carried out 22 interviews with NHS clinical staff in 10 departments of 3 London hospitals. In addition, I have carried out a number of more informal conversations in the main theatres of one of those hospitals where staff found it difficult to make time for the formal interviewing process. All interviewees were given information about the project as well as a hand-out including my contact details and provided written informed consent prior to the interview.

No major ethical issues arose during the interviews. In one case, a staff nurse volunteered to be interviewed but withdrew after being informed in more detail about the procedure and the purpose of the project. On three occasions, staff had to be interviewed in the presence of others because no separate facilities were available to carry out the interview in private. Staff were explicitly asked whether they felt comfortable carrying out the interview under these circumstances or whether they preferred to rearrange which they did not wish to do. It is appreciated that this may not be ideal neither from an ethical nor from an analytical perspective but could - given the constraints on NHS staff and facilities - not be avoided.

As for the informal conversations in the theatre department, the presence of the researcher was authorized by the head of the department. All members of staff were informed by him about the upcoming visit of the researcher and the purpose of the project. In addition, handouts were displayed on the information board of the theatre one week before the visit. Theatre staff were free to speak or not to speak to the researcher who always identified herself and explained the purpose of the project before asking any questions. Their statements remain anonymous and are more isolated, this will be considered during analysis.

Overall, a major challenge for most employees was to find time to participate in the interviews. Often their speaking to the researcher resulted in an absence which had to be covered for by other members of their team. It was hence considered appropriate to not only thank the interviewee for their participation through a piece of cake but to also bring some sweets for the rest of the team. These little gestures of acknowledgement were generally well received.

The data collection phase of the project has now been completed. In a next step, the collected data will be analysed and interview data will be viewed in the context of other strands of data collected through facility audits, technical measurements and document analysis.

## Energy use in hospitals - Interview Information Sheet

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully.

### What is the purpose of the study?

The NHS needs to reduce its energy use to save both money and carbon. But hospitals are complex buildings and its currently poorly understood what energy is used for in different hospital departments and areas. This research will work towards providing a clearer picture of energy requirements in hospitals as well as clarifying how some energy could be saved.

### Why have I been invited to participate?

You have been chosen to participate in this study as a volunteer because of your professional role in this hospital. You were recruited by Paula Morgenstern.

### Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason.

### What will happen to me if I take part?

You will be asked to complete an interview at your workplace which will take no more than one hour maximum.

### What are the possible disadvantages and risks of taking part?

Taking part in this study involves the time taken for completing the interview.

### What are the possible benefits of taking part?

By taking part in this study you will contribute towards understanding how we can reduce the current energy use in UK hospitals without compromising patient and staff comfort and health. If you are interested you can be fully informed of the outcomes of the study.

### Will what I say in this study be kept confidential?

All information collected about you will be kept strictly confidential (subject to legal limitations). Your name will be fully anonymised. Anonymised data generated by the study will be retained by the UCL Energy Institute.

### What will happen to the results of the research study?

The results of the research study will be written up as part of Paula Morgenstern's PhD thesis who may see to publish extracts from it. Research papers on particular aspects of the study may be published in reputable academic journals. If you would like copies of these please contact Paula Morgenstern in the first instance (details overleaf).

### Who is organising and funding the research?

Paula Morgenstern is conducting the research as a PhD student at UCL. The research is entirely funded by the EPSRC: <http://www.epsrc.ac.uk/Pages/default.aspx>.

### Who has reviewed the study?

The research has been approved by UCL,  
Reference No Z6364106/2014/02/15



Figure C.3: Informed consent: a) Interview Information Sheet

### Energy use in hospitals – Interview Consent Form

Please tick

I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.

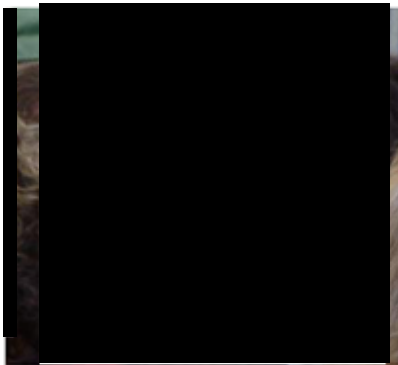
I agree to take part in the above study.

I agree to the use of anonymised quotes in publications.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.

\_\_\_\_\_  
Name of Participant                      Date    Signature

\_\_\_\_\_  
Name of Researcher                      Date    Signature



#### Contact for Further Information

Paula Morgenstern  
UCL Energy Institute,  
Central House  
14 Upper Woburn Place  
London, WC1H 0HY  
paula.morgenstern.11@ucl.ac.uk  
02031085927

By completing and returning this form, you are giving us your consent that the personal information you provide will only be used for the purposes of this project and not transferred to an organisation outside of UCL. The information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

If you have any concerns about the way in which the study has been conducted, you should contact the UCL Research Ethics Committee on 020 7679 7844.

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



Figure C.4: Informed consent: b) Interview Consent Form

# D Data analysis process

This appendix gives an insight in the analysis process, by exemplifying the type of records kept in the process. D.1 is at the core of the bottom-up representation of electricity use in quantitative analysis, while D.2 - D.4 are associated with the qualitative analysis process:

- D.1 List of all lighting and equipment item encountered in the case study departments
- D.2 Example of the cross-tabulation of interview information as basis for quantitative modelling
- D.3 Example of an interview transcript
- D.4 Excerpt from the analytical research notes kept during qualitative data analysis

## D.1 List of lighting and equipment items

**Table D.1:** List of lighting and equipment items

Equipment	End-Use <sup>1</sup>	Average power demand during operation <sup>2</sup> [W]	Source	Code	Reduced power demand [W]	Source	Code	Control <sup>3</sup>	Comment
Anaesthesia machine task lamp	L	20	Observed	3	0	L	L	A	
Analog imaging processing system	M	362	Rating given as 7A(max) by manufacturer; Average consumption assumed to be 25% of rating	5	29	Standard stand-by fraction assumed	7	A	Brand: FujiFilm
Analyzer (Alifax)	M	68	Technical specifications of specific equipment; bottom	5	47	Assumed to be 70% of maximum	7	U	Alifax Test 1 BCL Analyzer for EPS
Analyzer (Architect i4000SR)	M	1150	Power consumption of specific equipment	5	805	Assumed to be 70% of maximum	7	U	Architect i4000SR Analyzer for Aminoacid Analysis
Analyzer (Beckman)	M	430	Technical specifications of specific equipment (PDF; 2-2 p.28)	5	301	Assumed to be 70% of maximum	7	U	Beckman COULTER LH 750 Analyzer
Analyzer (ESR)	M	225	Manual of specific equipment	5	54	Specific equipment	2	U	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Analyzer (LIAISON by DiaSorin)	M	350	Power in use given as 1.5kW (kWh?)(Interval?)	4	28	% of active	6	U	
Analyzer (Olympus AU2700)	M	1350	Equipment specs; external	6	945	Assumed to be 70% of maximum	7	U	
Analyzer (Olympus AU640)	M	900	Equipment specs; external	5	630	Assumed to be 70% of maximum	7	U	
Analyzer (Ortho AutoVue Innova)	M	476	Technical specification of specific equipment	5	333	Assumed to be 70% of maximum	7	U	Ortho AutoVue Innova analyzer for blood groups
Analyzer (Siemens Advia 2120 Haematology)	M	311	Maximum according to manufacturer	5	25	% of active	7	U	
Analyzer (Siemens Advia 2400)	M	400	Power in use given (Interval?)	5	64	% of active	7	U	
Analyzer (Siemens Advia Centaur XP)	M	375	Power in use given as 1.5kW (kWh?)(Interval?)	5	30	% of active	7	U	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Analyzer (Stago: STA-R Evolution)	M	500	Power use in kWh given (unclear over what interval); also Manufacturer statement: Power 2kW	5	40	% of active	7	U	
Analyzer (Sysmex CA)	M	312	Technical specifications of specific equipment: PDF; p.3	5	227	Assumed to be 70% of maximum	7	U	Sysmex CA 1500 Analyzer for Co-Ag
Balance	M	8	Equipment type; Hosni 1999:6 quotes similar order of magnitude	2	1	Assumed to be 10% of actual consumption	5	A	Brainweigh B 3000 D Balance
Battery Charger for arthroscopic shavers and blades	M	236	Rating of 350VA observed	5	0	Reported to be unplugged when not in use	5	A	
Battery Charger for Orthopaedic drill	M	79	Peak power of comparable hand-held device: 95W	6	6	Standard stand-by fraction assumed	6	U	



**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Bedpan washer	M	1800	No details for specific equipment; General numbers: 0.16kWh/cycle; 0.3kWh/cycle - Capacity of washer: 4 bedpans; 29 patients on ward -> 7 cycles per day assumed; Cycle time 10min	4	0	Power estimate based on energy use; no stand-by assumed	7	A	
Bedside entertainment unit	IT	30	HOSPICOM unit	5	2	Standard stand-by fraction assumed	7	No	Under patient control; use will depend on patient
Blood Gas Analyzer	M	40	3.4kWh/week according to Christiansen et al. (2015): Assumed to be on 12 hours a day	3	3	% of active	7	U	
Centrifuge; tempererd (Eppendorf 5702)	M	140	70% of specified maximum power requirement (Hosni 1999 for lab equipment < 1000W)	3	14	10% of active consumption assumed during stand-by	5	A	
Centrifuge; tempererd (eppendorf 5804)	M	450	Specific equipment; Average consumption	5	0	No stand-by	7	A	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Centrifuge; tempererd (Hettich EBA 20)	M	41	Technical specifications of specific equipment: 65VA	1	4	10% of active consumption assumed during stand-by	4	A	
Centrifuge; tempererd (Rotina 420R)	M	338	Specific equipment; Power factor; Average consumption	5	0	No stand-by	7	A	
Centrifuge (non-tempered)	M	80	Power consumption; Average consumption assumed to be 70% of plate rating (Hosni 1999; Lab equipment < 1000W)	3	16	10% of active consumption assumed during stand-by	3	A	Desage LC 2 Centrifuge
CFL 4 Pin Quad		27	(Comparable to RLH consumption assumed as fairly typical for type)	4	0	Lighting		L	
CFL 4 Pin Quad Emerg	L	31	Total circuit watt given by manufacturer; O1E: Mirage recessed down lighter with 3hr COMET integral emergency	2	0	Lighting		L	
CFL 4 Pin Quad KCH	L	42	Wattage from Charlie	3	0	L	L	L	
CFL KCH	L	19	Wattage from Charlie	3	0	L	L	L	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
CFL TC-L Patient Uplight	L	55	Luminaire identified; but available with many different lamps. No details on lamps observable due to luminaire design. Midrange consumption picked out of available luminaires.	4	0	L	L	L	
CFL Tube (RLH Corridors)	L	61	Total circuit watt given by manufacturer; PE: Broadspread DUO fully recessed with DUO diffuser optic and high frequency gear with 3hr COMET integral emergency	2	0	L	L	L	
CFL Circular	L	23	Typical consumption; no further details available	4	0	L	L	L	
Chemo Infusion Pump	M	23	Pump details	4	0	Unplugged when not in use		A	
Cloud light (RLH)	L	80	Circuit wattage given by manufacturer	2	0	L	L	L	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Cold room	M	228	Double of the electricity consumption benchmark for cold storage	7	228	Always on	7	No	
Commercial microwave	C	373	Specific equipment	5	2	Menezes et al 2014; p.80 Stand-by mode (Stand-by of commercial microwave assumed to be similar to normal microwave)	3	A	
Convective warmer (Bair Hugger)	M	380	Measured by Tom Pierce	2	0	Reported to be unplugged when not in use	5	A	
Cooling fan	LHC	500	Rating of 1000W observed	5	0	No stand-by	2	A	
Daikin Split Unit	LHC	750	Reported for the Daikin Units at KCH (Norton); Slightly above measurement	5	150	Measured at KCH Day Care	1	B	Potentially overestimating use
Datex Ohmeda Aespire View Anaesthetic machine	M	110	No details available; machines seems to be between Drager Fabius Trio and Drager Primus in size	5	9	% of active	7	A	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Datex Ohmeda Avance Anaesthetic machine	M	160	No details available; machines bigger than Aespire view; potentially bigger than Drager Primus in size	6	13	% of active	7	A	
Defibrillator	M	40	Specific equipment; Charging of battery is 53Wh	5	3	Standard stand-by fraction assumed	6	U	
Desktop PC + Monitor	IT	95	CIBSE Guide F 3rd ed.; also CIBSE TM 54. Computers are low intensity application; so lower end of spectrum measured by Menezes	3	3	CIBSE Guide F; Menezes	3	A	
Diabetes Monitor	M	24	No information on average power consumption available; estimated on the basis of equipment type: small hand-held measurement device with charging station	7	2	Standard stand-by fraction assumed	7	A	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Dialysis machine	M	525	Based on Measurements were taken at Maidstone renal unit (East Kent Hospitals University NHS Foundation Trust) between 03/06/2010 to 15/06/2010. By Fraser Campbell; Renal technician	3	42	Are normally switched off entirely according to technician to avoid water problem; about 8% are left in stand-by	3	C	
Dinamap Patient Monitor	M	9	12W rated according to manufacturer	5	1	% of active; manufacturer advice is to always keep plugged in to safe battery	7	A	
Dish washer; commercial	C	425	Total connected load 1.7kW; Average power use of 50% assumed	5	34	Standard stand-by fraction assumed	6	No	Domestic staff
Draeger Fabious Trio Anaesthetic machine	M	93	Manufacturer specifications + 30W for a monitor	4	7	% of active	5	A	
Draeger Primus Anaesthetic machine	M	130	Hinz et al. (2012)	2	10	% of active	5	A	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Drug fridge (small)	M	26	Equipment specs	2	26	Always on	1	No	LABCOLD drug fridge; small; wall mounted; 3degC
DVD/CD Player	IT	10	Generic equipment of this type	4	2	Generic equipment of this type	4	A	
ECG	M	31	For GE MAC 1600	5	2	Standard stand-by fraction assumed	7	A	
Electrosurgical Generator (Conmed System 5000)	M	375	Output wattage of 300W according to specifications; Efficiency assumed	6	0	Reported to be unplugged when not in use	5	A	
Electrosurgical Generator (Eschmann TD850)	M	120	Equipment specs	5	10	% of active	7	A	
Electrosurgical Generator (Eschmann Unit E30)	M	439	Power rating observed: 650VA	5	35	% of active	8	A	
Electrosurgical Generator (Valkeylab Force TX)	M	403	Equipment specs; external source	6	0	Reported to be unplugged when not in use	5	A	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Endoscopic lightsource (ELITE 180 Medical Grade 180W Xenon Lightsource)	M	135	Equipment specs	5	11	% of active	7	A	
Endoscopic monitor (Zeiss MediLive Trio)	M	41	Maximum power consumption given	5	0	Observed and reported to be unplugged when not in use	4	A	
Fax	IT	30	CIBSE Guide F Ed. 2	2	10	CIBSE Guide F Ed. 2	2	A	
Fluid Warming Cabinet (Kanmed 1002W)	M	200	Manufacturer give average power consumption between 150 and 250W	2	16	% of active	7	U	
Fluid Warming Cabinet (LEEC W100)	M	120	Technical rating: 240W according to manufacturer	5	120	Equipment is always on	1	U	
Fluid Warming Cabinet (QED; 46degC)	M	120	QED give little detail on their cabinets; no rating known -> LEEC value used	6	120	Equipment is always on	1	U	



**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Fluid Warming Cabinet (unspecified)	M	120	QED give little detail on their cabinets; no rating known -> LEEC value used	6	120	Equipment is always on	1	U	
Fridge	C	53	Menezes et al 2014; p.80 Average consumption in use	3	53	Always on	3	No	
Gyrus Ent Equipment for nasal surgery	M	357	Observed 2.3A	5	0	Observed and reported to be unplugged when not in use	4	A	
Hi-Fi System	IT	20	Audio Minisystem	4	9	Audio Minisystem	4	A	
Honeywell electric heater	LHC	2010	Measured	1	0		1	A	
Hot beverage system	C	233	No idea - Ultrakart for 50cups of water; heats them 40K in 2hours	7	23	To keep the volume warm: 2K are constantly lost	6	No	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Hot water provider	C	575	Manufacturer specs	5	0	Zip Hydroboil give weekly consumption figures based on a 40h/working week of 8 - 10 kWh/week. Based on this standby consumption we have 10kWh/week which given the longer working week seems reasonable.	5	No	
Incubator (Helmer)	M	455	Power factor; Correction for part load through linear assumptions on temperature; Average: 70% of specified maximum power requirement (Hosni 1999 for lab equipment < 1000W)	5	0	No stand-by	2	U	Helmer Incubator with Helmer Agitator inside chamber; see Photo; 22.3degC; Range according to Manual: 20 to 35degC
Incubator (Ortho Vue)	M	210	Technical specifications of specific equipment; pdf p.8; Hosni 1999 <1000W	3	21	% of active	7	U	Ortho Bio Vue System
IV pump	M	7	Manufacturer power rating for Voluminat Aguila	5	7	Always on	7	U	Recommended by manufacturer to always remain plugged in

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Kettle	C	500	Firth et al. 2008; p.928 - Small appliances with infrequent use	6	0	No stand-by	2	A	
Label Printer	IT	40	Power demand given as 90 - 265 VAC; Technical specification of specific equipment	5	16	Menezes et al 2013; p.80 Small desktop printer	3	A	Zebra Z4MPlus Commercial printer
Laptop	IT	65	CIBSE Guide F; Menezes found that basic specification laptops fit this estimate well.	2	2	Menezes et al 2013	2	A	
LED Spotlight	L	5	Lamp type observed; Photo available; Manufacturer unknown; Exact size unknown -> Philips LED Spot with 4.5W assumed	6	0	L	1	L	
LED surgical light (trilux Aurinio L120)	M	145	No information for specific piece of equipment found; iLED value used	3	7	Based on general lighting control factor	5	A	
LED surgical light (Trumpf iLED 5)	M	145	p.15 Download from pdf	2	7	Based on general lighting control factor	5	A	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Maxillume 250-1 Endoscopic light source	M	211	Power rating (V; A) observed	5	0	Unplugged when not in use	1	A	not plugged in
Medical fridge/freezer	M	57	Christiansen et al. give 9.5kWh/week for medical fridges/freezer until -18degC	3	57	Average consumption measured	1	No	
Medical scales	M	11	Manual of specific scale gives 12V; 2A as mains adaptor specification	5	1	Standard stand-by fraction assumed	7	A	
Micro-Osmometer	M	60	Type	2	0	No stand-by	7	A	
Microscope	M	83	Current observed for Olympus BX51TF ; Christiansen et al. (2015) give 50W as power rating; therefore low average consumption used	5	0	No stand-by	7	A	
Microscope (small)	M	20	O	5	3	Generic equipment	3	A	LABORLUX 12
Microscope (Zeiss Opmi Visu 200/S8 for eyes)	M	990	max. 2200VA observed	5	0	Reported to be unplugged when not in use	5	A	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Microscope for cataract/retina surgery (Zeiss lumera 700)	M	540	Maximum rated consumption; p.14	5	0	Reported to be unplugged when not in use	5	A	
Microwave	C	120	Menezes et al 2014; p.80 Average consumption in use	3	2	Menezes et al 2014; p.80 Stand-by mode	3	A	
Mitsubishi Split Unit	LHC	600	O - Rated input for specific unit	2	120	Assumed to be a bit smaller than the Daikin Unit	7	B	
Mobile Imaging (Siemens Arcadis Varic)	M	2300	During X-ray generation	4	184	% of active (understood as exposure)	7	B	Generator reportedly on
Monitor (Flat screen)	IT	30	CIBSE Guide F 3rd ed.; Computers are low intensity application; so lower end of spectrum measured by Menezes	3	1	Menezes et al 2014 Monitored value; CIBSE guide F 3rd edition	3	A	
Nerve monitor (Neurosign 100)	M	39	Power rating (V; A) observed	5	0	Observed and reported to be unplugged when not in use	4	A	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Nurse call system	M	55	Consumption of a nurse call system with about 60 powered devices; based on a simultaneous call rate of 25% Information provided by Mathew Wakelam of Static Systems	3	55	Always on	3	No	Always on
Operating equipment (medium)	M	673	Max rating of 6.5A observed	5	54	% of active	7	A	
Operating equipment (small)	M	100		7	8	% of active	7	A	
Operating table (Maquet Alpha Star Pro)	M	78	No information for specific piece of equipment found; Comparable equipment: p.10	6	6	% of active	7	A	
Other laboratory equipment (Medium)	M	75	O	5	0	No stand-by	7	A	Oven

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Other laboratory equipment (small)	M	10	Assumed; small equipment	5	2	Assumed to be 20% of maximum	5	A	SARSTEDT Multi Sealer MS 250 to seal blood bags; Electrophoresemaschine (Transmed Sahara iii)
PACS Reporting Station	M	179	Average power consumption measured at RLH X-ray	1-2	61	Measured at RLH	1	A	
Patient lamp (CFL)	L	18	Wattage observed	3	0	L	L	L	
Patient lamp (Halogen; KCH)	L	53	Wattage from Charlie	3	0	L	1	L	
Patient lamp (Incandescent)	L	60	Wattage observed; Inc; so no control gear	3	0	L	L	No	
Patient lamp (LED)	L	5	Equivalent to the 60W observed	4	0	L	1	L	
Patient lamp (Metal halide)	L	30	on Strumpf medical system Pod; patient controlled; Wattage observed as '20 - 60W lamp' specified on the tripod	5	0	L	L	L	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Patient Monitor	M	6	12W rated according to manufacturer of Dinamap Patient Monitor	5	0	Standard stand-by fraction assumed	7	No	Manufacturer advice is to always keep plugged in to safe battery
Photocoagulator	M	270	Power rating (V; A) observed	5	0	Observed and reported to be unplugged when not in use	4	A	
Photocopier	IT	230	Menezes et al 2014; p.80 Large network printer photocopier - Average consumption in use	3	35	Menezes et al 2014; p.80 Large network printer photocopier - Stand-By	2	A	
Platform for cataract removal	M	338	Maximum power rating observed	5	0	Reported to be unplugged when not in use	5	A	
Portable AC unit	LHC	569	Max current according to plate is 11A; Observed at NUH Ward	5	0	Observed unplugged when not in use	1	A	
Printer (Medium)	IT	49	Menezes; Average consumption	3	16	Menezes et al 2013	3	A	
Quantum 2 Controller for anatomical procedures	M	414	Rating observed: 4A for 220 - 240V or 400W output power	6	0	Reported to be unplugged when not in use	5	A	



**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Regenkitchen	C	375	Average consumption from monitoring (calculated to be constant independent of demand)	1	0	Off if not in use	1	No	Food is prepared by hostesses
RESUS	M	54	LIFEPAK 20 Defibrillator/Monitor on Parity Medical Trolley - Technical manual states '(p.127) total power draw less than 120 Volt-Amperes' when AC powered	5	54	Always on	6	No	Required in the case of emergency
RLH HDE 13W ECO	L	18	Total circuit watt given by manufacturer	2	0	L	L	L	
Roller Mixer	M	12	Technical specification of Axiom Roller Mixer (as in NUH Lab)	3	0	No stand-by	7	A	
Rotator (Tubes; Stuart SB3)	M	25	Specific equipment	5	3	% of active	7	A	
Router	IT	5	Generic equipment of this type	4	5	Always on	4	T	Unfeasible

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Shredder (DS Dahle)	IT	5	Assumed to be similar to Rexel Shredder as Dahle does not provide consumption figures	4	5	Assumed to be similar to Rexel Shredder as Dahle does not provide consumption figures	3	A	DS Dahle 20404 Shredder
Shredder (Rexel)	IT	475	Technical specifications of specific equipment (p.11; Some uncertainty about which exact model)	3	1	Technical specifications of specific equipment	2	A	Rexel Mercury Jam Free Shredder RDX2070
Spirometer with old monitor	M	250	Observed (see photos)	5	0	Unplugged when not in use?	5	A	
Surgical Clipper	M	13	Typical use of electrical shaver: 15W	5	1	Standard stand-by fraction assumed	6	A	
T12 NUH	L	38	Wattage observed	3	0	L	L	L	
T5 1ft Emergency or Signal light	L	16	Total circuit watt given by manufacturer (RLH E1)	2	0	L	L	L	
T5 2ft KCH updated control gear	L	19	Wattage according to Charlie; also observed on lamp	2	0	L	L	L	
T5 2ft NUH	L	25	Wattage observed	3	0	L	L	L	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
T5 2ft RLH	L	17	Total circuit wattage given (RLH H or N)	2	0	L	L	L	
T5 KCH	L	15	Wattage from Charlie	2	0	L	1	L	
T8 2ft NUH	L	32	Typical consumption; no further details available	4	0	L	L	L	
T8 4ft KCH updated control gear	L	38	Wattage observed	3	0	L	L	L	
Tea-Reheater	C	60	Measured with plug in (spot check)	1	0	Off at plug if not in use	1	No	Hostess
Telephone	IT	3	Roth and McKenney (2007, p.41)	3	0	On or Off only	1	No	Underestimates use during calling -> small for rooms with high phone use
Theatre panel	M	445	Data sheet	6	445			No	
Toaster; biggish	C	825	Rating observed at NUH	5-6	0	On or Off only	1	No	Domestic staff
Tower fan for cooling	LHC	25	Power rating observed: 50W	5	0	Observed unplugged when not in use	1	A	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
TV	IT	130	Firth et al. 2008; p.928 for normal TV	3	2	Firth et al. 2008; p.928	3	A	
UCV Canopy (Exflow 32)	UCV Canopy	4100	Operational (Mean) Power Consumption According to Technical Summary	2	2050	According to the manual; Stand-by mode is 50% of operational mode	2	B	
UCV Canopy (MAT)	UCV Canopy	2708	Measured in NUH Theatre 4	1	1781	Measured in NUH Theatre 4	1	B	
Ultrafreezer	M	1024	Measured by Christiansen et al. (2015)	3	1024			No	
Uninterruptible Power Supply	M	16	Estimate	6	16	Is ready	6	No	PowerVar
UV sterilizer	C	25	Rating of 50W observed	5	25	Always on	5	No	Required on for health & safety reasons
Vending machine	C	583	14 kWh/day according to overview	4	583	Always on	7	U	
Wall mounted electric heater	LHC	2070	Measured: 2070 W on stage II; 1050 W on Stage I	1	0		1	A	De Longhi wall mounted electric heater
Water cooler	C	311	Power factor; FLA as given 1.5A	5	7	OASIS Water cooler; Cold only	6	No	

**Table D.1:** List of lighting and equipment items (continued)

Equipment	End-Use	Average power demand during operation [W]	Source	Code	Reduced power demand [W]	Source	Code	Control	Comment
Water cooler unit; Cold only	C	7	Labelling scheme	3	7	Always on	1	No	Always on
Water purification system	M	300	Comparable water purification system; p.5. Power consumption < 0.4kW	6	210	Assumed to be 70% of maximum	7	No	Millipore Progard TL1C12

<sup>1</sup> End-use: C - Catering; IT - IT equipment; L - Lighting; LHC - Local heating/cooling; M - Medical equipment

<sup>2</sup> For equipment of type C and D: In 'Ready mode'

<sup>3</sup> Default Control Code:

- A - Clinical staff can switch from on/ready to off
- B - Clinical staff can switch from on/ready to stand-by
- No - No switching by clinical staff possible
- U - Unclear

**Table D.1:** List of lighting and equipment items

## D.2 Example from the RLH Day Clinic for the cross-tabulation of interview information as basis for quantitative modelling

**Table D.2:** Cross-tabulation of information for RLH Outpatients

Element	Fieldwork preparation with Renal technician	Interview I: Staff nurse	Interview II: Health Care Assistant	Interview III: Nursing support
Morning		We start 7:30. We start from 7 to 6:30.	We come in at seven. The patients... Sometimes patients get here before us, the reason being the transportation. It's when they are picked up. Yeah, so once we have lined the machines 07:30, they are meant to come in. Some people do come in before time. Colleague: I usually turn up here at half past six.	7am
Evening		And so if you are late with your bay, these patients don't get to go on at 5 and staff don't finish 11 o'clock which obviously puts them in more of a situation because they have to get their way home and people don't live locally.	I mostly work twilight. It starts at 11:30, so there is kind of like an overlap till 11pm.	6:30 (She never does twilight) It is just this bay and this bay which do twilight and only on Monday, Wednesday and Friday.

**Table D.2: RLH Outpatients (continued)**

Element	Fieldwork preparation with Renal technician	Interview I: Staff nurse	Interview II: Health Care Assistant	Interview III: Nursing support
Dialysis schedule	<p>CE holds chronic dialysis patients who have to come three times a week. During the morning and the afternoon shift, usually all dialysis machines are in use. During the 'twilight shift' it will be about half, but they are noting an increasing demand now. Clinicians sometimes request to offer dialysis on Sundays as well, but the technician thinks there needs to be time for the machines to be maintained.</p>	<p>The first batch go on between half seven and eight o'clock. And everything is about timing, so they have got to come off with enough time, then the machine has got to disinfect to be ready for the next set. Which is one o'clock.</p> <p>And the thing is, the last session, which has patients going on between 5 and 6. Then they have to finish for 10 for staff to go home by 11.</p>	<p>Some people come in before the time, they are meant to be in at 7:30.</p>	
Cleaning		<p>Well, that's normally done in the night. They completely clean the place.</p> <p>They work throughout the day. So they come and they come into the bays and do dusting.</p>	<p>When we leave at night, the domestics do come in. They come, yeah... Or sometimes we are finishing up and they are already here. And then while we finish up and all the patients are gone by the time, they come in... Obviously, when we get here at 7 o'clock in the morning, they are here doing the dusting etc, toilets. (...) The floors are mopped at night, because it's a health hazard. During the day you couldn't do it because there would be lots of falling. So it's the last thing they do.</p>	

**Table D.2:** RLH Outpatients (continued)

Element	Fieldwork preparation with Renal technician	Interview I: Staff nurse	Interview II: Health Care Assistant	Interview III: Nursing support
Nurse base CFLs		And here (in the nursebase), we have lights here, we control that behind the computer. That's fine.		No control. On when in use.
Nurse base LEDs		And you have these as well (the LED type lamps on the 'counter')...I don't really notice them. (laughs) I don't really think about these ones.		Sometimes. Not really. As it is up now. (They were not in use during the interview)
Corridor lights		We don't really need any corridor lights. What about the ones which are on at the moment? Oh yeah, yeah... I think they are on, but I never notice them really. But if they were on or off, it wouldn't make a bit difference really. We don't really need it as such.	What, these ones? I don't know... (laughs) (I keep insisting and she sees herself forced to give some answer) <i>Who would be switching on the lights in the corridors?</i> Mmh... <i>Is that just the first person in?</i> Yeah, that could be. The first person in, yeah.	Because they do automatically go off, because they are sensed and as soon as somebody comes through. And then if nobody is there around, they will go off.
Bay lights Cloud lights		Controlled by staff	You can turn it off on the main switch which is there (point to a switch on the wall opposite the nurse base) and then everybody got their individual light.	



**Table D.2: RLH Outpatients (continued)**

Element	Fieldwork preparation with Renal technician	Interview I: Staff nurse	Interview II: Health Care Assistant	Interview III: Nursing support
Patient bed lights		<p>... but if you have that one (cloud light) you don't need to touch the lamps. But at the bottom (the patient beds at the periphery of the building, further away from the nurse station), they don't have it so you have to put the lamps on.</p>		

**Table D.2: RLH Outpatients (continued)**

Element	Fieldwork preparation with Renal technician	Interview I: Staff nurse	Interview II: Health Care Assistant	Interview III: Nursing support
Uplights at patient beds		<p>For example, there is another light, but it is behind the machine and it is behind the bed. I have to go behind to switch it on. And if you switch it on, and obviously patients will want to turn it back off when you finish, so you got to behind the machine, behind the bed, or behind the handbags and coats. It's not... easy accessible. It would be nice maybe if there was some form of remote control or so maybe. <i>And do you use these uplights a lot?</i> Yes, because at the back that is the only light, that and the lamp. <i>So generally in the back of the bay, these lights will be on all the time?</i> Unless the patient don't want it on. So you switch it off. <i>And then the little lamp, patients can also switch them on and off themselves?</i> Yeah, yeah. So for that reason I would say six.</p>		

**Table D.2: RLH Outpatients (continued)**

Element	Fieldwork preparation with Renal technician	Interview I: Staff nurse	Interview II: Health Care Assistant	Interview III: Nursing support
Toilet lights			<p>See, the good thing is - if you walk into like a place, sorry , I said seven, we don't have full control over some of the lights - I will give it a five - because if you walk into the toilets, it is like immediately, it senses your presence and will immediately come on.</p>	
Nurse base PCs	<p>Technician says there is no automatic PC power down in the department. Monitors go into sleep mode and PCs into standby.</p>	<p>No, they will be off in the mornings. (...) Because they normally go off in the evenings... They have a power thing that switches off. <i>Is that like an automatic power down?</i> Yeah. I don't think we actually switch it off. We just log-off. Most of us just log-off.</p>	<p>Mornings: And... for the first person... because when we come in immediately, we don't go straight to the computer. It's hands on - we go straight to the machine. But once, we are ready we will switch them on. Maybe at about eight, I don't know maybe between eight and nine. Actually, it's mostly about nine because we are not gonna be... Sometimes we are putting patients on. About 8:30... <i>Evenings - automatic shutdown?</i> Yes, they do. They do.</p>	<p>On: That is not priority first thing. - If somebody needs to check something. Probably half eight, nine o'clock. Once all the patients are on - unless somebody needs to check something. Off: Probably about 6 o'clock, half six.</p>

**Table D.2:** RLH Outpatients (continued)

Element	Fieldwork preparation with Renal technician	Interview I: Staff nurse	Interview II: Health Care Assistant	Interview III: Nursing support
Dialysis machines	He expects there to be no significant difference between the electricity use of the dialysis machines used in house and those people use at home. The machines have different switch off behaviours: The old Gambro machines require to be switched off manually after heat disinfection. The newer, green Gambro machines automatically go into stand-by, while the Fresenius switch themselves off completely.	But they are actually timed, They should come on at about 10 to 7. And then they disinfect themselves... I think they probably come on at half six. Come on at half six, by the time we get here disinfection should be finished. No, we switch it off. (...) We put it into what is called night-mode. If it is still messing around, we switch it off. They do still switch off. But we just want to be safe. So we switch it off. Because it can... it can... They say if it is not switched off, it messes up the whole water system.	They are set, so they will come on. Colleague: Half five, quarter to six. And they will be ready for seven, but we - so I usually turn up here at half past six. So one or two machines might still be going then, but they will be ready for quarter to seven. Colleague: Well, we actually set them to go off. So with the last disinfection of the day, the procedure is slightly different. You can do a quick disinfection and then shut down and then they start off at six o'clock to go into a long, a proper disinfection cycle... About 11 o'clock...	Some turn themselves off after the heat clean (big Fresenius type), others not.
Blood pressure machines				Constantly plugged in, two in the department
Patient TVs	They have only few TVs or anything for the 4 hour treatment. Technician thinks this is stupid because having to spend 24 of you life every week (including travelling) on dialysis one could at least give them TV.	Yes. But there is only a small number. This guy for example, he inherited the TV from someone else. They pay a pound and then they can use it for 8 hours.	It is 8 hours for £1 - Not many. Because... we did have many, but they just need to be prepared. It's not like they weren't provided - they were provided, but then they just need to be repaired.	

**Table D.2:** Example from the RLH Day Clinic for the cross-tabulation of interview information as basis for quantitative modelling

### D.3 Example of an interview transcript

<21:55> *Do you know when the area is being cleaned?*

*[Confusion whether theatres or whole department]*

The whole department they usually clean after we finish work. One of them will clean. Or when you come in in the morning as well... The cleaning staff start earlier. Because when we come, some of them will be like finishing cleaning. But it's not this staff. There is a cleaning team from a private company. They just clean the floors and the beams in the theatres. For us when we finish our lists, we do our own cleaning of beds, our medical equipment we do it ourselves, because they don't know how to handle it. And then when we come in the morning, you know particles and dust can come from anywhere, you never know so we do a bit of cleaning before we start as well.

<23:20> Lighting

*Let's talk a little bit about the lighting in your normal work are. I brought a scale in order to help us do that. [Show scale] Which number on this scale describes best how you feel about the lighting - do you think it is 7 - satisfactory? Or 1 - Unsatisfactory? Or somewhere in between?*

The lighting is good, but... I give you an example of where we are now. So for example the gentleman in the corner there, if he wants to read, he has good eyesight but for someone with bad eyesight – look at it, it's a bit dark, isn't it? But the lights are on. So that means the distribution or the whatever the panels they use, I feel they are limited to a particular place like this. For us here, we are okay, but for him if he has a bad sight like me, it will be – he will be straining his eyes.

*And do you feel that is the case in many of the rooms?*

Many of the rooms... Operating theatres, I can't complain, the lighting is quite good. The panels <she refers to the lighting panels> are bigger than this, the lighting in theatres is quite good. I wouldn't complain, honestly. Since everything is too new, everything is working at best capacity.

*What number would you go for?*

I would give it a six, because so far we haven't experience any problems with our lighting except what I said.

<25:40> Lighting control]

*[Researcher presents scale]*

In our working area, I would say we have got full control. You know, in other areas where you go, the moment you step in the lights will just go on. So as if there is a sensor... But with us, we have to really switch them on. If you don't know where the switch is... that is why you see people sneaking in the dark, looking for the switches and they cannot find the switches.

*[She agrees for it to be a 7]*

Figure D.1: Example of interview transcript

## D.4 Excerpt from the analytical research notes

### 28.04.2015: Interview 'G'

- This interview was actually really interesting because she is a different part of the **hierarchy**: lower by education and responsibility. In KCH Outpatients, I also interviewed a support worker. We should compare their takes on hierarchy etc.
- I now created '**Main motivation**' as a category in the table: this needs to be understood with care but might be really interesting to cross match 'Individual motivations' with 'Perceived constraints' and 'Ideas for change' >> maybe only in board categories
- Motives now grouped under headlines: Individual / Social ... Other seems not to have occurred yet? [Could there be such a thing as someone driven by technology? I am thinking of a geeky person maybe, would they be in an NHS job?]
- Not sure about the "does admin/no admin category": we are now recording what people said with this respect, but actually what people may have understood by the question will be quite different in each case.
- This is actually a really valuable interview: She just admits that she has never thought about what she personally should do to save energy while intuitively she does feel it is somehow important. Or at least she feels that it is not unimportant. Okay.

### 29.04.2014: Interview 'T'

- Changed **position in hierarchy** based on experience to position in hierarchy (official) because here we are really looking at how they are classed: Junior vs. Senior, A sister vs. a 'normal' nurse, etc.
- I imagine the twilight shift is the one for which all delays accumulate. Like with airplanes, the ones later in the day are always later than the ones first thing in the morning.
  - ➔ Staff can only go home after all is finished. For some machines, they would need to stay after the last clean to switch them off. Probably asked a lot.
  - ➔ However, is there a heat clean done after the last shift? Or more like a quick disinfection like James said: because on the electricity profile it does not look like any heat clean is happening?! Would that be more like a quick disinfection cycle: if that takes less time, there is less reason why staff might not be around for a switch off afterwards?
- **There are several dimension to this**: "But I don't think there is a lot I can do." Does this refer to "no control" or "no impact" I think this needs to be distinguished. For NUH Ward Nurse, based on this technical understanding it might refer to "No impact" (he related to energy intensive areas where saving might be more useful), for RLH Renal Nurse it will be more "no control".
- **Home** is also interesting: Do you do something at work because you do it at home or do you not do something at work which you do at home because it is not your home? How is this different between staff and patients? For patients, the hospital is clearly not home and they have less control/responsibility because part is taken over by staff. For staff, it is actually not dissimilar with the only difference that it is shared by the team. Like people taking less responsibility in shared housing.
- **How important is saving energy** --> in theory or in practise. She makes this distinction and I have seen it before (Pilot 1) but it is not common. I think this could be an interesting point to see who and how many people make this distinction.

### 30.04.2014 Interview 'A'

- I think I need to work a lot more on the notion of **emergency**. Because this is important. Was is really the necessary state of operation to be ready for emergency? Was it perceived by outsiders? What by staff themselves?
- She makes excellent statements about the time available to you even in case of emergency.
- There is some element about temporal flexibility: actions can be shifted: documentation can be done at any point, overtime and breaks are given back to people when needed.

**Figure D.2:** Excerpt from the analytical research notes kept during qualitative data analysis

## E Quantitative findings

This appendix illustrates the operational changes that seem conceivable in each case study department from a theoretical standpoint. They have been used to calculate the theoretical electricity savings potentials presented in section 5.4.

**Table E.1:** Details for departmental savings potentials

Name	Promoting simple energy behaviours	Modifying catering procedures	Modifying IT equipment procedures	Modifying lighting procedures	Modifying local heating/cooling procedures	Modifying medical equipment procedures	AGS Switching
NUH Imaging	Reduced lighting and appliance use during lunch breaks; Reduced stand-by	-	One PC off in the viewing room during the night	X-ray room III off between 11pm and 9am when only one radiographer is around	Not much can be done due to poor ventilation	2 out of 3 analogue imaging processors off throughout; One PACS station off from 11pm to 9am	-
RLH Imaging	Weekend and after-hour lighting use	-	Printers completely off during weekend	After-hour lighting consumption at $0.7W/m^2$ <sup>1</sup>	-	Lesser used PACS station completely off during weekend	-

**Table E.1:** Departmental savings potentials, continued

Name	Promoting simple energy behaviours	Modifying catering procedures	Modifying IT equipment procedures	Modifying lighting procedures	Modifying local heating/cooling procedures	Modifying medical equipment procedures	AGS Switching
KCH Laboratory	Load consistently lower throughout the day, likely associated with fewer computers in use	-	PC and label printer operations streamlined during the night	Lights off in empty registrar's room	Less heat through redistribution of equipment, equal thermostat settings	Sharing fridges as suggested in NUH (Reducing number of fridges by 2)	-
NUH Laboratory	Very little potential, dominated by high base loads	-	Concentrating IT use during the night: Permanent tasks on one computer per section, 3 printers per night	Lights off in Room 5 when not in use; Corridor lights off during the night in back part of department (not in use)	Higher temperatures in blood fridge room (10% less power draw from AC assumed)	-	-
RLH Main Theatres	Night time lighting; Earlier power down in the evenings	-	-	Scrub room lights off during surgery	-	-	AGS plant off when theatres not in use
NUH Main Theatres	Based on measured data therefore for core theatre areas only	-	-	Scrub room lights off during surgery; Lights off in elective theatres after last surgery there; Concentrating emergency surgery in adjacent theatres (lights off in rest of the department)	-	Increasing room temperatures to reduce convective warmer use	Switching of AGS plant when theatres not in use



**Table E.1:** Departmental savings potentials, continued

Name	Promoting simple energy behaviours	Modifying catering procedures	Modifying IT equipment procedures	Modifying lighting procedures	Modifying local heating/cooling procedures	Modifying medical equipment procedures	AGS Switching
RLH Day Theatres	Night time lighting in particular over the weekend	-	-	Lights off during lunch breaks; Scrub room lights off during surgery; Looking department overnight: Corridor lights may be switched off	-	Increasing room temperatures to reduce convective warmer use	Switching of AGS plant after-hours
RLH Out-patients	Weekend night time lighting; Lights off in self dialysis areas during non-active twilight; Consistent switch off of dialysis machines	Microwave completely off after-hours	Printers off after hours	Asking patients whether they want their light on (instead of default on)	-	Unplugging IV pumps when not in use (after-hours)	-
KCH Out-patients	Less lighting use on weekends, Space conditioning from 8am and not earlier, Unplugging IV pumps during the night	New vending machine is 10% more efficient	Switching off printers after hours	-	Reducing split unit use by 20% through less space conditioning outside opening hours	-	-

**Table E.1:** Departmental savings potentials, continued

Name	Promoting simple energy behaviours	Modifying catering procedures	Modifying IT equipment procedures	Modifying lighting procedures	Modifying local heating/cooling procedures	Modifying medical equipment procedures	AGS Switching
KCH General Ward	Lights in peripheral rooms switched off during day time; Half of corridor lights switched off during night	Staff microwaves completely off	Monitors in corridor providing patient information off during the night; 2 out of 8 computers off completely overnight; Printer in office and reception completely off overnight	Reception light off after-hours, Introducing quiet time (2 hr/day switch off of bay lights)	(Savings through improvements in heating control conceivable, but currently not feasible)	-	-
NUH General Ward	Increased quiet time; Earlier sleeping at night	Staff microwaves completely off	2 out of 6 computers off overnight	Better use of day light: switching lights of in bays for one additional hour per day	(Needed due to overheating issues)	-	-

<sup>1</sup> Minimum measured consumption, also in CIBSE TM 54 Standard (CIBSE, 2013)

**Table E.1:** Details for departmental savings potentials