Assessing savings potentials from changes in energy behaviours of hospital staff: benefits and challenges of energy audits

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Keywords

behavioural change, metering, user behaviour, non-domestic, audit

Abstract

Behaviour change is increasingly considered as potentially cost-effective measure to reduce organisational energy use, while campaign evaluation remains a major challenge. Previous research has shown that especially in complex non-domestic buildings the variability in baseline energy use may often equal campaign effect sizes. In hospitals, evaluative attempts are further complicated by a prevalent lack of sub-metering. Surveying and energy audits are common tools to obtain information on buildings and organisational processes and identify energy conservation opportunities in the face of these obstacles.

This paper investigates the viability of using energy audits as explicit resource to explore the theoretical potential of energy savings obtainable through behaviour changes of healthcare staff. Detailed audits of lighting and appliance use were carried out in 11 hospital departments for which plug loads and lighting consumption were also monitored at the distribution board level. Reduction opportunities from specific changes in energy behaviours were then modelled on their basis to establish ex-ante estimations for savings potentials.

The method proved useful in ranking different end-uses to guide behavioural energy conservation efforts in hospitals. Usability was however limited by uncertainties remaining for data inputs from audits, both for power ratings and more importantly for usage hours and frequencies with which behaviours were currently performed. Detailed energy audits were hence found to be a workable tool for campaigns reforming protocols and procedures to eliminate redundant energy use, while they seemed less helpful for those promoting easy standard behaviours. For the latter, it seems advisable to consider additional methods of data collection as part of evaluative strategies depending on project aims, available budget, access to technical staff and the importance of respective end-uses.

Introduction

Increasing energy costs and climate change legislation have globally prompted efforts to reduce energy consumption in hospitals. In the UK, the National Health Service (NHS) commits to reducing its total emissions, of which 24 % are from energy use in buildings, by 10 % by 2015 (based on 2007 baseline data) and in the long term by 80 % up to 2050 (NHS SDU 2013). This represents a serious challenge given the financial constraints on the NHS within the current economic and political climate, while service delivery and standards of patient care keep increasing (NHS England 2013). All energy reduction strategies in hospitals consequently need to operate in a 'trilemma' between costs, carbon and care.

Traditionally, strategies to reduce energy use in buildings have focussed on improving the building itself and its services through retrofit or better management (Ziebik & Hoinka 2013). But it is increasingly recognized that energy savings in non-domestic buildings can also be achieved through changes in user behaviour. For the NHS, this option could be appealing as in the short-term because it potentially is more cost-effective than most technological consumption-reduction options. But while scope and impact of initiatives targeting user behaviour are comparatively well understood in domestic settings (see for example Abrahamse et al. 2005 for a review), their potential in organisations in general and in hospitals in particular remains less clear. For the latter, indicative saving potentials from energy awareness campaigns between 3 and 10 % are presented (Carbon Trust 2010, NHS SDU 2010).

One reason for the uncertainty about how much energy can be saved through energy behaviour change programmes in hospital seems to be the lack of a clear framework for their evaluation. 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 (for example Vine and Sathaye 1999). However, little work seems to have been done on the holistic evaluation of behavioural energy efficiency programs despite a continued call for better evaluation from both academia and practitioners. Behavioural initiatives may co-generate a number of non-energy-benefits in particular regarding patient experience (Gray 2011), employee satisfaction and morale (Knight and Haslam 2010), organisational image (Pellegrini-Masini and Leishman 2011) and potentially some transferability of pro-environmental behaviours between work and home (McDonald 2012). These 'knock-on effects' (benefit or cost) need to be taken into account to allow for a comprehensive cost-benefit analysis of behavioural interventions (Skumatz et al. 2000). In addition, unresolved issues around the persistence of behaviour change may not be overlooked (Banks et al. 2012).

As for determining energy effects of behavioural initiatives, evaluation is often hindered by the complexity of building energy use and the prevalent lack of sub-metering. Previous research in hospitals has shown that especially in complex non-domestic buildings the variability in energy use may often equal campaign effect sizes due to the variety of ongoing processes (Morgenstern et al. 2014). In hospitals, evaluative attempts are further complicated by a limited understanding of what drives energy use. At a building level, built forms, floor areas, number of patients as well as outdoor temperatures have been investigated using statistical top-down approaches (Witt 2013, Rabanimotlagh 2014), but little is known about drivers for electricity use at a departmental level. It is, however, this level of detailed understanding which is necessary in learning about energy behaviours and their potential contribution to energy conservation. On its basis, ex-post evaluations of actual savings, but also comparisons to benchmarks as well as energy modelling are eventually conceivable.

At a buildings or system level, surveying and energy audits are common tools to obtain information on buildings and organisational processes and identify energy conservation opportunities (Russen et al. 2010, Field et al. 1997, also CIBSE TM 22). Depending on their level of detail, energy audits commonly can include the analysis of fuel bills, walk-throughs, the study of installed equipment and operating data as well on-site measurements and computer-based simulation. But the viability of their use as resource to explicitly explore the theoretical potential of energy savings obtainable through behaviour changes of healthcare staff has so far not been comprehensively assessed. In the past, a number of other methods have been used to assess factors related to occupant energy behaviours, with varying degree of success:

- Window opening behaviours, lighting switching as well the use of shading have been monitored using **time-lapse digital photography** (see for example Hagemeier 2014 for an example in the hospital context).
- Temperatures and light levels were recorded using **distributed data loggers** (for example Mahdavi et al. 2008).
- 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.
- Ucci et al. 2012 developed an **occupant survey** to assess the current efficiency in performing a number of energy behaviours.
- The location of occupants within a building (which is especially relevant for HVAC control questions) was monitored using a range of techniques (see Spataru & Gautier 2014 for a detailed review).

In different contexts, simulation has also been used to understand behaviour. Feola and colleagues (2011) for example present an agent-orientated dynamics model to explore the use of personal protective equipment among pesticide applicators in Colombia.

This paper investigates the viability of energy audits and other methods of data collection as resource to identify potential energy savings from staff behaviour changes in hospitals in particular and in organisations more generally. It is focussed on electricity use because it, firstly, accounts for about 60 % of the NHS fuel bill and is, secondly, more often under local control while heat is predominantly controlled centrally and may hence not be addressed through behavioural initiatives focussing on clinical staff. Detailed audits of lighting installations and appliances were carried out in 11 hospital departments for which plug loads and lighting consumption were also monitored at the distribution board. Envisaged reduction opportunities from specific changes in energy behaviours were then modelled on their basis to establish ex-ante estimations for their potential. Benefits and challenges of energy audits in this as well as potential alternative methods will be discussed.

Methodology

This study uses an exploratory case-study approach to investigate the electricity use and the potential for its reduction through changes in staff behaviours in different hospital buildings and departments. The unit of analysis of the study is a department. 11 departments across 3 hospitals were investigated, allowing for a comparison of both different department types within the same building and one department type across different buildings. Given that the evidence on hospital electricity use is currently extremely sparse and health care processes seemed to be poorly understood from an energy perspective (Witt 2013, Benke et al. 2009,), such in-depth approach seems appropriate.

DATA COLLECTION

From the range of data collection methods reviewed above, a number were selected for the use in this study because they were both promising and applicable in a hospital context. Time-lapse photography to monitor lighting and window use was disregarded because many of the departments investigated had little or no external windows. Instead of paper-based occupant surveys, a limited number of questions focussed on extracting durations of room and equipment use were asked face to face. It was felt that this method was more appropriate to the extremely dynamic hospital context where staff were 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 may not be well-regarded there. Occupant location was not monitored because it is primarily relevant for issues around HVAC zoning and was therefore outside of the scope of this study.

Table 1 consequently provides an overview of the methods applied for each department in this study to investigate building electricity use *W*. For each item, its electricity use *W* can be determined as product of the item's average power consumption $\bar{P}$ and the duration of its use *t*. This approach focuses on average usage and disregards peak power consumption which, although of interest for power system stability in hospital areas such as imaging, seems less relevant to understanding staff impact on energy use.

$$W = \int P(t)\, dt \sim \bar{P} * t \qquad (1)$$

In order to investigate potential changes in staff energy behaviours, analysing average power consumption and durations of use separately can be useful. In many instances, staff influence on electricity use will be mainly through influencing durations, so for example for lights with binary operational states (on/off only) or computers. Average power consumption can here be approximated as constant, assuming for example the use of a computer is prescribed by operational needs with constant processor requirements. In contrast, with dimmable lights, fans or fan heaters as well as with most medical equipment clinical needs or staff preferences impact on both power consumption and duration of use. To estimate energy savings potentials *S*, avoided electricity use $W_{avoided}$ then needs to be considered with respect to how frequently promoted behaviour alternatives are currently already being carried out *(f in %)*.

$$S = W_{avoided} * (1 - f) = (\bar{P} * t)_{avoided} * (1 - f) \qquad (2)$$

Measurement of electricity use

The most accurate method to obtain information on item electricity use is to monitor the item individually. Doing so will both provide detailed information on power consumption and on usage hours. In this study, Current Cost individual appliance monitors with the EnviR data logger (Accuracy of 97 % according to manufacturer specifications) were 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 disruption. This is a known problem in the hospital context and probably contributes significantly to the poor understanding of hospital electricity use.

To avoid this issue, individual lighting and plug circuits were monitored at the distribution board level for some departments including a theatre and an imaging department. Again Current Cost EnviRs were used as well as HOBO UX120-006Ms with CTV-C current sensors (Accuracy ±2.1 % of full scale according to manufacturer specification). Frequency of data collection generally ranged between every 10 minutes and every 2 hours.

Table 1. Overview of electricity assessment methods applied in this study. (Methods in bold could be considered part of general energy audits.)

Data collection methods				Hospital 1				Hospital 2				Hospital 3		
				Day theatres	Main theatres	Outpatients	Imaging	Laboratory	Imaging	Surgical Ward	Theatres	Laboratory	Surgical Ward	Outpatients
Electricity use W	Average power P	Measurement of electricity use	Main incomer	O	O	O		O	O	O		O	O	O
			Circuit level				O				O			
			Plug level				O			O				O
		Collection of secondary data (plate ratings, technical manuals, literature)		O	O	O	O	O	O	O	O	O	O	O
		Collection of reported data		O	O	O	O	O	O	O	O	O	O	O
	Duration of use t	Measurement of electricity use profiles (see above for level)		O	O	O	O	O	O	O	O	O	O	O
		Measurement of environmental variables					O			O		O	O	O
		Collection of reported data		O	O	O	O	O	O	O	O	O	O	O

Collection of secondary data on power consumption

If no measurement data is available, lighting and equipment power consumption can be estimated. For lighting, such estimates will frequently depend on the identification of lamp type, size and type of control gear. Light colour, strike time etc. can be used as additional classification criteria (Russen et al. 2010) For equipment, estimates may in the first instance be based on the respective plate rating or the consumption reported in the equipment manual. It then needs to be considered that plate ratings provide a measure of maximum consumption as opposed to average consumption. For office equipment, CIBSE (2012) state that actual power consumption is about 10–25 % of the nameplate rating. For hospital equipment in particular, Hosni et al. (1999) provide the following rule of thumb: for items with nameplate ratings up to 1,000 W, the average consumption will be between 25 % and 50 % of the plate.

Measurement of environmental variables

In some departments lighting levels as well as ambient temperatures were recorded every 30 minutes over a period of two to four weeks using HOBO U12-012 data loggers. Especially for spaces without natural light which were reasonably frequent in most departments visited, the analysis of local lighting levels allowed with some certainty a statement as to whether lights were on or off. Temperature data has not been analysed yet but will be of interest in departments where thermal discomfort is reported and the use of fans for cooling or fan heaters for additional heating is common.

Collection of reported data

A comparatively inexpensive way to obtain some information on the use of rooms, equipment and building services is the collection of reported data. Paper-based or online self-administered surveys are probably the most common method to do so in organisations, but due to the contextual constraints elaborated on above, it was preferred to use an interviewer-led approach for this study. In each room, the respective occupants were asked about the use of the room, their working hours and any equipment present. In addition, two to three in-depth interviews were carried out in each department aimed at generating ideas on how energy could be saved as well identifying social, operational and organisational constraints on staff behaviour. Statements were then validated against each other while information had to be inferred for rooms where no occupants were present. Occasionally, data on power consumption was reported in conversation with technical staff.

Energy audits

It can be difficult to define which of the aforementioned data collection methods would form part of an energy audit. Energy audit can be hugely variable and are generally tailored to client needs (Russen et al. 2010). In most cases, however, they will be limited in duration and depending on the size of a property, surveyors might not spend more than a couple of hours on the premises. Electricity consumption will often be inferred from fuel bills and introducing monitoring for either electricity or environmental variables is less common. The main pillars of general energy audits as they currently stand could hence be understood to encompass the identification of systems and major energy consumers and the collection of secondary as well as reported data. Those elements are marked bold in Table 1 and define the term 'energy audit' as it will be used in the remainder of this paper.

It may be noted, however, that energy audits are currently primarily used as diagnostic tool at buildings or systems level to identify opportunities for energy conservation. This paper sets out to discuss the viability of energy audits as resource to help the evaluation of behavioural energy conservation initiatives. Since savings can be expected to be reasonably small here (The NHS Sustainable Development Unit (2010) for example expects energy savings of 3 % from energy awareness campaigns in hospitals), an investigation at a much more detailed level may be required. This paper aims to contribute to the discussion on which components need to be part of successful energy audits and evaluation methodologies more generally in the behavioural arena.

DATA ANALYSIS

Given the scope of this paper, the analysis will focus on data collectable within the remit of energy audits while other sources of data will occasionally be brought in to supplement the interpretation. 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:

- Difficulties for auditor in identifying unknown specialist equipment.
- Limited availability of energy use information in the literature for specialist equipment.
- Irregular nature of processes making it for difficult for occupants to describe typical events and average durations of use.
- Transient nature of NHS employment in some departments (many agency staff) resulting in limited knowledge of local customs.

It was hence decided to adopt a classification system to code the certainty of each data input; allowing for the analysis of uncertainty effects on behaviour estimates. In scenario modelling, uncertainty is often characterised at three levels, with some variation on 'low–medium–high' (see for example CAR 2012). For this project it was decided to use a more granular scale specifying seven levels of uncertainty. The codes are to be understood primarily descriptive in character aiming to provide the reader with an understanding of the origin for each data input (Tables 2–4), comparable maybe to evidence hierarchies used in systematic literature reviews. 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 will vary depending on the analysed behaviour.

All audit data was tabulated using individual tables for room, lighting and equipment information, similar to the example provided by Mortimer and colleagues (2000). But while they only account for uncertainty in usage hours, this study also codes uncertainty of power consumption. The tables are then used to estimate the electricity use for six end-use categories potentially relevant locally: lighting, medical equipment, IT equipment, ventilation, local heating or cooling and other. It may be noted

Table 2. Coding uncertainty 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: assumptions on lamp type based on shape of luminaire and colour of light, consumption inferred on this basis)

Table 3. Coding uncertainty for average equipment power consumption.

		Specific piece of equipment	Equipment type*
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 (e.g. open sources data bases, expert opinion)	6	7
	Other non-academic sources	7	7
Other	Other assumptions (incl. assumption on type of equipment if unknown)	7	7

** The reference group needs to be clearly defined, for example 'Medical fridge, 300L, Energy Star' but also 'Standard Desktop PC' depending on the complexity of the appliance.*

that ventilation and local heating or cooling will be in addition to services provided centrally which can only with difficulty be accounted for at a departmental level. At the same time, they will be of less interest when thinking about staff energy behaviour as they are commonly not controlled locally. Results are presented in the format suggest by CIBSE TM 22 (2006) and compared with measured consumption data at departmental level.

In a further step, potential changes in energy behaviours and operations more generally were identified from the conducted interviews, the analysis of the electricity use profiles, the input of clinical experts and from literature (for example Pierce et al. 2014, Twomey et al. 2012, Maughan & Ansell 2014, Batty et al. 1988). For the purpose of this analysis, it was found useful to distinguish three levels of operational change among them (Figure 1), depending on their complexity and how strongly they were focussed on the behaviour of individuals as opposed to changes in social and physical arrangements (taxonomy adapted from health to energy behaviours from Craig et al. 2009; also Banks et al. 2012, McKenzie-Mohr 2000, Shove 2010). Based on the model of electricity use developed earlier, potential savings could then be computed for each of the conceivable changes. The uncertainty classifications quickly provide an overview of how certain each of the savings estimates were. For the most uncertain inputs relevant to the saving estimates, codes are translated into uncertainty ranges (Eisenhower et al 2012). Scenario analysis could then be used to identify a realistic range for the technical potential of behaviour change.

Table 4. Coding uncertainty for duration of use and current frequency inputs.

1	Author's measurement
2	Consistent information from interviews, observations, process understanding and self-reports during audit (information available from four sources)
3	Process requires defined mode of operation (e.g. continous operation); ascerted by expert judgement (e.g. manufacturer specifications)
4	Information mostly consistent between interviews, observations, process understanding and audit self-reports; minor ambiguity or lack of data (Information available from three sources)
5	Information somehow consistent between interviews, observations, process understanding and audit self-reports; some ambiguity or lack of data (Information available from two sources)
6	Process requires defined mode of operation (e.g. continous operation); based primarily on author's understanding of process
7	Substantial ambiguity or lack of data; rating based primarily on author's understanding of process (one source only); very subjective

Findings & Discussion

Detailed results will now be presented for one department type: Theatres were chosen to be of interest here due to the high degree of influence clinical staff had on their environment as opposed to other areas where especially the control over temperatures was often found to be very limited. In addition, it will be focussed on behaviour changes of type I and II because those of type III require an extensive analysis of the social and organisational context which is outside of the scope of this paper.

EXAMPLE: ENERGY USE AND ENERGY BEHAVIOURS IN THEATRE DEPARTMENTS

For the study, three theatres departments were investigated: adult main theatres (elective and emergency surgery) in hospital 1 and 2 and day theatres (elective day-cases only) in hospital 1. Their local electricity use (excluding central electricity requirements for air handling and cooling) estimated on the basis of the energy audits compared within the range of 20 to 30 % specified by Mortimer for their bottom up approach according to Liddiard (2012:44) (see Figure 2). Some confidence

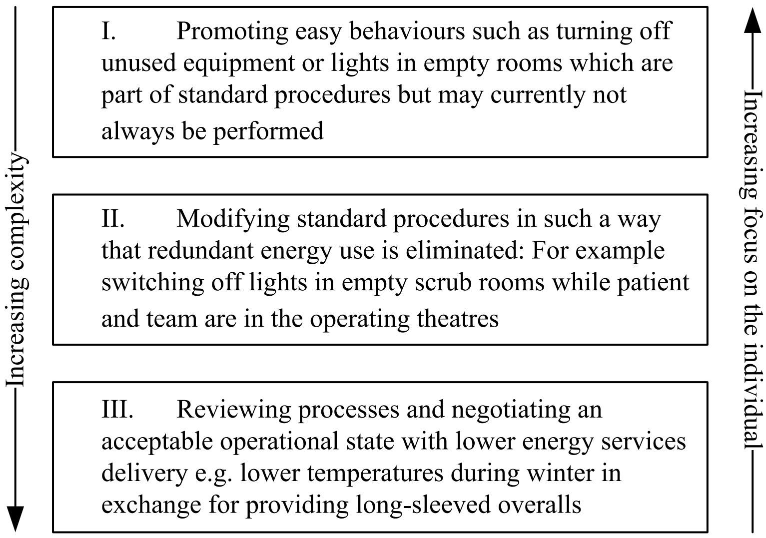

Figure 1. Levels of operational change potentially addressable through behavior change campaigns.

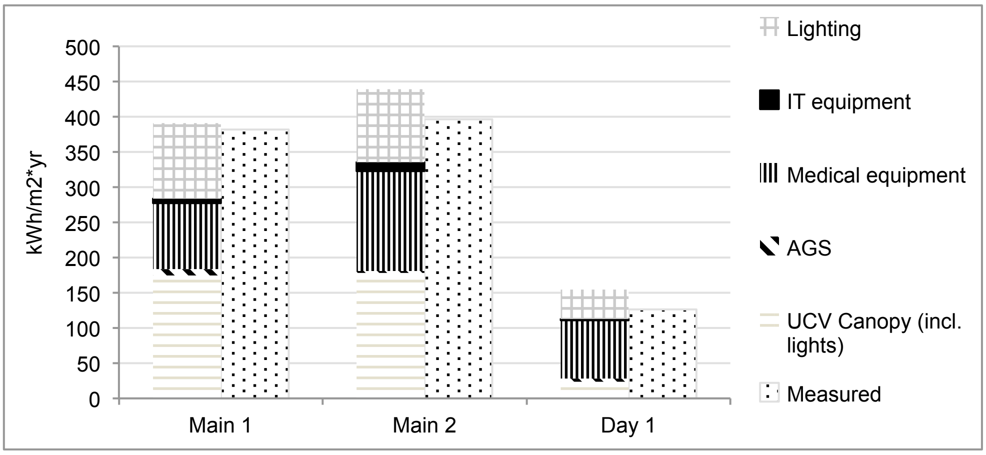

Figure 2. Estimated as opposed to measured local electricity use for three theatre departments.

can hence be had in the description of departmental electricity use through the audit. It was noticed, however, that the bottom-up estimation procedure tended to overestimate actual annual usage figures in the theatres. Also, estimated peak loads exceeded actual peak loads suggesting limited understanding of diversity factors while some base load components appeared to remain unaccounted for in the model.

In main theatres, most electricity (41–45 %) was locally used by the ultra clean ventilation (UCV) canopies, which even if only used one day per week as the case in hospital 2 contributed significantly due to their high stand-by consumption. In the investigated day theatres, only one out of six theatres was equipped with a UCV canopy and the consumption share was hence lower. Medical equipment accounted for 24 % and 32 % of local electricity use in main theatres 1 and 2 respectively and for 53 % in day theatres, while literatures suggests a range of 21–35 % for hospitals generally (Shares for local electricity use calculated based on estimates for total electricity use provided by Carbon Trust 2010, Benke et al. 2009, Jensen & Petersen 2011). Given the more intense use of medical equipment in theatres as opposed to in wards and other departments, this suggests that electricity use for medical equipment might be underestimated in this study – possibly unsurprisingly so in the light of the difficulties encountered during the audits in identifying unknown specialist equipment. Lighting use was estimated to account for 24–28 % of local electricity use in theatre departments, while literatures presents whole hospital averages ranging between 30 and 56 % (ibid).

A number of behaviour changes were investigated for theatre departments and basic saving potentials (not yet accounting for uncertainty) estimated. The eight behaviour alternatives A to H promising the highest percentage savings are shown in Table 5. Such initial analysis suggests that savings from behaviour change rarely exceeded 5 % of total departmental electricity consumption in theatres, while the highest saving potentials in both absolute and percentage terms were from improved light switching (A, B and C). This finding reflects the importance of lighting as major end-use in hospitals but may be somehow biased by the expertise of the authors in buildings rather than in health care processes. For future projects in health care, it is hence recommended to form interdisciplinary teams including both interested clinicians and technical personal to fully embrace the variety of options available to reduce hospital electricity use during operation.

It was also noted that day theatres exhibited more saving opportunities than main theatres due to shorter occupation, resulting in more down time. While the former seemed to hold total theoretical savings potentials of up to 15 %, the potential in the latter was much lower. This suggests that especially behavioural initiatives focussed on level I changes might want to orientate themselves towards areas with less occupied hours in complex buildings and those where the boundaries between used and un-used are clear.

For the promising behaviour alternatives A to H the impact of uncertainty within the two most uncertain inputs was analysed (Figure 3). For behaviour changes of level I (behaviour alternatives A to C), it proved difficult to estimate the frequencies with which behaviours were currently performed based solely on audit data. Current frequencies were hence the most uncertain input in collecting saving potentials (Figure 3a). Level II changes on the contrary introduce behaviours that are currently not or very limitedly performed, so current frequencies were less uncertain and uncertainties in time (Figure 3b) or power domains (Figure 3c) prevailed.

BENEFITS AND CHALLENGES OF ENERGY AUDITS FOR EVALUATING CHANGES IN ENERGY BEHAVIOURS

On the whole, energy audits were found to be somehow useful in improving the understanding of hospital electricity use. In agreement with what was previously suggested for example by Field et al. (1997), they proved a useful tool to assess the importance of different end-uses in hospital departments. In doing so, they are crucial to designing and implementing behavioural initiatives which are clearly linked to actual environmental impacts (Gatersleben et al. 2002). Going forward, they might also help to improve capacities to link post-campaign observations to specific campaign efforts.

Usability was however limited by uncertainties remaining for data inputs from audits, both for power ratings and more importantly for durations and current frequencies of the respective behaviours. The developed classification system coding the certainty of each data input allowed for identification and analysis of uncertainty effects on behaviour change estimates. This was found useful in order to increase transparency while also helping the understanding of baseline electricity use. It is therefore recommended to apply such or similar systems in future research while it may be suspected that they would be too resource intensive for practitioners. More academic work focussing on hospitals and synthesizing results on the importance of different end-uses from bigger samples as basis for the implementation of behavioural initiatives would hence be beneficial.

On the whole, it would appear that energy audits are more helpful in developing ex-ante estimates for behaviour changes of level II, those concerned with modifying standard procedures in such a way that redundant energy use is eliminated without impact on service delivery. For those aiming to promote easy standard behaviours (level I), estimates based on audit information only resulted more difficult due to the need to estimate current frequencies in addition to power and duration of use (Figure 4). For initiatives addressing level I behaviour change the use of alternative methods for evaluation is hence recommended.

Table 5. Exemplary exploration of changes in energy behaviours in theatre departments (based on Eq. 2).

Alternative behaviour *(Department, **Level of operational change according to Figure 1**)*	**Power use $\bar{P}$ [kW]**	**Code** (Table 2, 3)	**Duration of avoided use** $t_{avoided}$		**Code** (Table 4)	**Current frequency** *f*	**Code** (Table 4)	**Saving potential** *S* **[kWh/yr]**	**% of measured total**	
			[h/d]	[d/yr]						
Switching off all lights in the department while not in use over weekends (*Day 1*, **I**)	22	2	24	104	4	60 %	5	21,543	8.5 %	**A**
Switching off all lights in unused theatres suits over night (*Day 1*, **I**)	22	2	12	252	3	85 %	5	9,787	3.9 %	**B**
Switching off all lights in unused theatres suits over night (*Main 1*, **I**)	15	2	12	365	5	85 %	5	10,041	2.7 %	**C**
Looking department overnight: Corridor lights may be switched off (*Day 1*, **II**)	2	2	12	365	3	0 %	2	6,616	2.6 %	**D**
Switching of anaesthetic gas scavenging (AGS) plant when theatres are not in use (*Day 1*, **II**)	1	5	16	365	4	0 %	2	6,310	2.5 %	**E**
Switching off scrub room lights during surgery (*Main 1*, **II**)	4	2	6	272	5	0 %	2	6,236	1.7 %	**F**
Switching off scrub room lights during surgery (*Day 1*, **II**)	3	2	6	252	5	0 %	2	3,852	1.5 %	**G**
Switching of AGS plant when theatres are not in use (*Main 1*, **II**)	1	5	12	365	4	0 %	2	4,833	1.3 %	**H**

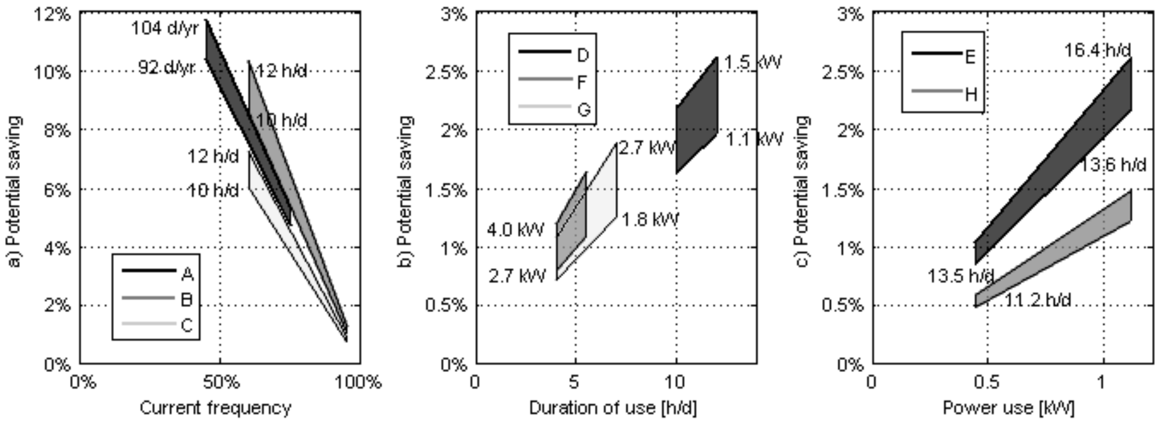

Figure 3. Impact of the uncertainty within the two most uncertain inputs on estimates of saving potentials for behavior alternatives A to G. (Most uncertain input on x-axis, second most uncertain input in graph with a) current frequency and duration of use, b) duration of use and average power consumption and c) power and duration of use.)

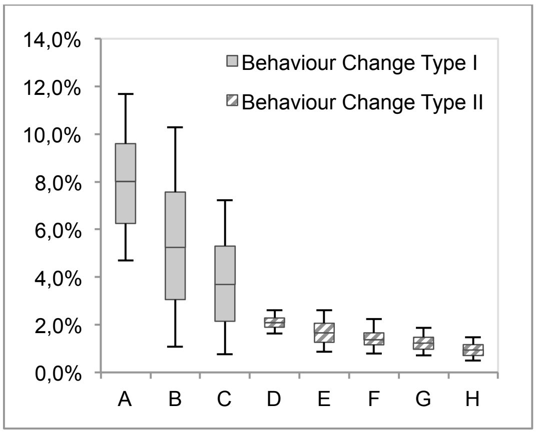

Figure 4. Overview of saving potentials for behavior alternatives A to G.

In this study, a number of alternative methods was applied to investigate local electricity use. All of them required that data be collected over a number of days, ideally several weeks to build an accurate picture of use of space and occupant behaviour while minimizing the impact of atypical days. In this, they greatly exceeded the time required for energy audits and potentially also the budgets available for evaluation procedures which will commonly be less than 5 % of a project budget (Gentry 2013, Rathmell 2014). In promoting learning on behaviour change, it nevertheless seems important to consider these methods in order to understand which conservation initiatives worked well and why. A summary of their advantages and disadvantages as experienced in this project as well as indicative cost implications for measurement equipment was collated in Table 6.

Conclusion & Outlook

This paper investigated the viability of energy audits and other methods of data collection in helping the evaluation of behaviour change campaigns in hospitals. It is thought that many of the methodological issues encountered also apply to other complex buildings e.g. in retail or industry. Previous research had shown that especially in complex non-domestic buildings the variability in energy use may often equal achievable effect sizes of behavioural initiatives due to the variety of ongoing processes. In hospitals, evaluative attempts were further complicated by a prevalent lack of sub-metering, often resulting in limited understanding of baselines of organisational energy use. In the face of these obstacles, detailed energy audits proved useful in providing information on the importance of different end-uses to guide energy conservation efforts. Given their labour-intensity, however, they may continue to be used primarily in research to improve on the understanding of hospital electricity use by increasing sample sizes as basis for practical applications.

On the whole, energy audits were also found to be a workable tool for the identification of potential savings from campaigns aiming to eliminate redundant energy use in standard procedures (in this paper referred to as behaviour changes of level II). In order to avoid misinterpretations, however, it proved crucial to be explicit about uncertainties for data inputs from audits, both for power ratings and more importantly for durations of uses as well as estimates of current frequencies of staff behaviours. For this purpose, the project developed a classification system which conveniently allows an overview of sources and associated uncertainties for all data inputs. The system is not restricted to hospitals and may be applied across a wide range of organisational contexts. It is felt that transparency about assumptions is crucial for any evaluation attempt and will benefit from addressing uncertainties in data inputs.

For behavioural initiatives promoting easy standard behaviours such as turning off unused equipment or lights, energy audits proved less helpful in estimating saving potentials. For these cases, the main uncertainty resulted from the frequencies with which the desired behaviours were currently performed already, a factor hardly determinable through energy audits only. This difficulty is also a key issue for ex-post evaluations of actual energy savings from behavioural initiatives, for which the use of alternative data collections methods hence seems recommended whenever possible. Depending on project aims, the available budget, the access to technical staff and the importance of respective electricity end-uses the use of data loggers

Table 6. Alternative data collection methods for assessing energy behaviours.

Method	Useful for	Advantage	Disadvantage	Cost of measurement
Measurement of electricity use at plug level	– IT equipment – Catering equipment	– Detailed activity profile available	– Not possible for sensitive equipment or in clean areas – Large quantity of monitoring equipment required for comprehensive picture	Equipment cost per plug monitor: ~ £40–50 (€50–60)
Measurement of electricity use at circuit level	– Lighting – Power circuits – Fan coil units	– Not or mimimally disruptive to clinical activity	– Intense collaboration with facilities management required – Feasibility needs to be checked for each board individually – In older buildings often unclear what is served by which circuit	Equipment cost per circuit: ~ £40–130 (€50–160)
Measurement of electricity use at the main incomer	– All local electricity	– Not or mimimally disruptive to clinical activity – Allows for the identification of abnormalities such as high baseloads or loads in closed areas	– Potentially covering large and/or unrelated areas – No differentiation of individual uses possible – Intense collaboration with facilities management required	Loggers for single phase boards: ~ £230–360 (€290–450) Loggers for three phase boards: ~ £1,400–1,600 (€1,770–2,000) (Low costs if sub-meters are present already)
Measurement of environmental variables such as illumination levels & temperatures	– Lighting use – Supplementary heating/cooling	– Little disruptive – High logging frequency possible – Temperature data potentially useful to occupants in buildings with temperature control issues	– Require calibration to local illumination levels	Temperature loggers only: ~ £80–85 (€100–110) per logger Temperature, Relative Humidity and Light Levels: ~£150 (€190)
Occupancy sensors	– Lighting use	– Occupancy directly available as binary variable	– Potentially perceived as threat by occupants – Sensitive to positioning	Indicative cost of equipment: ~ £220 (€280) per logger
Observation of target behaviours (Behavioural Audit)	– Lighting use – Door and window use	– Clearly linkable to target behaviours (for example night time audits for 'lights out at night' campaigns) – Potentially combinable with staff engagement	– Very time intensive if more than a spot check at one moment in time – Inter-auditor variation despite auditor training and pre-audit checks	Roughly 0.5 manhours should be estimated for auditing a department with 500 m^2 floor area.

recording environmental variables or the monitoring of individual circuits within distribution boards could be considered. In operating theatres for example savings from improved light switching were thought promising, making lights sensors a potentially rewarding component of a campaign's ex-post evaluation strategy.

The presented paper has a number of important limitations highlighting the need for further research: Firstly, it focussed exclusively on electricity as major cost to hospitals. But many energy behaviours are associated with both electricity and heat use, such as the use of convective warmers to maintain patient body temperatures during surgery. Further research is hence needed to clarify for example how central changes in room temperatures would impact on warmer use in theatres as well as on the use of fan heaters and coolers in all departments. Secondly, the expertise of the authors was in buildings rather than in health-care processes and some difficulties were encountered in identifying processes and equipment. For future projects in health care, it is recommended to form interdisciplinary teams including both interested clinicians and technical personal to fully embrace the variety of options available to reduce hospital electricity use during operation. Such course of action would further allow for expanding the scope of initiatives to include demand flexibility with the view to reducing peak power, an increasingly important concern for grid stability given high renewable penetration.

Finally, the concept of the technical potential for behaviour change is in itself limited as it does not account for organisational, social or individual constraints on staff energy behaviours. So while technical saving potentials can be useful in prioritising and planning of behaviour change campaigns, they may not be confused with actual campaign effect sizes. Especially in high-pressure environments such as hospitals where staff are under multiple pressures from care and cost constraints, actual savings may fall a long way short of ex-ante potentials. Further research determining minimum levels of technical potentials which justify the implementation of a campaign would hence be very useful.

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