Measuring changes in energy behaviours in complex non-domestic buildings

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ABSTRACT

It is increasingly recognized that considerable energy savings can be achieved in non-domestic buildings through changes in occupant behaviour. The evaluation of behavioural initiatives in complex non-domestic buildings, however, can be difficult because baseline building energy use is often poorly understood due to the variety of organisational processes and the prevalent lack of sub-metering. This paper aims to investigate the evaluation of an energy awareness campaign at a large acute hospital. Although the sub-metering levels in this hospital were comparatively high, there were considerable difficulties in measuring and attributing changes in energy use to the behavioural campaign due to the complexity of the underlying consumption profile from building services and appliance use as well as varying engagement of occupants with the awareness campaign across the hospital. These findings highlight that the methodology used to estimate energy savings from behaviour change in complex non-domestic buildings is hugely important, while so far no standardised methodologies are available. It is suggested that behavioural initiatives in complex non-domestic buildings could be more fairly assessed using intermediate performance indicators of their impact on participants.

Context

The energy used for heating and powering non-domestic buildings is responsible for around 12% of the United Kingdom's GHG emissions [1]. Against this background, it is increasingly recognized that considerable energy savings can potentially be achieved cost-effectively through changes in occupant behaviour. But while the impact of user-centred interventions is comparatively well understood in domestic settings [2], this remains less so in complex non-domestic buildings such as big offices, university buildings, schools or hospitals. Studies indicate that energy savings measured in organisations can vary between 1 and 12 % for heat [3, 4, 5, 6] and 1.5 to 8% for electricity [3, 4, 7, 8, 9, 10], while simulations more consistently claim a potential of up to 20% of total energy use [11, 12].

There are numerous reasons for this mixed success of energy behaviour change programmes in complex non-domestic buildings, which have been reviewed elsewhere (see for example [13, 14]). They include the design and implementation of the respective interventions, organisational culture and hierarchical structures as well as environmental values of individual employees. Reconciling differences between various behaviour change programs is further complicated by the absence of a clear framework that facilitates the building-specific evaluation of staff-centred energy conservation initiatives [14].

So far, the primary evaluation of behavioural initiatives in complex non-domestic buildings seems to mostly have been attempted using quasi-experimental strategies based on interrupted time-series of energy data. Such approaches are known to be problematic for gradual rather than abrupt interventions and those where effects might be delayed [15]. In the non-domestic context, evaluative attempts are further aggravated by the complexity of building energy use whose baseline is often poorly understood due to the variety of organisational processes and the prevalent lack of sub-metering. It also needs to be noted that direct changes in energy use can only be one outcome of any initiative addressing occupants and their behaviour. Non-energy effects, both positive such as increased comfort, ownership or productivity and negative e.g. confusion and sense of overload, need to be taken into a count for a holistic cost-benefit analysis [16].

Approach

Research aim

This paper aims to investigate the evaluation of an energy awareness campaign at a large UK acute hospital (hereafter referred to as the hospital) which was piloted in 2012/2013. From January to May 2013, the authors of this paper worked closely with the respective NHS Trust and the implementing body in analysing the hospital's electricity use over the course of the campaign. In the respective hospital building, small power and lighting use is sub-metered at departmental level, which is outstanding compared to the vast majority of NHS hospitals which have electricity data available at building or even site level only. The richness of the meter data allowed for the detailed analysis of the electricity use for each hospital department.

The awareness campaign focussed on wards as 24 hour areas, but included some offices and clinical day areas. Rewards within small teams and improving patient experience were identified as central motivators for trust staff and consequently stressed in communicating the campaign. The roll-out primarily took place across three channels from December 2012 to March 2013:

1. Energy Champions were recruited on wards and in administrative areas to engage colleagues and to encourage energy efficient behaviours. Ideally, they were volunteers with an already developed interest in energy efficiency/sustainability, but in their absence line manages were asked to simply appoint someone.
2. A 'Sustainability Team' performed regular ward rounds to prompt action, troubleshoot problems, share success stories and give out rewards (e.g. green goody bags or vouchers for tours to the hospital's helipad) to champions and their teams.
3. As it is widely acknowledged that senior support is crucial in promoting any pro-environmental behaviour in organisations [see for example 14], prominent campaign advocates within the NHS Trust featured on screensavers and produced short videos showing them to engage in the promoted energy-efficient behaviours.

It was found that despite the high sub-metering levels, the difficulties encountered in measuring and attributing changes in electricity use to the behavioural campaign were substantial due to the complexity of the underlying consumption profile from lighting and appliance use. Also, the engagement of occupants with the awareness campaign varied across the hospital and while some departments could achieve significant reductions in electricity use through switching off un-used lights and electrical equipment, in others the daily electricity consumption only changed marginally over the duration of the campaign.

Methods used

The above observations raise the immediate question to what extent small effects of behaviour changes (for hospitals, the Carbon Trust expects reductions in total energy costs through good housekeeping of 10% [17]) can be detected through the analysis of energy consumption profiles in complex buildings given the daily variability in activities and resulting energy use itself. In a first instance, this question was investigated by analysing the means and standard deviation values of the daily electricity consumption [kWh/d] before and after the campaign at the hospital. The availability of half-hourly electricity data also allowed for a more in depth analysis of changes in specific energy behaviours, such as reduced lighting use during afternoon down time on wards, but for the purpose of this research question daily electricity use was found to be a useful metric.

Three different criteria were used to determine whether changes in mean daily electricity use based on four weeks of pre and post campaign data respectively (normalized for seasonal differences in daylighting) were statistically significant in each metered area:

I. According to the International Performance Measurement and Verification Protocol (IPMVP) which provides standards for the evaluation of technical energy efficiency improvements, “Savings are deemed to be statistically valid if they are large relative to the statistical variations. Specifically, the savings need to be larger than twice the standard error (…) of the baseline value.” [18, p.86] Notably, similar rules will apply for statistically valid losses / increases in electricity uses which, although not desirable, might occur for example due to procedural alterations.

II. A more conservative approach will not only take into account statistical variations of the baseline value but also those during the post-intervention period. Changes are hence only regarded as statistically valid if they exceed twice the sum of the standard error of baseline and post-intervention value. This definition is equivalent to requiring for non-overlapping 95% confidence intervals.

III. A repeated measures t-test can also be used to determine whether the sets of electricity consumption data pre and post intervention differ from each other at a given significance level, here 0.05.

For each of the above criteria, only departments which had seen statistically significant changes in electricity use between pre and post intervention periods where included in calculations of mean campaign effects. The applied criteria will hence be referred to as ***inclusion criteria***. It should be noted that other drivers of energy use such as operational activity are not (yet) included in the presented analysis.

In addition to the analysis of electricity consumption data, the project team carried out observations of the energy behaviours targeted by the campaign. All involved departments/wards were visited both before campaign begin and after its completion; counting for example the numbers of lights left on in unoccupied rooms.

Findings

This project analysed the small power and lighting use of 49 hospital departments, most of which wards. Table 1 shows the number of areas where electricity use had changed significantly and the range of overall effect sizes depending on each inclusion criteria. Absolute effect sizes are not given to protect commercial interests.

Table 1. Comparison of intervention analysis approaches (The overall change in electricity use based on all metered campaign areas (Control) is denoted by X %.)

	Number of metered areas meeting the inclusion criteria	**Overall campaign effect size**
Control: All metered areas	49	X %
Inclusion criteria I	35	1.3*X%
Inclusion criteria II	18	1.5*X%
Inclusion criteria III	20	2.5*X%

The table shows that the results of the different analysis approaches differ as much as the actual effect size of the energy awareness campaign was thought to be across the whole hospital. This identifies the importance of looking behind headline figures to understand not only effect sizes, but also what changes made them happen and whether they correspond to the campaign aims and efforts.

A more detailed analysis of departmental electricity consumption can help this understanding, especially if detailed expectations for a campaign's outcomes (such as a reduction of lighting use during afternoon downtime on wards) have been specified. Figure 1 shows changes in the electricity use of a 12 hour clinical area which, according to the project team, was very engaged with the campaign at the large acute hospital. The area's night-time electricity use after the campaign has clearly reduced – very likely in response to staff taking action to switch of lights and appliances at the end of the day.

Observations of the target behaviours are indispensable for supporting this interpretation as they allow the linking of changes seen in the electricity consumption profile to staff energy behaviours. The behavioural audits carried out at the large acute hospital were, however, seen to have a number of limitations. Most importantly, they were carried out at opportune moments during the day, as opposed to being linked clearly to the behaviours the campaign was trying to motivate. In particular, night-time switch off behaviours suspected on the basis of changes in the electricity consumption profile could not be verified due to a lack of observations after hours. It is therefore recommended for future campaign evaluations to clearly link observational activities and target behaviours.

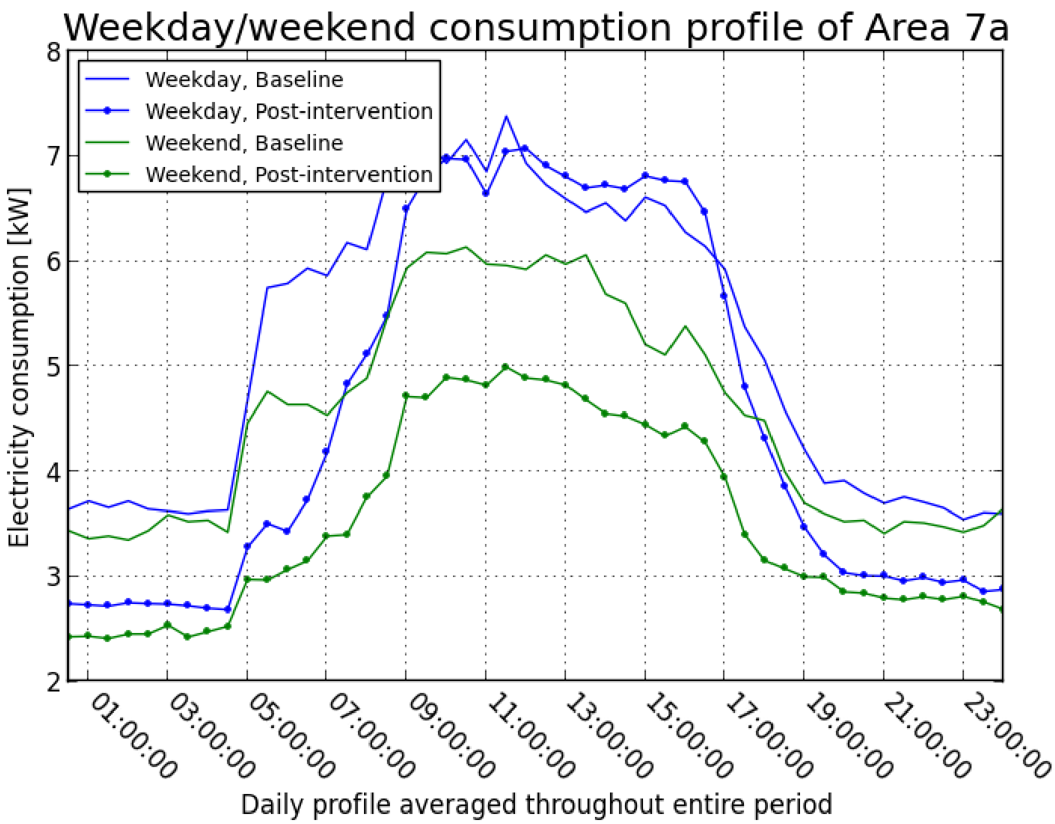

Figure 1: Changes in electricity use of a hospital 12 hour clinical area

Discussion and conclusions

The above findings highlight that the methodology used to estimate energy savings from behaviour change in complex non-domestic buildings is hugely important, while so far no standardised methodologies are available and the pressures to present actual savings are high, especially in the consultancy sector. Thus it is crucial to stimulate discussion on this issue between campaign developers, building operators and independent evaluators to arrive at consistent methodologies for the measurement and the verification of energy savings through staff-centred conservation initiatives, similar to those existent for technical energy efficiency measures.

At the same time, the presented findings query whether it is at all realistic to place individual energy behaviours reliably within the context of total building energy use in complex non-domestic buildings due to the high variability of ongoing processes and resulting loads. The study suggests that the reliable evaluation of such conservation initiatives can be difficult or impossible if based exclusively on the analysis of energy data. For building owners and operators, however, hard energy savings and resulting cost reductions are a prerequisite for business plans and funding proposals. New approaches are consequently needed to bridge this gap.

The use of intermediate performance indicators could provide a potential means by which to address this issue. To achieve this, such indicators would ideally need to be:

- linked to specific target behaviours and times / areas, e.g. turning off lights at night / in unused shower rooms
- based on a clear understanding of the impact different behaviours have on energy use (This is relevant to identify target behaviours which make a staff-centred intervention worthwhile. In many non-domestic buildings, such as industrial buildings, hospitals or laboratories this question cannot be underrated because significant unavoidable process loads may well outweigh any positive difference staff effort may have on total energy consumption. Due to the heterogeneous nature of non-domestic buildings, a thorough analysis of the local context seems inevitable.)
- recorded systematically, e.g. through a comprehensive survey of participants

Commonly, self-reports of building occupants on their practises as well as observations of target behaviours are already included in best-practise evaluations. Yet often they cannot go beyond levels of anecdotal evidence and spot-checks on relevant behaviours given the resources available for evaluative efforts. The systematic application of a questionnaire-based benchmarking tool for the assessment of behaviour change potentials might help to offset this weakness (see [16] for an example questionnaire for offices and industrial settings).

But substantial challenges remain, first and foremost with regard to how energy behaviours relate to building energy use in the first place – an area that especially in complex non-domestic buildings merits further attention of researchers from both behavioural and technical backgrounds. Also, the range of impacts on programme participants, which might include non-energy effects as well as the diffusion of ideas on energy and sustainability into the domestic context, remain intrinsically hard to value using standardised quantitative tools. It might, hence, be at the heart of any discussion on behavioural energy efficiency measures whether they can simply be placed alongside technical measures and evaluated purely on the same grounds.

Potentially it would be more beneficial in promoting learning from successful staff-centred conservation programmes and initiatives especially in complex buildings if the focus of reporting was moved away from headlines based on absolute energy and cost savings and towards honest accounts of what worked and what did not in both design and implementation. Naturally, this is a bold call in a context where contracts are won on the basis of prospective savings, but not least building owners, operators and organisations more generally will appreciate that their staff are to be valued differently from mere assets.

References

[1] Department of Energy and Climate Change (DECC) 2011. “The Carbon Plan: Delivering our low carbon future.”. London: Crown.

[2] Abrahamse, W., L. Steg, C. Vlek and T. Rothengatter (2005). "A review of intervention studies aimed at household energy conservation." Journal of Environmental Psychology 25(3): 273-291.

[3] Matthies, E., Kastner, I., Klesse, A., Wagner, H.-J. 2011. “High reduction potentials for energy user behavior in public buildings: how much can psychology-based interventions achieve?” *Journal of Environmental Studies and Sciences* 1 (3), 241–255.

[4] Schahn, J. 2007. “Projekt Energiemanagment am Psycholgischen Institut der Universiät Heidelberg: Ein erfolgreicher Fehlschlag.“ [in German] *Umweltpsychologie* 11 (2), 138–163.

[5] Siero, F. W., Bakker, A. B., Dekker, G. B., Van Den Burg, M. T. C. 1996. “Changing organizational energy consumption behaviour through comparative feedback.” *Journal of Environmental Psychology* 16 (3), 235–246.

[6] Staats, H., van Leeuwen, E., Wit, A. 2000. ”A longitudinal study of informational interventions to save energy in an office building.” *Journal of Applied Behavior Analysis* 33 (1), 101–104.

[7] McClelland, L., Cook, S. W. 1980. “Energy-Conservation in University Buildings - Encouraging and Evaluating Reductions in Occupants Electricity Use.” *Evaluation Review* 4 (1), 119–133.

[8] Murtagh, N., M. Nati, W. R. Headley, B. Gatersleben, A. Gluhak, M. AliImran, D. Uzzell 2013. "Individual energy use and feedback in an office setting: A field trial." *Energy Policy* 62(0): 717-728.

[9] Nye, M., Hargreaves, T. 2009. “Exploring the social dynamics of proenvironmental behavior change.” *Journal of Industrial Ecology* 14 (1), 137–149.

[10] Carrico, A. R., Riemer, M. 2011. “Motivating energy conservation in the workplace: An evaluation of the use of group-level feedback and peer education.” *Journal of Environmental Psychology* 31 (1), 1–13.

[11] Junnila, S., 2007. “The potential effect of end-users on energy conservation in office buildings.” *Facilities* 25 (7), 329–339.

[12] Kattenstein, T., Unger, H., Wagner, H. 2002. „Handlungskonzepte zur Optimierung des Energiebedarfs und der Energieversorgung der Ruhr-Universität Bochum“ *Abschlussbericht zum Vorhaben: IV A4-20600298 Optimierung der bestehenden wirtschaftlichen Energieversorgung der Ruhr-Universität Bochum (in German).* Ruhr-Universität: Lehrstuhl für Energiesysteme und Energiewirtschaft.

[13] Abrahamse, W., L. Steg 2013. "Social influence approaches to encourage resource conservation: A meta-analysis." *Global Environmental Change* 23(6): 1773-1785.

[14] Cox, A., T. Higgins, R. Gloster, B. Foley, A. Darnton 2012. “The Impact of Workplace Initiatives on Low Carbon Behaviours.” *Scottish Government Social Research.* London: Crown.

[15] Shadish, W. R., Cook, T., Campbell, D. 2001. “Experimental and quasi-experimental designs for generalized causal inference.” New York: Houghton Mifflin.

[16] Bicknell, C. and L. A. Skumatz (2004). Non-Energy Benefits (NEBs) in the Commercial Sector: Results from Hundreds of Buildings. ACEEE Summer Study on Energy Efficiency in Buildings.

[17] Carbon Trust (2010). “Hospitals. Healthy budgets through energy efficiency.” London, HMSO.

[18] Efficiency Valuation Organisation 2007. “International Performance Measurement and Verification Protocol” San Francisco, CA: Efficiency Valuation Organisation.

[19] Ucci, M., Domenech, T., Ball, A., Whitley, T., Wright, C., Mason, D., Corrin, K., Milligan, A., Rogers, A., Fitzsimons, D., Gaggero, C., Westaway, A. 2014. “Behaviour change potential for energy saving in non-domestic buildings: Development and pilot-testing of a benchmarking tool” *Building Services Engineering Research and Technology* 35: 36-52, first published online on November 13, 2012 doi:10.1177/0143624412466559