Understanding Energy Consumption at Work: Learning from Arrow Hill

Ben Bedwell* **Enrico Costanza†** **Michael O. Jewell†**

*Horizon Digital Economy Research
The University of Nottingham
Nottingham, UK
benjamin.bedwell@nottingham.ac.uk

†Electronics and Computer Science
The University of Southampton
Southampton, UK
{E.Costanza, M.O.Jewell}@soton.ac.uk

ABSTRACT

Most work around technological interventions for energy conservation to date has focussed on changing individual behaviour. Hence, there is limited understanding of communal settings, such as office environments, as sites for intervention. Even when energy consumption in the workplace has been considered, the emphasis has typically been on the individual. To address this gap, we conducted a study of energy consumption and management in one workplace, based on a combination of workshops with a broad range of stakeholders, and quantitative data inspections. We report and discuss findings from this study, in light of prior literature, and we present a set of implications for design and further research. In particular, three themes, and associated intervention opportunities, emerged from our data: (1) energy wastage related to "errors"; (2) the role of company policies and the negotiation that surrounds their implementation; and (3) the bigger energy picture of procurement, construction and travel.

Author Keywords

Sustainability; Public Displays; Buildings; Energy; Workplace; Error

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Climate change is a global threat: reducing the energy consumed by living and working in buildings is one significant opportunity to reduce the greenhouse gas emissions that fuel this threat. The CSCW, HCI and Ubicomp communities have been addressing this challenge in terms of reducing energy demand, mostly focussing on understanding and changing *individual* behaviour, yet there is a gap in the understanding of communal settings, such as an *office environment*, as sites for intervention. A significant portion of the population spends most of their time in offices, hence that is where a large share of our energy consumption takes place. In shifting our focus, we believe that it is necessary to reassess our understanding of energy consumption, which has been informed mostly through studies of the home [8, 12, 43].

Even the smaller set of prior work addressing energy consumption in the workplace still focuses mostly on the individual: it concentrates on the electrical appliances over which single employees, or very small groups, have control. Examples include personal computers, task lights, and telephones (e.g., [30, 44, 47]); individually controlled machines in industrial workshops (e.g., [41]); or individual apportionment of shared resources, such as how many pages each employee prints [35]. In contrast, we draw attention to consumption that is intrinsically difficult, or impossible to apportion precisely, such as that related to building and domestic water heating, network servers, and appliances used for services beneficial to everyone in the building, such as cleaning and maintenance. Closely related to heating is the notion of *comfort*, which is well understood to be a driver of consumption [9, 40]. What opportunities and barriers to energy savings exist around these issues? How are responsibility and decision-making around energy shared? Such analysis is relatively absent from the literature, but we argue it is critical to support the design of novel, appropriate technologies to reduce energy consumption.

To explore this gap in understanding, and look for concrete opportunities for intervention, we conducted a study of energy consumption and management in one particular building – Arrow Hill[1] – used by a UK district council (a regional government body). We conducted two workshops with a broad range of stakeholders from the council, from energy and facilities managers to employees working in the building; one workshop was structured to an extent around visualisations of quantitative data from the building monitoring systems, while one focused on unpacking workplace comfort. We complemented the workshops by subsequently collecting evidence of reductions in consumption through follow-up data inspections. In this paper we present the data we collected, its discussion, and a set of implications for design and further research that we derived. In particular, three themes, and associated intervention opportunities, emerged from our data: (1) energy wastage related to "errors"; (2) the role of company policies and the negotiation that surrounds their implementation; and (3) the bigger energy picture of procurement, construction and travel. These themes go beyond what prior lit-

[1] an invented name to protect the privacy of our participants

CSCW '16, February 27-March 02, 2016, San Francisco, CA, USA

ACM 978-1-4503-3592-8/16/02$15.00
DOI: http://dx.doi.org/10.1145/2818048.2819993

erature addressed, hence their definition and the implications they lead to constitute the contribution of this paper.

RELATED WORK

There is now a significant body of work that describes studies of energy consumption in the home (e.g. [8]) and interventions that seek to reduce domestic energy consumption (see [16]). Reviews of such work for national policy makers have asserted potential for reductions in electricity consumption ranging up to 15% as a result of feeding back house-level energy profiles to domestic occupants [11]. In comparison to domestic research, there have been fewer studies that focus on energy use in the workplace, as noted by recent reviews (e.g. [34]), despite it being known that organisations are typically poor at identifying and addressing energy inefficiencies [45].

Designing appropriate interventions for other environments requires an understanding of their characteristics. Some work has recently been carried out to this end by other researchers. Jain et al. provide an insight into the attitudes and concerns of office staff, revealing barriers that prevent efforts to conserve [22], while Schwartz et al. highlighted the controversial nature of revealing energy data out of context of situated practices (e.g. to a distant manager) [37]. Foster et al. conducted workshops with a range of staff to explore perceptions of energy use in the workplace, also emphasising the need for workplace interventions to be particularly sensitive to specific organisational cultures [17]. Through a set of interviews Castelli et al. note that there are differences between industrial and office-based work settings [7], and propose that enterprise information systems should present energy consumption information according to different users' roles. This related work calls for further studies that reveal unique characteristics of workplaces – our paper extends such work by contributing empirical evidence and identifying specific issues that confound attempts to save energy in workplaces, including the scattered knowledge of context of consumption; the ever-evolving nature of workplace architecture, layouts, occupancy and infrastructure; political tensions around hierarchy and organisational change; and the difficulty of communication across organisations.

Examples of existing interventions into workplaces provide useful insights into what may or may not create energy savings. Building certification schemes such as LEED[2] address energy consumption in the workplace. While mostly focusing on guiding sustainable building management, the LEED system also recommends a digital display (the *LEED Dynamic Plaque*[3]) providing summative measures of the building's performance to staff. However, research has shown that these schemes tend to deliver negligible impact [28, 39].

Existing research interventions in the workplace adopt a variety of approaches. An early study by Siero et al. [41] found that comparative feedback given to staff in an industrial setting results in energy efficiency gains. Katzeff et al. report field studies of two design probes to investigate employees' interpretation of eco-feedback, highlighting the challenges of defining best practice around effective workplace interventions [25]. Pousman et al. [35] proposed Imprint, a system that tracks the documents people print in the work environment, and provides a visualisation of the resources consumed in this way on a semi-public display. Jentsch et al. [23] presented an energy-saving support system for work environments that leverages a variety of sensors (temperature, electricity, light, contact) to provide workers with suggestions about how to act in an environmentally friendly way, however no real-world evaluation is reported. A number of other interventions in office environments take the form of games. Climate Race [42] used sensors to track players' energy-related behaviour (e.g., switching off lights when not in) awarding positive or negative points as appropriate. In the Energy Chickens game [30], virtual pets represent the energy consumed by individual devices; their visual aspect is designed to encourage staff towards lower consumption. The IdleWars game [44] targets a specific wasteful individual behaviour: leaving personal computers on when not in use. The game design aims at curtailing such phenomenon, but evaluation revealed mixed results. Beyond games, Yun et al. present a study of an "intelligent dashboard" which allows office workers to monitor, remotely control and schedule the power-off times of a number of personal devices [47]. Their evaluation results indicate that remote control and automatic scheduling are effective in delivering energy savings.

These interventions suggest that it is possible to make an impact, but they also highlight research gaps. For example, a common focus of these interventions is that they target energy consumption related to *individual* employees. Recent critiques and meta-reviews of sustainable HCI have suggested that a tight focus on individual behaviour is limiting the HCI community's impact on global environmental issues [31, 26]. The community has been encouraged to shift away from considering sustainability purely as a resource management issue [43], to question whether new technology can be the answer to sustainability issues [2], and to think more holistically about where consumption happens and why [31, 26]. As detailed in our discussion section, our findings strongly resonate with some of the arguments put forward in these critiques. However, our work is original in that it grounds the discussion in empirical data, opening up discussion around underexplored aspects of sustainability. Our research specifically addresses consumption that goes *beyond the individual*, such as space heating, and issues relating to consumption that are shared, such as thermal comfort.

Thermal comfort has an important link to energy consumption: Shove describes the convergence of factors that has led to the goal of maintaining "room temperature" [40]. Milenkovic et al. have demonstrated that, as a result, staff typically feel low levels of control over their personal comfort [27]. Smart heating systems have been explored in recent ubicomp research. For example, PreHeat leverages presence sensors and machine learning to optimize heating energy efficiency [21]. Clear et al. suggest that ubicomp can contribute towards allowing building occupants to pursue personal comfort goals and use less energy collectively as a result [9]. In-

[2] http://www.usgbc.org/leed

[3] https://www.leedon.io/faq.html

deed, Feldmeier and Paradiso presented a control system to allow individual occupants to customize their office climate [15]. While such technology could have considerable implications on workplace sustainability, the system has reportedly been tested only in one specific building (where the system was developed), and over one specific season (cooling). So it is unclear how well its benefits may generalize, leaving the problem of negotiating communal thermal comfort open.

Our research method – data exploration workshops, bringing together multiple stakeholders – was deliberately chosen to tackle these shared issues. In addition, it also focuses our attention on what value *existing data* generated by the workplace has in engaging staff, rather than relying on the deployment of costly new sensing and control technology.

DATA GATHERING

Our research took place in Arrow Hill (AH), a flagship building of the Southshire[4] Council. Here we gathered *building monitoring data*, then directly engaged staff through *two workshops*. We maintained a relationship with the Council to allow for *follow-up activities* to explore issues raised as a result of the workshops; our aim was to learn not just from the workshop proceedings, but also from subsequent reactions to them.

Arrow Hill

AH combines a restored Grade II* listed house from the 18th century with a new section completed in 2010. The new section contains 2600m^2 of open plan offices; the original building retains a largely traditional office layout of many rooms housing small groups of staff, as well as several larger public function rooms. The new construction was originally commissioned in 2002 by a different local authority, merged in 2009 into the current Southshire council, as a result of a nation-wide administrative reorganization.

Approximately 500 staff are based at AH, performing a variety of roles from on-site marriage registration to highly sensitive social services. While the building has been designed with the ambition to achieve high energy efficiency (the BREEAM's[5] 'excellent' rating), it has performed below expectations, and the council has been keen to explore means of realising the efficiency potential of the building in real-world conditions.

Building Data Monitoring

The operation of AH is recorded via an energy monitoring system (which collects consumption data from the building's gas and electricity supplies) and a building management system (BMS, which monitors internal and external conditions, such as temperature). Gas and electricity consumption is monitored separately in the original and new parts of the building, and electricity consumption is also monitored per floor. It is worth noting that, while the systems are capable of collecting half-hourly data and storing it indefinitely, the provided UI has very limited visualization capabilities. In line with observations of other workplaces by researchers, e.g. [24], monitoring was deployed in AH without a proactive strategy for making use of the data.

Six months' worth of half-hourly data from the AH monitoring systems was retrieved as background information. This data provided the researchers with a history of the workplace from which to create visualisations as prompts for workshops.

Workshops

Two workshops were run in AH, targeting strategic "energy decision-makers" within the organisation and office staff. We engaged these two communities separately to minimise the chances of hierarchy affecting the accounts given by participants. We also intended to engage the communities differently, based on our hypothesis of their concerns, i.e. of energy decision-makers around cost and efficiency, and office staff with a comfortable and supportive working environment. In both cases, the workshops were introduced as a collaboration between the Council and a University, to understand how energy can be saved in workplaces; beyond providing lunch, no explicit incentives were provided for attendance. Although the content of the workshops differed, both were structured around activities designed to elicit accounts of energy (and related resource) management. Both workshops were facilitated by four researchers, three of whom were subsequently involved in analysis. Conversations during the workshops were audio-recorded and later transcribed for analysis. Participants were also asked to provide their job title.

Energy decision-makers

The first workshop (W1), lasting approximately a full working day, was attended by 14 managers (12 male, 2 female) with varying stakes in the operation of AH. Participants were selected and invited directly by the leader of the council energy team, involving a wide range of stakeholders. Their responsibilities included savings and efficiency within the organisation; development and implementation of sustainability strategy; facilities management and support; facilities maintenance; and IT management, as well as the surveyor of the "new" build. A number of these attendees are not physically based at AH on a daily basis, even though the building falls under their direct responsibility.

W1 was structured around instances of the data collected from the building. We analysed the six month long dataset to generate a series of visualizations, with the aim to provide a wide range of options that would encourage participants to explore the data without overwhelming them. The choice of initial visualizations was informed by our own exploration of the data in advance of the workshop and included: a comparison of the electricity consumption per square metre of floor space in various parts of the building; the changes in consumption across the seasons; and the variation between work and non-work days in the week. All visualizations were designed to be appropriate to the technical background of participants, rather than being novel in visualisation terms. Further analyses highlighted characteristic features of the typical daily consumption profile, and pinpointed the days of the year with highest and lowest energy consumption. To prompt critique and support discussion, large paper print-outs of the

[4] also an invented name

[5] BREEAM is an internationally recognised benchmarking method for building sustainability; see http://www.breeam.org/

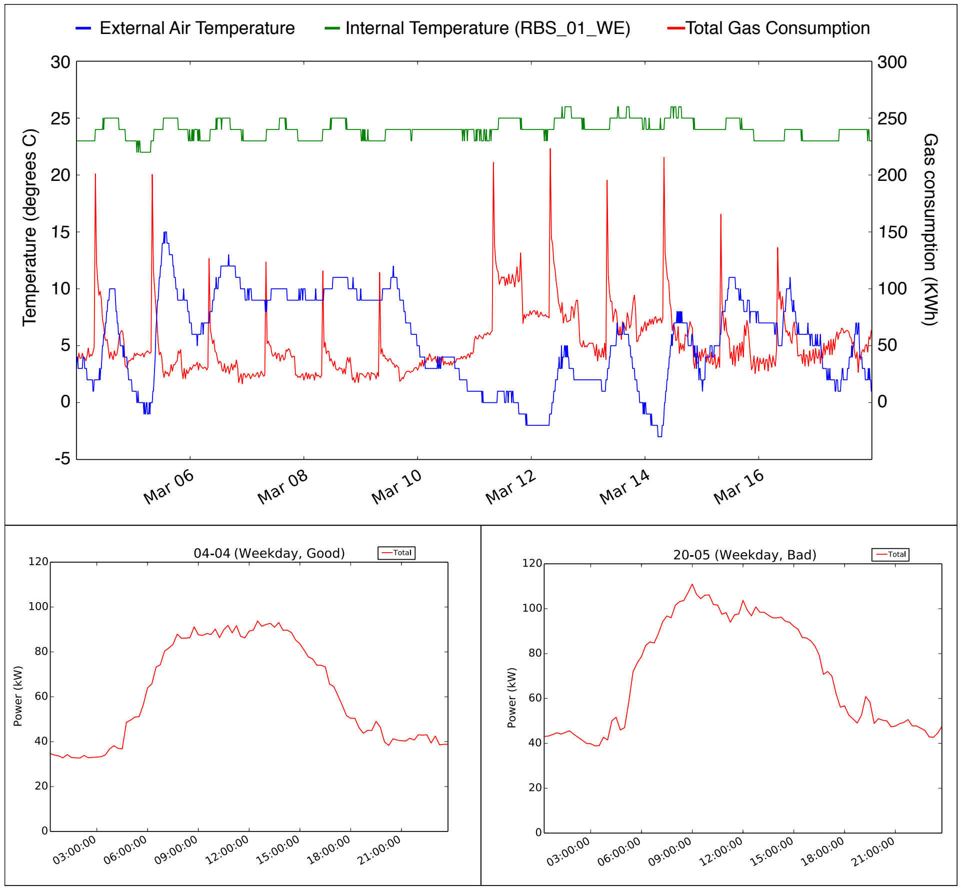

Figure 1. Three examples of the plots used in the first workshops. Each was shown to participants as A3 colour print-out. Top: two weeks of gas consumption data, internal and external temperature. Bottom: electricity consumption over time, plotted for an example weekday when the overall electricity consumption was exceptionally low (left) and exceptionally high (right).

visualisations were given to the participants to mark-up, and the potential insights spotted by the researchers were briefly presented. The participants were then also allowed to directly explore the data behind the visualisations in more detail, assisted by the research team during the workshop (who had the data and query tools on a laptop).

Office staff

The second workshop (W2) took place several months after W1 and was shorter in duration – lasting approximately two hours over lunch provided as compensation by the researchers – to fit around staff working schedules, and was attended by 11 staff (6 male, 5 female) with varying office roles within AH, including business development, finance, and marketing. The participants were split randomly into two groups and given a series of discussion tasks. The tasks were designed to encourage participants to explore the notion of comfort by ranking factors that contribute to a comfortable and productive environment, the degree and mechanisms by which they could control those factors, and how they could measure them. We note that participants for W2 volunteered their time in response to an advert posted by AH managers on internal email lists and so may exhibit certain self-selection biases; where appropriate, we reflect on this in our findings. Given the focus on perceived comfort (rather than directly on energy savings) and the limited time availability of participants in W2, no data visualisations were presented.

FINDINGS

Using transcriptions of the workshop discussions, we carried out a thematic analysis [4]. This analysis started by categorising the material at the sentence level through open codes. Initially 126 open codes were used, later iteratively grouped into 4 broad categories, described in the following subsections. Quotes are labelled with the pseudonym of the speaker, their job family, and the workshop that they attended.

The Difficulty of Understanding the Building Operation

Where energy goes

During W1, participants attempted to make sense of the electricity and gas consumption in the building using the data visualizations and figures we showed them. Specific pieces of equipment were pointed at as causes of energy consumption: from printers and monitors to vacuum cleaners, to mobile air conditioning units, to servers. The group tried to infer information from the technical specifications of appliances to explain the consumption on specific electrical circuits.

Contextualising consumption

Participants in both workshops tried to explain consumption using their various understandings of their workplace context. Consumption was related to causes such as health concerns, for example: "*[heating the water is] a way of managing legionella [...] heat it above 60 degrees and that'll kill everything off.*" [Scott (Engineering), W1] Health also came up in W2, as a justification for an employee using a fan "*the policy is you wouldn't have a fan without a medical reason*" [Dennis (Office staff), W2] Specific patterns of building occupancy – relating to the activities in AH as well as seasonal conditions – were linked to consumption, e.g. "*more people get married in the lighter months of the year. So you can have up to three, four, five weddings a day, whereas in the winter months they might not have any at all.*" [Paul (Facilities management), W1]

Interrogation and explanation

The data visualisations prompted some participants to raise questions about the heating settings in AH, such as the fact that it is turned on from the early hours of the day: "*..we think because staff start at seven, that the boilers have to come on at six, so at seven this building has reached 19 degrees, but is that a presumption or do we know we have to have those boilers on that long before a member of staff arrives?*" [Jimmy (Energy management), W1]. In some cases, the group agreed that further investigation was necessary around specific issues ("*Jimmy (Energy management): There's something about the gas, but in terms of the profile it looks right ... Scott (Engineering): The dodgy base load I think needs investigation ...*" [W1]) Some of this analysis, especially when comparing day and night consumption, was focussed on understanding "always-on" consumption[6]: where it comes from, and its size in comparison to the daytime consumption.

An ever-evolving system

Energy consumption was also related to the complex process of *commissioning*, *designing* and *constructing* the building. Participants highlighted that the building project was originally commissioned by one organization, which was later merged into the current council, and this transition affected the final design of the building. Even the position of furniture in the open space offices was suggested to influence the air flow and hence the building thermal performance: "*if you look at some of the very early drawings, the layout of furniture and storage cabinets, it's no resemblance to what we've got in the building today, which is obviously affecting the natural ventilation, so I think what seems quite minor detail [...] it's what seems an innocent change is having long term effects*" [Walter (Property operations), W1]. The building is perceived by our participants as a system in evolution, then, with thermal performance that has changed over time.

Brought together, these elements point towards a *complex* system of appliances, routines, architectural and infrastructural features, people and physics. In particular, it was clear that no single participant had a clear understanding of all these factors, or of how they interact. Bringing the groups together allowed them to pool their individual understandings, and also led to the identification of issues that needed further investigation (leading to follow-up events described later in this paper).

[6]energy consumed by devices that are never turned off

Heating Perception and Adjustments for Comfort

From W1 we learned that heating was considered a major cause of consumption and that the council has a temperature policy that limits temperatures to 19-21°C (66-70°F). However, such policy is not always strictly enforced, partially as a result of staff complaints. Indeed the management group seems to be quite aware of staff complaints about the building comfort and temperature.

The subjective nature of thermal comfort

In W2, participants ranked temperature as a key factor in determining their productivity and comfort. However, part of the discussion in both workshops focussed on the subjective perception of temperature and its conflict with the temperature policy. Participants mentioned a variety of factors that influence thermal comfort, ranging from age, to doing physical activity, to the appearance of outdoors elements. In both workshops various anecdotes were reported to demonstrate how subjective the matter is, for example: "*You can't satisfy everybody, [...] I've been to sites where people have said, let's get the heating down to 18, it's far too hot here. [...] So if you shifted the heat to 22, you'd have more people complaining about it being hot*" [David (Energy management), W1] While, one of the building occupants said: "*One of our colleagues [...] likes to have fresh air and so she opens the door, the whole rest of the office is like... sitting in scarves.*" [Nicholas (Office staff), W2]

Sanctioned adjustments for comfort

This previous quote points also at the use of clothing to adjust the individual thermal comfort, and to conserve energy. Indeed, we learned that the council implements an explicit policy around this matter: it distributes branded fleece jackets to employees as a measure against cold. Participants directly related a change in dressing style to energy conservation: "*if we tell the reception staff to put on thicker socks and trousers, then we can turn those heaters off under their desk as well*" [Scott (Engineering), W1], but also that dressing style may be an obstacle: "*I hear so many people going oh, I'm freezing. They know they're going to work on the reception on a Saturday, [...] I'll look at them and say how many layers have you got on? They're in a T shirt and a* frilly *cardigan*" [Judith (Office staff), W2].

Personal adjustments for comfort

Besides clothing, we also heard about a number of other ad-hoc, individual interventions and remedies that the occupants of AH adopt to improve their own comfort at the office. Many of the efforts seem to be related to thermal comfort, whether trying to cope with cold: "*..everyone is bringing in hot water bottles*" [Paul (Facilities management), W2], "*So that becomes really a part of your working day, making a nice warm cuppa, which of course is going to help with the temperature*" [Lori (Office staff), W2], or with heat: "*some people brought their own fans in, didn't they?*" [Walter (Property operations), W1].

Thermal comfort was a common topic in both workshops, and the question of how to use AH's heating systems to provide a comfortable temperature for all remained unresolved. Some participants raised a lack of control (echoed elsewhere [22]), but we noted many adjustments to circumvent systems and policy to regain control over participants' personal environments (also noted by others [9]). Notably, the discussions painted a picture of an uncertain political stance on whether these individual adjustments for comfort are tolerated.

Cost and Organisation Changes

Issues of cost in relation to energy consumption came up in the workshop with *energy decision-makers*, as they are directly responsible for the bills. However, *office staff* also considered the issue, but from different perspectives.

Energy as an indirect financial concern

Office staff drew attention to their concerns as taxpayers as well as employees: "*we work for a local authority but we also, you know, we're ratepayers. I don't want to be wasting. Once again my council tax hasn't gone up this year: how lucky are we for that to have happened?*" [Lori (Office staff), W2]. Moreover, the financial issue was sometimes framed into a wider picture of financial cuts to the public sector in the UK, and job security: "*..that is a reasonable temperature, that's how much it's costing, one more degree will cost that, that would cost x amount of jobs*" [Adam (Office staff), W2] Indeed we learned that the employees of this council had recently gone through a stressful voluntary redundancy (VR) process: "*..they're all upset about stuff, not to mention VR, not to mention pressure, loss of staff, everything is being squeezed, so the management layer in the middle is getting it from all sides.*" [Walter (Property operations), W1]

Reorganising buildings and human resources

VR is just one measure adopted by the Council as an organization to adapt to recent changes. Small offices have been closed down, with employees relocated: "*a lot of people [who] moved into this building have come from [offices] around the city. They've come from small offices*" [Jason (Surveyor), W1]. Such a change appears to be part of a council strategy of closing down buildings that are not energy efficient and moving to newly built ones rather than renovating: "*you could go bankrupt trying to make that site energy efficient*" [Jimmy (Energy management), W1].

This drive to reduce reliance on older buildings has reduced workspace, leading to a complementary "work from home" policy: at the time of our workshops the AH building hosted 1.3 employees per desk, with a plan to reach "a two for one desk policy" within the following 8 months. To make this possible, a clear-desk policy and a hot-desk policy were also being increasingly implemented: staff should be prepared to work from any desk in the office. Adherence to the hot-desk policy, though, was reported to be low: individuals tend to stick to the same desk. The energy decision-makers perceived this behaviour to negatively affect the thermal comfort in the building: "*We've got people upstairs with coats on, because that's their desk; 50 desks will be empty, but they won't move, because that's their desk*" [Jason (Surveyor), W1].

In summary, awareness of policy and policy changes in both workshops seemed relatively high, although we note that the office staff who volunteered to take part in our workshop may be particularly engaged with their organisation's policy and activities. The range of organisational changes occurring within the council was notable, giving an impression of an organisation (like the building itself) in flux. Of particular significance was the continued focus by both sets of staff on heating as both a major financial and political concern, revealing ways that the impact of energy consumption can be made personal for decision-makers and office staff.

Behaviour Change: Education and Communication

Across both workshops participants referred to behaviour change, often in terms of *education*. Changes in behaviour were explicitly related to changes in comfort, and energy savings, often in relation to clothing style (as described in the previous subsection).

Skepticism of behaviour change

Some participants in W1, however, questioned the relevance of behaviour change to their situation. In some cases, it was pointed out that the level of automation in the building does not leave much control to occupants: "*in this building, there isn't a thermostat on the wall [that] I can go and whack up and influence*" [Walter (Property operations), W1]. In other cases, the relative impact was questioned: "*What's the point? What's the point of even wasting somebody's time to draft some energy thing that says, switch your monitor off, we're trying to save energy. It's negligible.*" [Walter (Property operations), W1].

(Lack of) communication

Communication was also suggested to be a possible strategy to increase conservation and reduce complaints: display how much the council spends or saves in energy (and what that would correspond to e.g. in jobs saved, see above), and remind everyone of the current temperature policy. At the same time, we heard skepticism about an existing intervention to address communication around comfort in the building: "building user group" meetings take place periodically, but participants in both workshops appeared doubtful about their effectiveness. Participants referred not only to internal communication, but also to the public image of the council around the issue of energy waste, and the impact it has on taxpayers (see also the previous subsection).

Behaviour change is a commonly discussed option in HCI and broader sustainability communities. In the workshops we found interest in behaviour change and education of colleagues, yet also skepticism about how to effectively integrate these into strategy.

FOLLOW-UP DATA INSPECTIONS

Subsequent to W1, we received communication that the participants had gone on to investigate anomalies in the data visualizations they had discussed during the workshop, and identified energy savings. They realized that the heating of domestic water to prevent legionella (which was briefly discussed at W1, see "Contextualising consumption" above) was being carried out in an overzealous fashion. Reverting to a more energy-conservative setting allowed the saving of approximately 20% of their total gas usage, while remaining within safe guidelines.

Another opportunity to clearly identify energy wastage came upon inspection of data from another council building: Dorton House (DH). DH is managed by some of the attendees of W1 and is an office building considerably smaller than AH, located approximately 30mi north of it. DH houses about 80 employees across two floors, both arranged into an open space. The smaller size means that DH does not have a dedicated facilities manager, but it is remotely managed by a person responsible for several small buildings.

Visually comparing the electricity and gas consumption logs, we noticed an inconsistency. As illustrated in Figure 2, the electricity consumption pattern indicates that the building is in use Monday to Friday, in accordance with the reports of the occupants. However, gas, which is used mostly for heating, also appears to be consumed on Saturdays, for no apparent reason. A few weeks after we reported this issue to the appropriate energy decision-makers we noticed that the gas consumption logs changed to the expected Monday to Friday pattern, suggesting that the heating settings were amended and there was truly no reason for the heating to be active on Saturdays. The difference corresponds to 1/6th of the total consumed gas, i.e. around 16.7%.

DISCUSSION

Reflecting on our findings, we see demonstrations of the energy consumption issues that make the office workplace distinct from other contexts, such as the home or industrial setting. For example, as in the home, staff do link changes in energy consumption to their financial situation, but we see that this link is *indirect* via concerns over job security. On the other hand unlike the home, we have seen that workplace energy decision-makers may not inhabit the building they manage, and that there are unique legal and ethical responsibilities for consumption during remote working. Becoming familiar with these nuances is important when considering designing interventions for the workplace, and so we unpack them in more detail here.

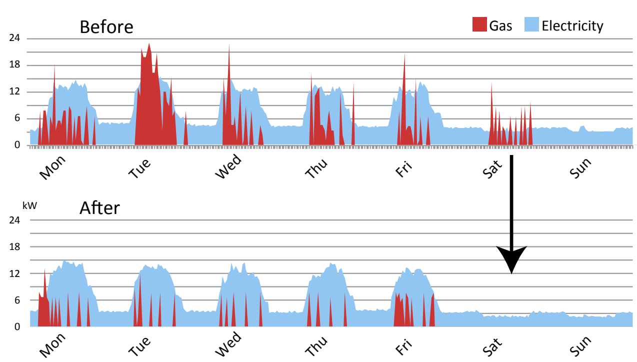

Figure 2. The change in gas usage patterns before (top) and after (bottom) reporting that the building was being heated for an extra day, compared to corresponding electricity usage.

Supporting Understanding: Preventing and Fixing Errors

In W1 we found that visualising monitoring data enabled "interrogation and explanation" of energy consumption. This led to further follow-up investigation, after which we observed concrete energy savings coming from two issues rectified by the Council. We consider these two issues "errors", in the sense that they did not influence anyone's comfort or convenience either before or after they were rectified, and did not require substantial effort to correct. We have found that such operational *errors* are apparently related to our theme of the "difficulty in understanding the building operation", as highlighted by the efforts (or degree of assumption) energy decision-makers made in explaining the complexity and opacity around "where energy goes". It seems that such complexity prevents facilities managers from having a concrete expectation for what a "normal" energy bill should be, similar reports from previous research on the domestic context [38, 43].

Foundational work about errors was carried out by Don Norman and James Reason in terms of cognitive psychology and HCI [36, 29]. In particular Norman relates errors to his *theory of action* – an error is a mismatch between intention or goal and the result of action taken – and to an incorrect system mental model. In our case the incorrect mental model could perhaps be described for building occupants as: "the heating is off when I am not in the building." Arguably, this is exacerbated by both the staff's awareness of the many automated features of the building, and the absence of complaints (during out-of-hours) that seem to drive in part the decision-making of the management. According to Norman's theory, one way to try to avoid errors is to reduce the gulf of evaluation by making the system status as clearly visible as possible. From a design perspective, then, what we need to make the status of the building easily visible, not only in terms of present status (since this would simply confirm the occupants' mental model of heating), but also historical. We shall return to this point in our implications section.

The occurrence of errors related to energy waste can be noticed in selected prior work, even though not always explicitly highlighted as such. For example, studies of domestic heating have shown that misconceptions of heat and heating systems can lead to constantly and inefficiently heating the home, rather than heating on demand [33]. Moreover, a recent study of a smart thermostat [46] found that participants had air conditioning *on* when they are away from home, and that this was noticed and recognized as a mistake only when they reviewed the smart thermostat logs with researchers. Yun et al. reported a study and intervention around the usage of individually controlled electrical appliances in the workplace [47]. They observed waste related to appliances like phones and task lights being left on out of office hours, and that savings could be achieved by programmatically turning them off on a schedule. Notably, behaviour change is an option that is commonly discussed in HCI and broader sustainability communities but difficult to implement, yet our findings empirically demonstrate that significant energy savings can also be made by fixing errors – an opportunity given less attention.

Policy and Communication

Through the workshops we have learned about a number of policies adopted by the council with implications on energy consumption, namely the *work from home* and related *hot-desk* policies, as well as the *temperature* policy and the *fleece jackets distribution*. As suggested through our "Heating Perception and Adjustments for Comfort" theme, a strict temperature policy and an array of "sanctioned adjustments for comfort" limit the amount of control that individual employees can exert. At the same time, it is worth highlighting how our data also indicates that policy implementation is not (or not always) literal or straight-forward, and reveals the spectrum of strategies and negotiations that exist around it. At one end of such a spectrum employees take advantage of sanctioned strategies to improve their wellbeing, such as bringing in extra clothing and drinking hot beverages – the policy is adhered to. In other cases, employees' complaints lead energy managers to relax the temperature policy. In other cases still, employees contravene policy to make "personal adjustments for comfort" or simply ignore the hot-desk policy, returning always to the same location in the office. All these examples indicate the potential for interventions that encourage employees to *understand and buy-in to policies*; a potential, we argue, that could be realized by interactive technology, and that we return to later in the paper.

Our findings on the theme of "Cost and Organisation Changes" suggest also that office staff may find it interesting and motivating to see the relation of energy policies to issues such as job loss (prevention) or tax. These issues link the council's cost of energy to their personal financial status, resonating to an extent with the domestic setting. Such link is most likely rather specific to public sector organisations like Southshire Council (especially in a time of severe job cuts), but it is interesting nonetheless. It contrasts with previous research that suggests that employees (of a profit-making company) do not believe that they may gain personal financial benefits from reduced workplace energy costs [22, 17].

The Bigger (Energy) Picture

In relation to sustainability, the CSCW – and related – research communities have focussed mostly on electricity, fuel, and water consumption [18]. Our participants made a number of comments that demonstrate that energy implications go beyond the energy consumed by the AH appliances, lighting and heating. Our theme of "Cost and Organisation Changes" reveals the extent to which the Council's resources are being reorganised: the migration of staff from small offices to one large building, the flexible working policy that means staff work remotely, the alternative strategies employees adopt to keep themselves warm, to name but a few, all play a role. As such, our data suggests that – especially in the context of the workplace – it is necessary to look at a *bigger energy picture*.

Through the 2-to-1 desk policy, the council is encouraging people to work from home 50% of the time and thus outsourcing energy consumption. However, research has shown that teleworkers actually tend to travel *greater* total distances than conventional workers, and can consume significant "home office" resources [19]. Heating one home for each employee is also arguably less efficient than heating one larger purpose-built building. What is the overall balance? It may be impossible to accurately calculate this for AH, but it is also overly simplistic to simply assume that teleworking is environmentally beneficial.

Carbon embodied in buildings is also an issue that emerges from our data: our participants reported that the council has a strategy of closing buildings perceived as being energy inefficient, and moving staff into new buildings. However, as the experience of AH has shown, it is often the case that new builds do not perform as expected (see "an ever-evolving system"). In addition, significant amounts of energy are consumed in replacing buildings (producing building materials, transporting them to a site, actual construction, demolishing, disposing, recycling) [3]. When the lifecycle of the building is considered rather than purely its operation, is the replacement of buildings (rather than refurbishment) energy efficient?

IMPLICATIONS

Our findings and discussion paint a picture of buildings as complicated energy-consuming systems of people, activities, infrastructure and architecture. At a general level the main implication of our work is that we need to go "beyond individual persuasion". While such an argument had been put forward before by others in the research community, based mostly on reflection and meta-reviews [5, 21, 26, 31], we *corroborate* such argument through data from our workshops and observations. Moreover, and perhaps more importantly, leveraging our findings from the field, we propose *three specific directions* for the research community where we see opportunities for interactive interventions that complement and go beyond existing interventions.

The first two implications are largely around interactive, ambient visualizations aimed chiefly at building occupants (rather than energy and facility managers). Even though ambient displays have often been proposed in the context of sustainable interactive technology, both in terms of research prototypes (see e.g., [18, 13, 35]) and actual products (e.g., the LEED Dynamic Plaque), the emphasis is generally on summative (usually aggregate) indicators, meant to capture the energy performance of the buildings or its users, sometimes in terms of monetary cost, sometimes in terms of comparison with other buildings. However, as discussed in the previous section, our data indicates that defining metrics that can unambiguously summarize the performance of a building, taking into account the complex context of usage may at times be a difficult, if not intractable problem. Therefore we propose alternative applications of such technology.

Making Building Operation Visible

We see an opportunity in helping building inhabitants (e.g. office staff) better understand its operation, to promote the development of a more accurate mental model, so that they could more easily recognize the kind of errors discussed above, and report them to the energy decision-makers. As revealed by our data, decision-makers are often physically distant from the buildings they are responsible for, and hence they may lack detailed information about the building's usage that is instead easily available to inhabitants. A concrete example would be a display of the building internal temperature traces over the past seven days, alongside information about human activity in the building. The visual comparison of these two streams of information may reveal instances where the empty building is heated (see e.g. Figure 2). Abundant data about the building are often already available from existing BMS installations; for example environmental information such as internal and external temperature, humidity and CO2. Activity data could be abstracted from presence sensors, often already installed in buildings for security purposes, or from electricity consumption logs. Such displays will need to be made engaging, to attract attention, and easy to understand for users who may not have technical training – design challenges that our community is well positioned to address [18, 13]. The participants in our W2 showed interest and commitment to energy saving, suggesting that a well designed intervention may have potential to attract the attention of at least *some* employees, such as 'energy champions' [20].

While we argue that the topic of interactive systems that illustrate the buildings operation to end-users is under-investigated, it is worth highlighting that a limited number of examples have already been published – these can provide inspiration for further development[7]. DoppelLab – a platform to create representations of general sensor network data – has been used to visualise and interrogate temperature data in workplaces [14]. An initial deployment of the system revealed malfunctions in the HVAC system, which had previously gone unnoticed. Similarly, FigureEnergy is an interactive system to annotate consumption logs, aimed at helping users make sense of the information [10]. A deployment of FigureEnergy with 12 households revealed that the system can enable users to shed new light and make discoveries around their own energy consumption. Finally, Yun et al. [47] reported an intervention in the workplace where historical energy consumption is displayed, even though their emphasis is on the automatic scheduling and the remote control of such appliances (raising questions about the energy efficiency and sustainability of such approach compared to a manual one).

Communicating and Contextualizing Policy

Having discussed the important role policy plays in relation to energy consumption in the workplace, and how this aspect is under-investigated, another important implication is to take policy explicitly into account in the design of energy-saving interventions. In particular, we see opportunities around reinforcing or enhancing policy communication, placing it in relation to the current building operation. Local, situated displays may be a useful means of framing local working conditions in terms of company policy. A specific example would be to show building occupiers that the current temperature is (or is not) within the policy range. Such display may reassure them that if they felt cold or hot it would be due to subjective perception. The display may also highlight the implications of adherence or deviation from policy, for example in terms of monetary cost and equivalent job cuts. Even though our data revealed that employees seemed generally aware of policy, and skepticism has been expressed towards displays of the current temperature, we believe that showing the two pieces of information together has potential to generate reflection and discussion about the policy, as well as to the more general strategies embraced by the company. Indeed, local displays (perhaps interactive) may be, more in general, a useful means of engaging building occupants in two-way dialogue around policy and organisational change.

[7]We exclude from this list papers that report the presentation of logs to study participants only as a probe, rather than as a final design, such as [37, 46]

Accounting for Energy Beyond the Building

Our research has emphasised the need to step back and consider the "bigger energy picture" of the workplace. To make it possible to design systems that reveal this picture, it is necessary to look beyond the walls of the workplace. To evaluate embodied and outsourced energy related to workplace activities, we must extend the reach of existing monitoring systems to track data on consumption that is both physically remote and temporally remote. For example, taking into account the energy consumed by staff working from home, but also energy consumed in constructing and demolishing the workplace, including the embedded energy costs of different construction materials [1, 3]. To this end, it is good to see that some certification programmes, such as LEED, already consider inhabitants transportation surveys to influence the performance score of a building, yet our data suggests opportunities to extend the scope of analysis even further.

Information systems could be developed to integrate elements of life-cycle analysis into the organisation's strategic decision-making, not just in building certification. However, given the range of actors and length of time involved in a building's life, maintaining provenance of the data may be difficult, and developing effective UIs to query such data is an open challenge [6]. Similarly, most life-cycle analysis is based on approximations and projections, so additional challenges involve the truthful representation of such sources of uncertainty, while still making the displayed information actionable. It is important to question not just the extent to which such systems might provide useful insights (how much detail is it useful for energy decision-makers to know?), but also the extent to which it is legal or ethical for an organisation to track an employee working from home. Researchers have shown how it is possible to infer television-watching and eating habits – among other personal insights – from domestic energy data [32]. We question whether staff would accept such monitoring, and suggest that designers of systems that harvest data from outside the workplace must consider whether and how to do so while being privacy-preserving.

CONCLUSION

This paper has presented a study of energy consumption and management in one particular building – Arrow Hill – used by a UK district council. Our approach involved collaboration with a broad range of stakeholders over two workshops, maintaining a long-term relationship with the organisation, as well as using real data from building systems as a prompt for critical interrogation. Such a combination of techniques allowed us to extract a number of novel findings, validating our approach. The usage of real building data led us to a discussion of how errors in building operation happen – such as those observed during our study of Arrow Hill – and how they might be detected. The involvement of different stakeholders revealed inconsistencies in the way they understand the building as a complex system, as well as the relationships across policy, energy and comfort. Drawing upon these findings, our contribution is in highlighting the complexity that surrounds energy consumption in the workplace, and putting forward specific opportunities to design interventions, while also emphasising the need for further research in this area.

At a more general level, our findings and subsequent themes empirically corroborate the suggestions made by previous literature, but also extend this previous research. While prior work reported interventions to address the (limited) control available to individuals within an office environment [30, 47], our engagement of both decision-makers and office staff demonstrated that both sets of stakeholders have distinct roles to play in *collaboratively* managing the building, bringing together knowledge of context, how the building functions and the ability to exert control. Little can be found in the literature to date about the role that interactive technology may take around *policy* to support sustainability. Even though others have convincingly questioned or criticised the emphasis on individual consumers found behind most sustainable HCI interventions [5, 21, 26, 31, 43], it is rare to find explicit and direct references to policies, whether at a company or public level. We consider this to be an important gap in the literature, given the central role that policy plays in the daily life of the workplace as well as, more generally, in society.

Finally, we note that our implications touch a range of research communities: designing sensing systems that capture the bigger energy picture of transient workforces and full building life-cycles draws on the expertise of the ubicomp community, while such systems raise ethical implications that will require the engagement of privacy researchers. We call on the CSCW and HCI communities to design interventions that encourage staff and decision-makers to collaborate on the task of error-fixing, and to consider how to incorporate representations of policy directly into such interventions.

ACKNOWLEDGMENTS

We thank Southshire Council and the workshop participants for their contributions. This work was supported by the EPSRC CTech project (EP/K002589/1), and approved by The University of Nottingham Computer Science Ethics Committee. The data referred to in this paper can be found at http://dx.doi.org/10.5258/SOTON/382356.

REFERENCES

1. Michael F. Ashby. 2013. *Materials and the Environment* (second ed.). Butterworth-Heinemann, Boston. DOI: http://dx.doi.org/10.1016/B978-0-12-385971-6.00025-7
2. Eric P.S. Baumer and M. Six Silberman. 2011. When the Implication is Not to Design (Technology). In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 2271–2274. DOI: http://dx.doi.org/10.1145/1978942.1979275
3. Mike Berners-Lee. 2010. *How bad are bananas?: the carbon footprint of everything*. Profile Books, London, UK.
4. Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.
5. Hronn Brynjarsdottir, Maria Hkansson, James Pierce, Eric Baumer, Carl DiSalvo, and Phoebe Sengers. 2012. Sustainably Unpersuaded: How Persuasion Narrows Our Vision of Sustainability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 947–956. DOI: http://dx.doi.org/10.1145/2207676.2208539
6. Lucian Carata, Sherif Akoush, Nikilesh Balakrishnan, Thomas Bytheway, Ripduman Sohan, Margo Seltzer, and Andy Hopper. 2014. A Primer on Provenance. *Queue* 12, 3, Article 10 (March 2014), 14 pages. DOI: http://dx.doi.org/10.1145/2602649.2602651
7. Nico Castelli, Niko Schönau, Gunnar Stevens, Tobias Schwartz, and Timo Jakobi. 2015. Role-based Eco-info Systems: An Organizational Theoretical View of Sustainable HCI at Work. In *ECIS 2015 Completed Research Papers*. AISeL, Münster, Germany, 1–8. DOI: http://dx.doi.org/10.18151/7217284
8. Marshini Chetty, David Tran, and Rebecca E. Grinter. 2008. Getting to Green: Understanding Resource Consumption in the Home. In *Proceedings of the 10th International Conference on Ubiquitous Computing (UbiComp '08)*. ACM, New York, NY, USA, 242–251. DOI: http://dx.doi.org/10.1145/1409635.1409668
9. Adrian K. Clear, Janine Morley, Mike Hazas, Adrian Friday, and Oliver Bates. 2013. Understanding Adaptive Thermal Comfort: New Directions for UbiComp. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '13)*. ACM, New York, NY, USA, 113–122. DOI: http://dx.doi.org/10.1145/2493432.2493451
10. Enrico Costanza, Sarvapali D. Ramchurn, and Nicholas R. Jennings. 2012. Understanding Domestic Energy Consumption Through Interactive Visualisation: A Field Study. In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing (UbiComp '12)*. ACM, New York, NY, USA, 216–225. DOI: http://dx.doi.org/10.1145/2370216.2370251
11. Sarah Darby. 2006. *The Effectiveness of Feedback on Energy Consumption*. Technical Report. Environmental Change Institute.
12. Tawanna R. Dillahunt and Jennifer Mankoff. 2014. Understanding Factors of Successful Engagement Around Energy Consumption Between and Among Households. In *Proceedings of the 17th ACM*

Conference on Computer Supported Cooperative Work & Social Computing (CSCW '14). ACM, New York, NY, USA, 1246–1257. DOI: http://dx.doi.org/10.1145/2531602.2531626

13. Carl DiSalvo, Phoebe Sengers, and Hrönn Brynjarsdóttir. 2010. Mapping the Landscape of Sustainable HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 1975–1984. DOI:http://dx.doi.org/10.1145/1753326.1753625
14. G. Dublon, L.S. Pardue, B. Mayton, N. Swartz, N. Joliat, P. Hurst, and J.A. Paradiso. 2011. DoppelLab: Tools for exploring and harnessing multimodal sensor network data. In *Sensors*. IEEE, New York, US, 1612–1615. DOI: http://dx.doi.org/10.1109/ICSENS.2011.6126903
15. M. Feldmeier and J.A. Paradiso. 2010. Personalized HVAC control system. In *Internet of Things (IOT), 2010*. IoT Conference, Tokyo, JP, 1–8. DOI: http://dx.doi.org/10.1109/IOT.2010.5678444
16. Corinna Fischer. 2008. Feedback on household electricity consumption: a tool for saving energy? *Energy efficiency* 1, 1 (2008), 79–104. http://dx.doi.org/10.1007/s12053-008-9009-7
17. Derek Foster, Shaun Lawson, Jamie Wardman, Mark Blythe, and Conor Linehan. 2012. "Watts in It for Me?": Design Implications for Implementing Effective Energy Interventions in Organisations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 2357–2366. DOI: http://dx.doi.org/10.1145/2207676.2208396
18. Jon Froehlich, Leah Findlater, and James Landay. 2010. The Design of Eco-feedback Technology. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 1999–2008. DOI: http://dx.doi.org/10.1145/1753326.1753629
19. Christian Fuchs. 2008. The implications of new information and communication technologies for sustainability. *Environment, Development and Sustainability* 10, 3 (2008), 291–309. DOI: http://dx.doi.org/10.1007/s10668-006-9065-0
20. Tom Hargreaves. 2011. Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change. *Journal of Consumer Culture* 11, 1, Article 1 (2011), 21 pages. DOI: http://dx.doi.org/10.1177/1469540510390500
21. Mike Hazas, A. J. Bernheim Brush, and James Scott. 2012. Sustainability Does Not Begin with the Individual. *interactions* 19, 5 (Sept. 2012), 14–17. DOI: http://dx.doi.org/10.1145/2334184.2334189
22. Mohit Jain, Ankit Agrawal, Sunil K. Ghai, Khai N. Truong, and Deva P. Seetharam. 2013. "We Are Not in the Loop": Resource Wastage and Conservation Attitude of Employees in Indian Workplace. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '13)*. ACM, New York, NY, USA, 687–696. DOI: http://dx.doi.org/10.1145/2493432.2493444
23. Marc Jentsch, Marco Jahn, Ferry Pramudianto, Jonathan Simon, and Amro Al-Akkad. 2011. An Energy-Saving Support System for Office Environments. In *Human Behavior Understanding*, AlbertAli Salah and Bruno Lepri (Eds.). Lecture Notes in Computer Science, Vol. 7065. Springer, Berlin Heidelberg, 83–92. DOI: http://dx.doi.org/10.1007/978-3-642-25446-8_10
24. Phil Jones. 2012. Problems with sub-metering energy consumption in UK non domestic buildings. In *ASHRAE Technical Symposium*. CIBSE, London, UK, 11.
25. Cecilia Katzeff, Loove Broms, Li Jönsson, Ulrika Westholm, and Minna Räsänen. 2013. Exploring Sustainable Practices in Workplace Settings Through Visualizing Electricity Consumption. *ACM Trans. Comput.-Hum. Interact.* 20, 5, Article 31 (Nov. 2013), 22 pages. DOI:http://dx.doi.org/10.1145/2501526
26. Bran Knowles, Lynne Blair, Paul Coulton, and Mark Lochrie. 2014. Rethinking Plan A for Sustainable HCI. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 3593–3596. DOI: http://dx.doi.org/10.1145/2556288.2557311
27. Milan Milenkovic, Ulf Hanebutte, Yonghong Huang, David Prendergast, and Han Pham. 2013. Improving User Comfort and Office Energy Efficiency with POEM (Personal Office Energy Monitor). In *CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. ACM, New York, NY, USA, 1455–1460. DOI:http://dx.doi.org/10.1145/2468356.2468616
28. Guy R. Newsham, Sandra Mancini, and Benjamin J. Birt. 2009. Do LEED-certified buildings save energy? Yes, but. *Energy and Buildings* 41, 8 (2009), 897 – 905. DOI: http://dx.doi.org/10.1016/j.enbuild.2009.03.014
29. Donald A Norman. 2013. *The design of everyday things*. Basic books, New York, USA.
30. Brian Orland, Nilam Ram, Dean Lang, Kevin Houser, Nate Kling, and Michael Coccia. 2014. Saving energy in an office environment: A serious game intervention. *Energy and Buildings* 74 (2014), 43 – 52. DOI: http://dx.doi.org/10.1016/j.enbuild.2014.01.036
31. Daniel Pargman and Barath Raghavan. 2014. Rethinking Sustainability in Computing: From Buzzword to Non-negotiable Limits. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational (NordiCHI '14)*. ACM, New York, NY, USA, 638–647. DOI: http://dx.doi.org/10.1145/2639189.2639228

32. Shwetak N. Patel, Thomas Robertson, Julie A. Kientz, Matthew S. Reynolds, and Gregory D. Abowd. 2007. At the Flick of a Switch: Detecting and Classifying Unique Electrical Events on the Residential Power Line. In *Proceedings of the 9th International Conference on Ubiquitous Computing (UbiComp '07)*. Springer-Verlag, Berlin, Heidelberg, 271–288. http://dl.acm.org/citation.cfm?id=1771592.1771608

33. Therese Peffer, Marco Pritoni, Alan Meier, Cecilia Aragon, and Daniel Perry. 2011. How people use thermostats in homes: A review. *Building and Environment* 46, 12 (2011), 2529 – 2541. DOI: http://dx.doi.org/10.1016/j.buildenv.2011.06.002

34. James Pierce and Eric Paulos. 2012. Beyond Energy Monitors: Interaction, Energy, and Emerging Energy Systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 665–674. DOI: http://dx.doi.org/10.1145/2207676.2207771

35. Zachary Pousman, Hafez Rouzati, and John Stasko. 2008. Imprint, a Community Visualization of Printer Data: Designing for Open-ended Engagement on Sustainability. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work (CSCW '08)*. ACM, New York, NY, USA, 13–16. DOI: http://dx.doi.org/10.1145/1460563.1460568

36. James Reason. 1990. *Human error*. Cambridge university press, Cambridge, UK.

37. Tobias Schwartz, Matthias Betz, Leonardo Ramirez, and Gunnar Stevens. 2010. Sustainable Energy Practices at Work: Understanding the Role of Workers in Energy Conservation. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries (NordiCHI '10)*. ACM, New York, NY, USA, 452–462. DOI: http://dx.doi.org/10.1145/1868914.1868966

38. Tobias Schwartz, Gunnar Stevens, Leonardo Ramirez, and Volker Wulf. 2013. Uncovering Practices of Making Energy Consumption Accountable: A Phenomenological Inquiry. *ACM Trans. Comput.-Hum. Interact.* 20, 2, Article 12 (May 2013), 30 pages. DOI: http://dx.doi.org/10.1145/2463579.2463583

39. John H. Scofield. 2009. Do LEED-certified buildings save energy? Not really... *Energy and Buildings* 41, 12 (2009), 1386 – 1390. DOI: http://dx.doi.org/10.1016/j.enbuild.2009.08.006

40. Elizabeth Shove, Gordon Walker, and Sam Brown. 2014. Material culture, room temperature and the social organisation of thermal energy. *Journal of Material Culture* 19, 2 (2014), 113–124. DOI: http://dx.doi.org/10.1177/1359183514525084

41. Frans W Siero, Arnold B Bakker, Gerda B Dekker, and Marcel TC Van Den Burg. 1996. Changing organizational energy consumption behaviour through comparative feedback. *Journal of environmental psychology* 16, 3 (1996), 235–246.

42. Jonathan Simon, Marco Jahn, and Amro Al-Akkad. 2012. Saving Energy at Work: The Design of a Pervasive Game for Office Spaces. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia (MUM '12)*. ACM, New York, NY, USA, Article 9, 4 pages. DOI: http://dx.doi.org/10.1145/2406367.2406379

43. Yolande A.A. Strengers. 2011. Designing Eco-feedback Systems for Everyday Life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 2135–2144. DOI: http://dx.doi.org/10.1145/1978942.1979252

44. Evangelos Tolias, Enrico Costanza, Alex Rogers, Benjamin Bedwell, and Nick Banks. 2015. IdleWars: an Evaluation of a Pervasive Game to Promote Sustainable Behaviour in the Workplace. In *International Conference on Entertainment Computing (ICEC)*. Springer, Berlin Heidelberg, 14. http://eprints.soton.ac.uk/378861/

45. Carbon Trust. 2007. *Advanced metering for SMEs: Carbon and cost savings*. Technical Report. Carbon Trust.

46. Rayoung Yang, Mark W. Newman, and Jodi Forlizzi. 2014. Making Sustainability Sustainable: Challenges in the Design of Eco-interaction Technologies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 823–832. DOI: http://dx.doi.org/10.1145/2556288.2557380

47. Ray Yun, Azizan Aziz, Peter Scupelli, Bertrand Lasternas, Chenlu Zhang, and Vivian Loftness. 2015. Beyond Eco-Feedback: Adding Online Manual and Automated Controls to Promote Workplace Sustainability. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 1989–1992. DOI: http://dx.doi.org/10.1145/2702123.2702268