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Decreasing our demand for energy is an important component of the global effort to reduce carbon emissions. Energy consumption, both at home and in the workplace, is greatly influenced by human behaviour. Our research investigates how technological interventions could support behaviour-based energy reduction. This paper reports a Living Lab study on the co-design of a device for improving energy efficiency via behaviour change in a large public-sector organisation. We emphasise the importance of taking a broad view of organisational behaviour, highlighting the complex and indirect ways that it influences energy use. Methods and findings are reported from a series of insight and innovation workshops that we held with staff, and which led to the development of a prototype device - LILEE: The Little Interface for Lab Equipment Efficiency. We describe LILEE and discuss how it embodies wider lessons for the design of effective energy-related behaviour change interventions.

1 INTRODUCTION

Finding ways to reduce our energy consumption not only provides potential financial benefits, but also plays a key role in the global effort to combat climate change. Whilst significant energy efficiencies can be achieved through material and infrastructure improvements, there are also substantial opportunities to tackle energy reduction from the perspective of behaviour change.

The use of technological interventions as a means of facilitating behaviour change has become a familiar topic [18]. From fitness trackers to smart meters, such interventions have been shown to have mixed results in achieving their intended goals [19]. In the context of organisational energy reduction, the design of interventions for behaviour change faces specific challenges. Varying degrees of control and influence over energy use are dispersed across multiple individuals, each with differing levels of responsibility, motivation, and knowledge. Furthermore, the web of relationships and interactions between these individuals adds a layer of dynamic sociocultural complexity. In

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our view, the success of existing non-domestic behaviour change interventions is often limited due to them inadequately accounting for these complex organisational characteristics in their design.

By establishing a living lab within a large public-sector organisation, we set out to identify realistic opportunities for behaviour-based energy reduction; and to co-design a technological intervention for energy efficiency that is founded upon an awareness of context-specific organisational characteristics. This paper documents a co-design process involving three insight workshops and three innovation workshops held with staff in our living lab. We describe the resulting intervention, its deployment, and some preliminary findings from a three month pilot study. We then discuss our approach, experiences, and findings; and how these can be generalised to inform researchers and designers undertaking similar work.

2 BACKGROUND

In the UK, it is estimated that 18% of the country's total carbon emissions come from non-domestic buildings [5]. By reducing energy demand in these buildings, organisations have the potential to play a substantial role in tackling climate change. Research on behaviour-based approaches to energy reduction has tended to address individuals and domestic-settings [8, 16, 29]. This could partly be due to the fact that behaviour-based energy reduction faces additional barriers in organisational settings. These include lack of direct financial responsibility for energy bills; communal facilities and workspace; and lack of feedback on the implications of personal actions [10, 15]. A report from the Department for Energy and Climate Change (DECC) [5] notes that the term 'non-domestic' actually incorporates many sectors and sub-sectors; implying that a less generalised approach needs to be taken when dealing with organisations.

Three levels of organisational analysis have been identified in existing studies: i) institutional structures, rules and policies; ii) social and behavioural characteristics of the organisation; and iii) individual behaviours within the organisational context [1, 6]. When discussing energy consumption in organisations, authors have referred to a social-technical 'system' [7] or 'landscape' [5], comprising the interaction of social, technical, and cultural factors that influence energy use. DECC developed a conceptual framework to provide an outline theory of energy-related behaviour in organisations [5]. It specifies four domains that exert influence on the socio-technical landscape: i) material (e.g. systems and equipment); ii) market (e.g. supply chains and customers); iii) social and cultural (e.g. codes of practice and folk understandings); and iv) regulatory and policy (e.g. laws and governmental schemes). A report by the Scottish Government on the impact of workplace initiatives on low carbon behaviours concludes that:

> Addressing individual, social and material factors jointly, in a coherent and holistic programme, is essential to foster lasting change [14, p. 6].

Researchers focusing on technological solutions for behaviour-based energy reduction in organisations have also identified the need for a more holistic approach. Piccolo et al. [28] stress that interventions should take into account formal and informal levels within the organisation, such as institutional practices and the motivations of individuals; whilst Schwartz et al. [31] highlight the importance of considering 'situated energy practices'. Despite these observations, existing work has tended to narrowly focus on the use of environmental messages and energy-centred feedback as a means of motivating behaviour change [22, 29]. Yun et al. [40] identified six intervention techniques - education, advice, self-monitoring, comparison, control, and reward - all of which revolve around energy-centred feedback. Indeed, from energy dashboards [9, 16, 25, 38], to educational emails and websites [10, 27], it seems that the status quo in designing interventions for energy efficiency in organisations has been to use content relating to energy and the environment as the central driving force for change. These observations suggest that it is high time we look beyond energy-related

information and feedback as a basis for the design of interventions for behaviour-based energy saving. Perhaps a more appropriate stance is captured in an observation made at the turn of the millennium:

> [N]o one really 'behaves' in relation to energy... Devices convert energy into services; people are interested in services, not energy [36, p. 6].

In this vein, a small number of authors have recognised a need to take a more user-centred approach to designing interventions for energy reduction. Lockton et al. [24] used participatory design methods to involve building users in the design of interventions for energy efficient behaviour. They found that none of their participants emphasised the 'environmental angle' on energy reduction; instead, user-centred concepts emerged, such as peer awareness and new working practices. Foster et al. [16] ran workshops to understand people's perceptions of energy use in their workplaces, and subsequently identified six design considerations for effective interventions: incentives, engagement, openness, leadership, communication, and visualisation. Unfortunately, neither of the aforementioned user-centred studies led to interventions that were empirically tested for their impact upon energy consumption.

A few researchers have developed interventions that actively capture aspects of building users' behaviours and working practices. Casado-Mansilla et al. [11] augmented a workplace coffee machine with eco-feedback, enabling it to learn its own patterns of use and inform users whether it was more efficient to turn the appliance off or leave it on at certain times of day. Jahn et al. [20] developed a system to support energy awareness, which tracked energy consumption alongside building users' interactions with heating, lighting, and windows.

There is evidently a need for more research that gives people in organisations a say in creating technologies that are designed to influence *their* behaviour. To do this, researchers should seek to understand the characteristics of the organisational environment (and its socio-technical landscape), whilst also using collaborative and participatory design methods to engage building occupants in the co-development of interventions [8, 14, 24]. Wulf et al. [37] stress the importance of acquiring detailed descriptions of social practices prior to deploying interventions, and Lockton et al. further emphasise that this requires researchers to go beyond focus groups and "spend time working in the same environment as the stakeholders, interacting with users and observing behaviour from within rather than solely externally" [24, p. 4].

Many of these research requirements are embodied in the 'living lab' approach, which has garnered particular attention in recent years, especially in sustainability research [21, 33]. The approach involves conducting research and co-design within real-world settings, and undertaking long-term interactions with relevant stakeholders. Living labs are effective in delivering innovation projects for organisations and can be a useful framework to establish change in an organisation [4]. It has been suggested that living labs should embrace five key principles [30]:

Continuity: long-term partnerships are established, enabling trust and cross-boundary relationships to be formed.

Openness: the approach is open-minded and inclusive, incorporating contributions from a range of stakeholders.

Realism: research takes place in real-world environments, facilitating the generation of ecologically valid outcomes.

Empowerment: stakeholders are engaged in the research, shaping and contributing towards its progress.

Spontaneity: flexibility enables the research to accommodate spontaneous contributions and contextual changes.

The living lab process has been variously described as comprising three or four phases. Pierson and Lievens [30] describe a four-stage research cycle comprising: i) contextualisation, ii) concretisation, iii) implementation, and iv) feedback; whilst, in their sustainable living lab research, Baedeker et al. [3] take a three-stage approach comprising: i) insight research, ii) prototyping, and iii) field testing. There is little consensus regarding methods for conducting living lab research, and methods are often borrowed from existing disciplines, such as ethnography and action research.

The following section describes how we established a living lab within our partner organisation, and the subsequent co-design process that was undertaken, leading to the development of a technological intervention for behaviour-based energy reduction.

3 THE LIVING LAB

The Enhance project has established living labs in two large public-sector organisations in order to investigate behaviour-based opportunities for energy reduction. Due to the different nature of each organisation, this paper concentrates on the work carried out in one of the living labs, based at The University of Edinburgh - an organisation employing over 13,000 staff and operating across large estates within and around the city centre. During the first ten months of the project (September 2015 - July 2016) researchers met with managerial staff in estates, sustainability, and energy-related roles across the organisation in order to identify potential locations in which to establish the living lab. Building visits and discussions with site-specific managers allowed locations to be assessed according to a set of criteria, which included factors such as: planned infrastructure changes, existence of energy metering, and the extent of building users' control over energy use (see Webb et al. [35] for the full criteria).

Having considered numerous sites, we selected the Roslin Institute - a recently built science research institute - as the location for our living lab. The Roslin Institute was completed in 2011 and is split into laboratories and office space, the former of which make a substantial contribution to the overall energy use. The institute is based on a campus 7 miles outside the city centre, and houses roughly 400 staff and 150 students. The Roslin Institute is linked to the University finance hierarchy as a separate business unit, which means that they pay their own utility bills. This contrasts with most other institutes within the University, which have their running costs managed centrally; therefore, removing some of their incentive to achieve energy reductions. Staff at Roslin Institute have been lauded for their approaches to sustainability in the labs, but recognise that further opportunities for behaviour-based energy savings exist.

We chose to adopt a three-phase co-design process in our living lab, comprising insight, innovation, and test phases (see Fig. 1). These sequential phases are informed by those described in the living lab research of Pierson and Lievens [30], and Baedeker et al. [3] (see previous section); and are also reflective of those found in more widely adopted design cycles. According to existing definitions, the insight gathering phase involves capturing the underlying characteristics and opportunities within the living lab. The innovation phase builds upon these insights and involves the exploration of ideas and progression through to design and development of an intervention. The intervention is subsequently deployed and evaluated in the test phase. Knowledge obtained during this final phase can be fed back into an additional innovation phase, leading to an iterative cycle of feedback and development.

The following two sections describe methods and findings relating to the work we undertook during the insight and innovation phases of our living lab.

4 INSIGHT PHASE

The insight phase lasted roughly eight months (September 2016 - April 2017). The aims of this phase were to: i) contextualise the living lab (both at a local building-level, and within the wider context
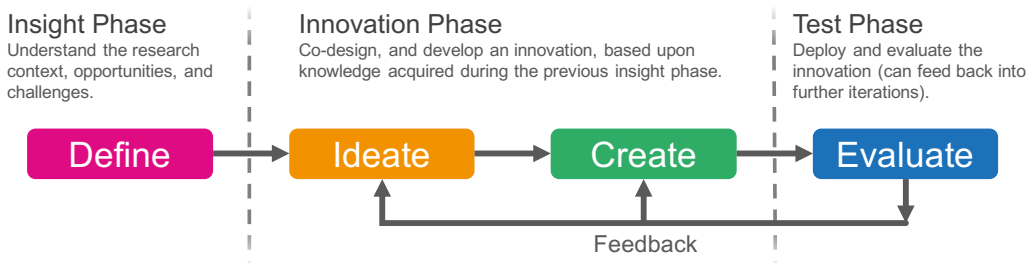
Fig. 1. The three-phase process that we are employing in our living lab.

of the organisation); ii) investigate and identify challenges and opportunities for energy saving; and iii) establish a broad understanding of people and their day-to-day working practices. This was achieved by applying a mixture of qualitative and quantitative methods, including one-to-one interviews, meetings, workshops, and the collection and analysis of energy-related data.

4.1 Initial Meetings and Interviews

During the formative stages of our Roslin Institute living lab, meetings were held with managerial staff in the building, enabling us to gain a preliminary insight into the management and use of the building in relation to its energy consumption. An initial meeting and building tour was held with the Facilities Manager (FM), who highlighted challenges for behaviour-based energy reduction in both the office and laboratory spaces. With respect to the latter, two existing concerns were raised: the efficient management of sample storage in fridges and freezers; and the efficient use of fume cupboards (for the controlled extraction of fumes during experiments). In a subsequent meeting with the FM and two lab managers, it became increasingly apparent that the large numbers of high energy use equipment in the labs presented substantial challenges and opportunities for behaviour-based energy savings.

Meetings were also held with members of the University Estates team, where we sought to gain a greater understanding of how the Roslin Institute's energy systems (heating, lighting, and ventilation) are managed. We learnt how aspects of heating and ventilation management in the laboratory spaces are directly related to the usage requirements of those spaces. For example, certain types of lab equipment require the building air extraction systems to extract air at a certain rate in order for them to be used safely. To save energy, the air extraction rate is set-back (reduced) during out-of-hours periods. However, the lab spaces are open 24/7, so determining the optimum set-back periods is not easy.

These meetings were valuable, as they enabled us to get to know managerial staff and to familiarise them with the aims of our research and the living lab process. They also enabled us to obtain top-down support for the project, as we progressed to conducting workshops with a wider cohort of staff within the building.

4.2 Insight Workshops

As a result of our initial meetings and interviews, we decided to focus on laboratory equipment related energy saving opportunities. To engage a broader group of Roslin Institute staff in discussing and exploring these topics, we designed and ran a series of insight workshops. Three workshops

were held with 17 staff members (6 in the first two workshops, and 5 in the third) who were recruited via email. Participants in each workshop were a mixture of researchers, lab technicians, and people with designated positions of responsibility in the labs, namely: 'wing coordinators', who are responsible for segments (wings) of the building's laboratories; and 'plus ones', who have supervisory responsibilities in the labs. We did not capture participants' existing knowledge of energy use in the building.

4.2.1   Method. The workshop format was inspired by the idea of a socio-technical landscape (see section 2), whereby a combination of social and technical factors shape the organisation's energy use. With respect to lab equipment, our meetings with managerial staff had already given us a sense of what some of these factors might be. We decided to use these insights to provide structure to the workshop, where staff would attempt to construct 'socio-technical maps' to represent the complex links between different factors. A card-based format was chosen, where blank 'factor cards' were prepared for the following **main**, and **influencing factor** categories.

> **Main factors:**
> **People:** individuals or groups of people who have influence over the use of lab equipment.
> **Devices:** any specific, or generalised pieces of lab equipment.

> **Influencing factors:**
> **Guidelines:** general advice or best practice (e.g. sample storage temperature guidelines).
> **Research:** research activities and commitments (e.g. publication deadlines).
> **Regulations:** rules that must be adhered to (e.g. health and safety rules).
> **Setup:** space and equipment setup (e.g. experimental settings).

The workshop was designed to last one hour, with the first half focusing on individual contributions, and the second half based around group work. Each workshop was audio-recorded to enable group discussions to be captured and analysed. The format of the first half was as follows:

(1) Staff members were given a five minute introduction to the project, its motivations and aims, and the principles of the living lab approach.

Fig. 2. Staff working on their 'socio-technical maps' during an insight workshop.

(2) Staff members were asked to individually identify types of equipment that they thought presented opportunities for energy saving, and to write them on the *device* cards.

(3) Staff shared their *device* cards with the rest of the group, and equivalent *device* cards were grouped together and ranked according to the number of cards they contained.

(4) The three most popular devices were identified and attendees were then instructed to use the *people* cards to write down individuals or groups who have influence or control over each device's use.

(5) Similarly to the previous step, staff members were asked to individually fill in at least two cards from each influencing factor category and assign them to whichever of the three devices they applied to. For example, 'defrosting on a regular basis' could be written on a *guideline* card and assigned to the device 'fridge'. To account for factors that didn't fit the supplied categories, wild-cards were also provided.

Having completed a set of *people* and influencing factor cards for each device, staff members were split into groups of two or three, and each group was assigned a specific device. The second half of the workshop comprised two tasks:

(6) Each group was instructed to arrange the *people* and *influencing factor* cards on a timeline (drawn on a large sheet of paper) with three segments: pre-use, in-use, and post-use of the device; and to draw and annotate any links between them (see Fig. 3 for an example). Participants were not instructed to perform this task according to any notions of right of wrong, since we wanted them to represent their own experiences and knowledge.

(7) During the last 10 minutes of the workshop each group was asked to verbally summarise their timelines, and to highlight any specific themes or ideas that had emerged during the process.

The timeline format was chosen to encourage staff to consider how factors beyond the immediate use of a device were also influential in determining its impact on energy use. For example, the consideration of device efficiency ratings during the procurement stage.
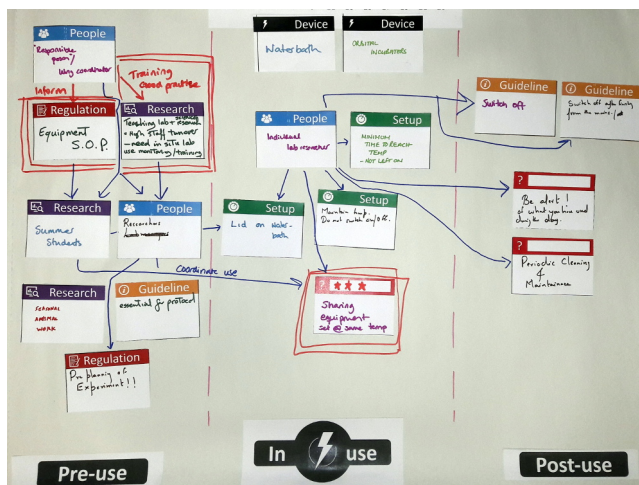

Fig. 3. Mapping people and factors that influence lab equipment use at the Roslin Institute.

4.2.2 Findings. The data collected during the insight workshops were analysed using a mixed qualitative/quantitative approach, whereby factors and pathways identified on the socio-technical maps were coded and counted to identify prevalent themes and trends. Figure 4 shows two plots that were generated from the insight workshop analyses. Figure 4a indicates that beyond the immediate user, there are many other people that have an influence on equipment use, and the point in time at which this influence is exerted varies according to the person or group. Lab users predominantly influence equipment use during the in-use phase, whilst others exert influence in the pre- and post-use phases. Annotations on the socio-technical maps enabled us to extract more detail regarding the nature of these influences. For example, principal investigators have influence by deciding which devices to purchase (efficiency vs. cost); and the times of day when certain types of equipment can be used are influenced by the University Estates Team, who manage the laboratory's ventilation systems.

Figure 4b shows factors that were identified as influencing lab equipment use. Some of these factors, such as 'switching equipment off' and 'temperature settings', apply to generic lab equipment use. As such, these factors are commonly the target of laboratory energy saving campaigns - as evidenced by 'switch off' posters and stickers distributed by the University's department for Social Responsibility and Sustainability. However, other factors, such as 'staff/student turnover' and 'equipment booking/sharing', are more context-dependent, since they are determined by the functional and organisational characteristics of the lab in which equipment is situated.

At a finer grained level of analysis, quotes and topics of interest were extracted from audio recordings of both the early interviews and insight workshops. Workshop participants emphasised the importance of taking a hands-on approach to behaviour change in the labs, stating that "it's all about presence". Specific issues were highlighted, such as the fact that "experiments are currently
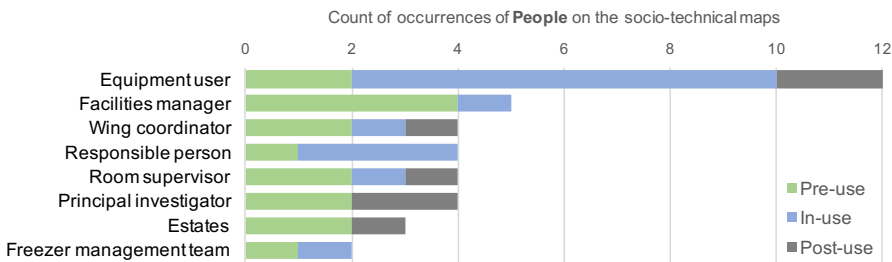
(a) A plot of the people most commonly identified as having an influence over lab equipment usage.
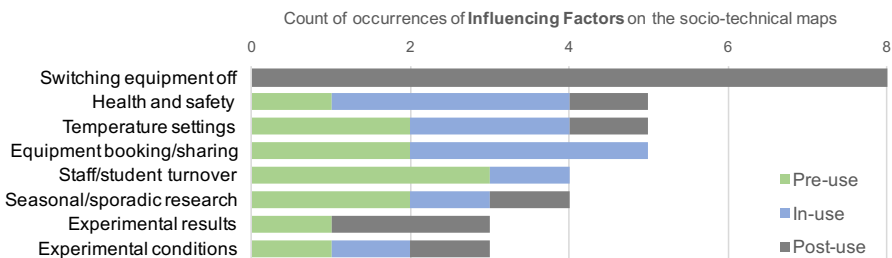
(b) A plot of the factors most commonly identified as having an influence over lab equipment usage.

Fig. 4. Example plots of data obtained from the insight workshops.

planned by individuals and are not visible to others"; and that equipment efficiency depends on "users maintaining the equipment and financial controllers upgrading it". Participants even came up with potential solutions, such as being able to "tell others what programme you're going to use, so that people can share devices".

The combined findings from our insight phase highlighted the importance of paying attention to context. From organisational structures to individual roles and personalities, we discovered that a complex array of variables determine the relationships between behaviour and energy use. These findings focused our attention on prominent areas of interest as we progressed into the innovation phase, described in the following section.

5   INNOVATION PHASE

The aim of the innovation phase was to engage staff in the process of co-designing a behaviour change innovation that could be deployed and tested in the living lab. We commenced this phase by recruiting a group of five staff members to form an 'innovation team'. Members were recruited via an email sent out to those who had attended the insight workshops, and included staff with varying levels of responsibility. Over the course of six months (April 2017 - October 2017) we ran three workshops with members of the innovation team as we progressed from ideation through to the creation of our prototype device. This section describes the workshops and their outcomes.

5.1   Innovation Workshop 1

The purpose of our first innovation workshop was to build upon insights acquired in the previous phase and to start developing design ideas for a potential intervention.

5.1.1   Method. We wanted to ensure that the insights and contributions of staff members obtained during the insight phase were at the forefront of people's minds as we started to consider innovation ideas. We also wanted to use these insights as a means of provoking ideas and discussion during the innovation workshop. To achieve this, we created a set of 'insight cards'. Each insight card was designed to highlight a specific question, theme, or finding that derived from the analysis of data from the insight phase. Two of the cards included findings from an audit of out-of-hours equipment use, which was undertaken by the facilities manager. Fourteen cards were created in total, which can be downloaded here - http://groups.inf.ed.ac.uk/enhanced/RI_Insight-Cards.pdf (see four examples in Figure 5).

To facilitate the progression from insights to design ideas, we wanted to encourage and inspire members of staff to consider alternative and novel approaches to design for behaviour change. In attempt to achieve this, we utilised the Design with Intent (DwI) toolkit - a collection of design patterns for influencing behaviour through design [26]. The DwI toolkit contains a set of 101 cards, which are grouped into eight 'lenses' that represent different design contexts or disciplines. Each card features a single question, which provokes the user to consider a particular approach to designing for behaviour change (see Fig. 6a for an example). We chose to use the toolkit due to evidence of its successful use in participatory studies on sustainable behaviour-related interventions in both domestic [23] and non-domestic [24] settings. Furthermore, each card features an everyday example to illustrate its design approach; making the toolkit suitable for use with non-designers. We sorted the cards into individual 'Designer's Toolkits', each containing 8 unique cards (one from each lens) in an envelope, with an additional instruction card.

Five members of staff attended the workshop, representing varied roles within the laboratories. During the workshop, members of the research team worked alongside the staff to facilitate discussions and assist them in progressing towards intervention ideas. The workshop was videoed
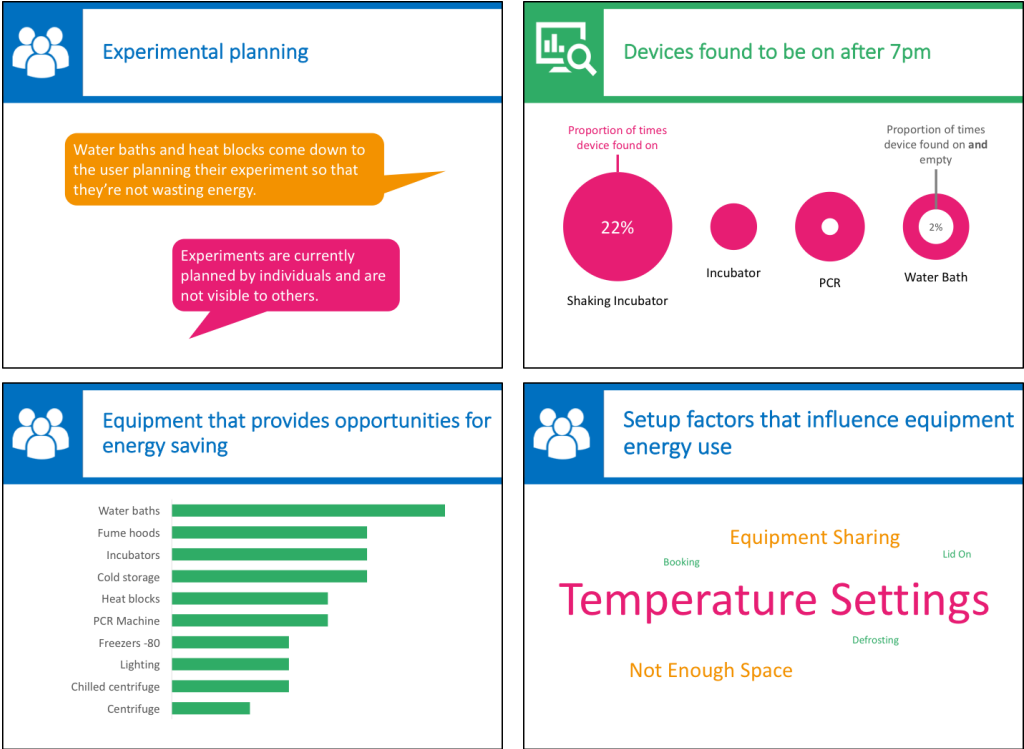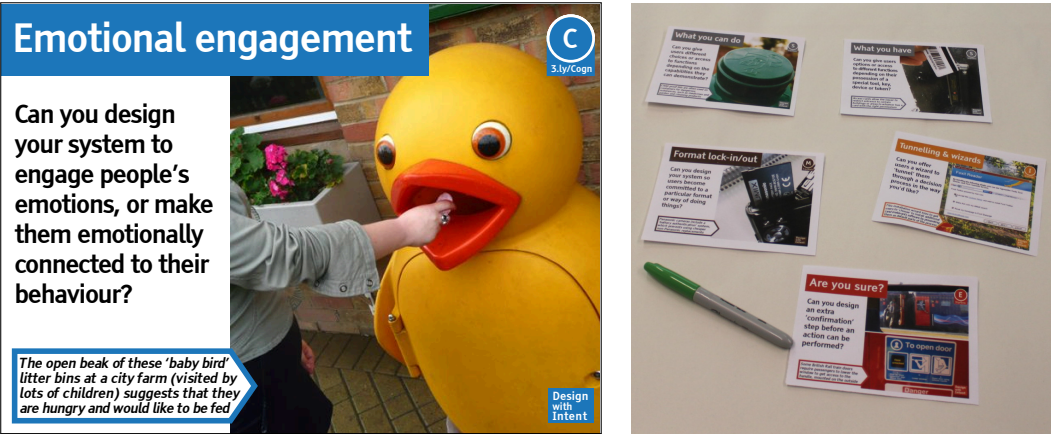
Fig. 5. An example of four Insight Cards that were used during the first innovation workshop.

(a) Example of a design pattern card.
Image: Dan Lockton - designwithintent.co.uk

(b) Cards grouped under the *control* theme during innovation workshop 1.

Fig. 6. The Design with Intent toolkit.

and audio-recorded, and photos were used to document the arrangements of insight cards and DwI cards into themes on the tables. The precise workshop format was as follows:

Hour 1:
 (1) Attendees were given a short presentation on the work undertaken so far; the overall goal of the project (to co-design a digital innovation for behaviour-based energy reduction at the Roslin Institute); the living lab process; and plans for future work.
 (2) Each attendee was given a printed booklet containing the insight cards and given roughly 15 minutes to familiarise themselves with each card and consider the questions or themes presented on them.
 (3) As a group, the attendees were given the full set of individually printed insight cards, and asked to discuss each card and arrange them on a table according to themes, ideas, or levels of interest.
 (4) The group presented key themes and ideas that they saw emerging from their consideration of the insight cards.

Hour 2:
 (1) Attendees were given a short introduction to the DwI toolkits, with an example of how one of the design patterns might be applied to one of the themes identified in the first hour.
 (2) Each attendee was presented with a Designer's Toolkit and given 15 minutes to consider each of their eight DwI cards, and whether they could apply any of the design patterns to the ideas and themes that had emerged during the first hour.
 (3) Attendees were each given an opportunity to put forward one or two of their DwI cards and discuss how they thought it could be applied to a particular theme.
 (4) The remaining time (~20 minutes) was spent discussing ideas further as a team, with the aim of progressing towards intervention ideas that could be implemented.

5.1.2 Outcomes. Over the course of the two hour workshop, progress was made from the consideration and discussion of the insight cards, to the identification of common areas of interest, motivations, and the generation of intervention ideas. By the second half of the workshop, the staff had roughly grouped the insight and DwI cards into two themes: feedback, and control (see Fig. 6b). Feedback was discussed in a broad sense, including both energy feedback and more generalised feedback relating to equipment usage. This included knowing who was currently using certain pieces of equipment; and using feedback to provide competitive and reward-based incentives for energy efficiency. The control theme was more concerned with directly influencing and controlling *how* equipment is used. This included restricting use to certain types of equipment, based on whether users were appropriately trained; providing users with advice on how to use equipment efficiently; automatically turning machines on/off; and collecting data on equipment usage as a means of influencing decision making on issues such as procurement. We found that some of most prevalent intervention ideas weren't founded upon motivations that centred on energy saving or concerns for the environment. Instead, the ideas were motivated by individual and cultural factors, specific to the socio-technical characteristics of the organisation. For example, staff were motivated by the possibility of saving time and work by automating aspects of lab equipment training and use.

By the end of the workshop, we had converged on the basic idea of a small device that could be placed alongside existing pieces of lab equipment, enabling them to be augmented with added functionality relating to the two identified themes. We also discussed the idea of this device incorporating radio-frequency identification (RFID) so that existing staff ID cards could be used as a means of identifying users and moderating access to equipment.

Subsequent analysis of the audio and video recordings enabled us to consider the themes that had emerged during the workshop in more detail. This led to the feedback and control themes being broken down into four, more specific design themes:

Monitoring: this concerns the sensing and collection of data concerning both energy and behaviours. It formed the basis of most of the *feedback-* and *control-*related innovation ideas discussed during the workshop, due to their dependency on some form of knowledge or information as an input. For example, the monitoring of lab equipment energy use to provide feedback; or of who's using equipment, to restrict access or provide advice.

Communication: this refers to an intervention's ability to communicate both behavioural- and energy-related information to/between people. It relates to the *feedback* theme that emerged during the workshop, but extends it to include multi-directional flows of information. For example, the communication required between multiple lab users in order to share equipment bookings.

Automation: the collection and processing of information via monitoring means that energy- and/or behaviour-related tasks have the potential to be automated. Energy automation was discussed as a means of achieving direct energy savings by facilitating more efficient control of lab equipment. Behavioural automation was discussed in the sense that an innovation might be capable of saving someone the task of manually processing and/or providing information. This was attractive to staff members as a means of reducing workload and improving task-efficiency.

Regulation: this theme most closely relates to the control theme and concerns the ability of an intervention to regulate or restrict aspects of energy use and/or behaviour. For example, regulating who can access/use certain pieces of equipment, or promoting standard operating procedures by providing training to staff.

These design themes were presented to the innovation team in the subsequent workshop, where they were used as a framework for considering the potential design features of our intervention.
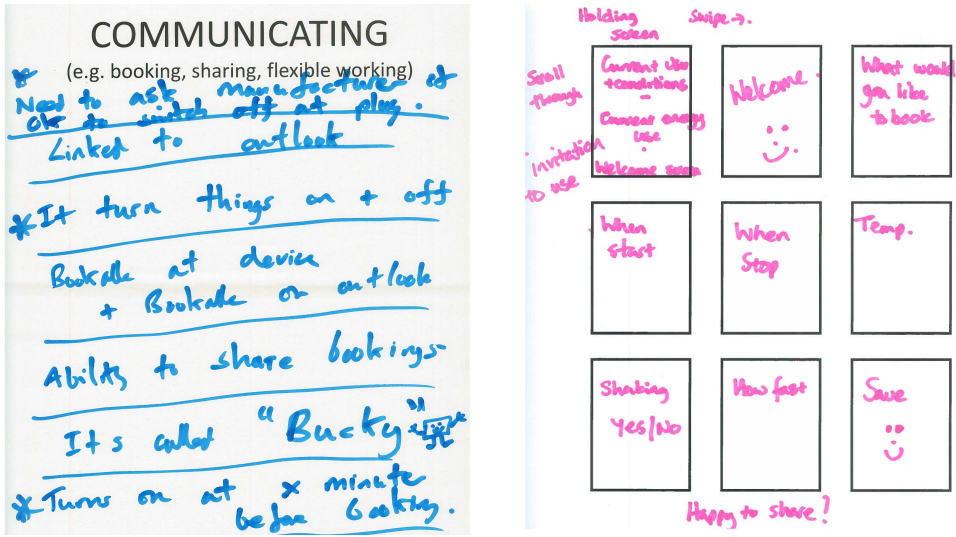
5.2 Innovation Workshop 2

The aim of the second innovation workshop was to develop the outcomes of the previous workshop towards the realisation of specific design features for a prototype device. Specifically, we wanted to build on the idea of a basic device that could sit alongside pieces of lab equipment, and to use the design themes (introduced in the previous section) as a framework for considering what the functionality of this device might be. Four members of the innovation team attended this workshop, which lasted just under two hours and was less structured than the first.

5.2.1 Method. The workshop began with a discussion about which specific pieces of lab equipment might be well suited to an intervention. Following this, we went through each of the four themes, discussing and noting down potential design features and considerations relating to each one. Figure 7a shows an example of what attendees wrote for the *communication* theme.

Having identified some initial features that could be implemented in our device, participants were asked to complete a short wireframing task. Each attendee was given a sheet with an array of blank screens (rectangles) and instructed to fill them in sequentially with potential user interface content (see Fig. 7b for an example).

During the final 20 minutes of the workshop, we went to the lab space to look at the specific pieces of equipment that the staff thought could benefit from our intervention. We also used this opportunity to fit plug-level wireless energy monitors to 10 pieces of equipment; allowing the collection of high resolution (ms) baseline data on energy consumption.

(a) Design features and issues relating to the *communication* theme.

(b) Considering the user interaction and a potential sequence of screens using wireframing.

Fig. 7. Participant worksheets from the second innovation workshop.

5.2.2 Outcomes. The main outcomes of our second innovation workshop were that key decisions were made concerning the basic functionality of our intervention, and the specific pieces of lab equipment that it would be initially designed for. Regarding the latter, shaking incubators were chosen because they are relatively high power devices (1.5kW) and tend to be used frequently (typically operational for 9.5 hours per day [2]).

The merits and practicalities of numerous potential design features were discussed in detail. These included being able to automate switching lab equipment on/off, and being able to view the energy consumed by individual pieces of equipment. However, attendees agreed that booking- and sharing-related features were of most immediate interest. We went on to discuss more specific and practical aspects of these features, such as how one might quantify the amount of shared space/capacity that they were using. The wireframing task enabled us to explore how some of these features could be presented on a basic user interface.

Our visit to the lab spaces at the end of this workshop gave us (the research team) a better understanding of how the devices are used in the laboratory. Specifically, we saw where the shaking incubators were located, how samples were arranged inside them, how settings were input, and how a paper-based (diary) system was used for equipment booking. This also allowed us to assess logistical issues, such as where an intervention device might be positioned. Finally, the installation of energy monitors meant that we could collect data on the energy consumption and times of use of different types of lab equipment. This served two purposes: facilitating the identification of existing patterns of use; and providing baseline data to compare against any post-intervention data.

5.3 Innovation Workshop 3

A very basic, semi-functional prototype was prepared for the third workshop (see Fig. 8a). We called it LILEE - the Little Interface for Lab Equipment Efficiency. The aim of this workshop was to discuss the specific features of LILEE in more detail, and to review a proposed phased-development

process for LILEE, whereby features would be incrementally rolled-out over time. The workshop lasted roughly one hour and was attended by four members of the innovation team.

5.3.1   Method. This workshop was loosely structured in comparison to the previous two workshops. We presented the attendees with the following three-phase development proposal, listing the features that LILEE could have at each phase.

Phase 1
- RFID login
- Booking functions
  - Display current users; settings (temperature, speed); and booking status
  - Create/edit bookings

Phase 2
- Sharing - display/suggest alternative devices
- Training - provide advice and standard operating procedures
- Feedback on energy use

Phase 3
- Control equipment (on/off)
- Measure current equipment state (on/off)

The selection and ordering of these features was based on the relative priority of different features, as identified in the previous workshop, and the time/resources required for development. For each phase, we went through the list of features and discussed implementation issues, practicalities, and any additional questions or ideas that participants had. We then used the LILEE prototype to discuss the physical design of the device, including the positioning of the screen, button, and RFID reader.

5.3.2   Outcomes. The final innovation workshop enabled us to finalise the detailed design features for our prototype intervention (LILEE). Attendees were satisfied with the phased approach to the development of LILEE. They suggested that an additional feature could be added in the first phase, whereby lab users could indicate during the booking process whether they were willing to share the equipment; and to potentially state how much of the equipment's capacity they were using. Staff also indicated that it would be useful to be able to scroll through future bookings so that they could see when the equipment was free.

Regarding the second phase features, attendees discussed the behavioural aspects of getting people to share equipment, highlighting that some lab users have preferences for particular pieces of equipment, which might limit their willingness to use alternative devices. Staff also re-iterated their interest in receiving some form of feedback relating to the energy used by the equipment. This included being able to see how much energy they had used over the course of their own bookings, and being able to compare the impact that different equipment settings had on energy use.

In general, attendees liked the physical design of the prototype device, but suggested that a touch screen interface would be easier to use. They also expressed the importance of providing sufficient information on how to use the device, prior to its deployment in the labs.

6   LILEE: A PROTOTYPE INTERVENTION

The idea for LILEE surfaced over the course of the first innovation workshop. It was inspired by findings from the insight phase of our living lab, where staff highlighted a wide range of factors that influence the use of equipment in the laboratories. These factors - such as coordinating equipment bookings, and training new lab users - presented opportunities, not just for energy saving, but also to improve the staff's working efficiency. By creating a small, low-cost, networked interface that

(a) Initial prototype with a small screen and rotary button on the side.

(b) Current prototype with a larger, touch-screen interface.

Fig. 8. LILEE device prototypes.

could sit alongside equipment in the laboratories, LILEE was conceived as a means of addressing multiple issues relating to lab equipment management and use.

The current LILEE prototype (Fig. 8b) was completed in March 2018, and two LILEEs have since been deployed in one of the laboratories for an initial test period. This section describes the design specifications of the current LILEE prototype; the process involved in deploying LILEE; and some preliminary test results on usage and energy consumption.

6.1 Design Specifications

6.1.1 Hardware & Software. LILEE's hardware comprises a Raspberry Pi Zero W computer with Wi-Fi capability; 3.5 inch resistive touch screen LCD; and RFID module - all housed within a custom 3D printed case. The total cost per device is less than £50. The software is written in Python, and uses Kivy - an open source Python library - to drive the graphical user interface. The booking functionality is provided by Booked Scheduler - an open source, web-based, resource scheduling system - which is hosted on a central server. The LILEE software utilises an open API to interact with the booking server.

6.1.2 Functionality. The current prototype features the RFID login, and booking features listed in Phase 1 of the development plan (see section 5.3.1), and the sharing features from Phase 2. These features were selected as being of most immediate interest by participants during innovation workshop 2 (see section 5.2.2). A basic usage scenario is as follows:

Login/signup: To begin using a LILEE device, the lab user simply taps their staff card on it. If they don't already have an account then they are taken through steps to create one; otherwise they are taken to a home screen.

Home screen: The home screen gives the user three options: view their bookings (where they can also delete bookings); make a new booking; or logout.

Make a booking: If the user decides to make a new booking then they are taken through a series of screens where they enter the date, start time, end time, equipment settings, and the amount of space (%) that they intend to use (see Fig. 9b).

Sharing options: Once the user confirms their booking, LILEE will attempt to find an option to share the proposed booking with existing bookings (firstly on this device, then on equivalent nearby devices). If a shared booking is possible then the user is given the option to review this shared booking (Fig. 9c and Fig. 9d). If no shared booking is possible and the device is free, then the booking is made. If the device is not free then the user is shown the clashes and given the option to edit their booking.

When nobody is logged into the LILEE, it displays a holding screen (see Fig. 9a), which shows the current status of the device ('in use' or 'not in use') and the details of the next three bookings (times, users, settings, and available space). The booking website allows users to view and delete their bookings, but does not allow them to make or edit bookings. This is due to the fact that the sharing functionality of LILEE is implemented on the device itself, and does not exist within the Booked Scheduler software.

6.2 Deployment & Testing

The final phase of the living lab process is the test phase (see Fig. 1). Whilst this phase is still ongoing, we have deployed and tested two LILEE devices in our living lab over a three month pilot period. This section describes the process of deploying the devices, and some preliminary results from the pilot.

6.2.1 Deployment. Prior to deployment, a meeting was held with members of the innovation team so that we could discuss the deployment process, and give them an opportunity to review the current prototype. During the meeting we decided that we would install the two LILEE devices on two adjacent shaking incubators that had been previously fitted with plug-level energy monitors. Some small changes to LILEE's interface were suggested, such as using the phrase 'sharing is caring' on the share setting screen (Fig. 9b). We chose to give all staff one week's notice of the deployment, which was given via an email containing information and instructions on LILEE as well as information about the Enhance project. We also created 'LILEE enabled' stickers, which
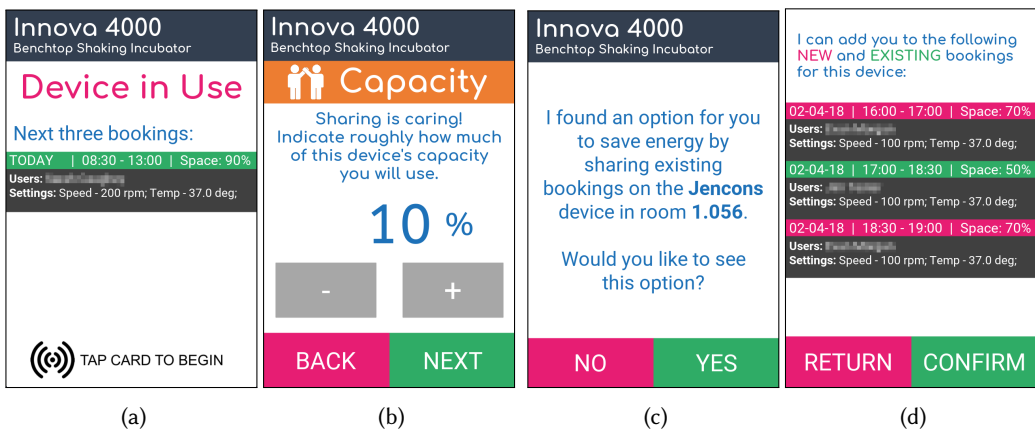

Fig. 9. Screenshots of LILEE's (a) holding; (b) share setting; (a) sharing option; and (d) shared booking screens.

were attached to each shaking incubator to notify users that the equipment was bookable using LILEE (see Fig. 10).

6.2.2   Testing. Each LILEE device creates logs of user interactions and uploads them to a database, facilitating detailed usage analysis. Over the course of the three month test period, 22 lab users signed up to use the LILEE devices and made a total of 91 bookings. 28 of the bookings were shared bookings, of which 27 were booked on the shaking incubator that the user originally intended to use, and 1 was the result of LILEE identifying an option to share on the adjacent incubator. When presented with the option to share a booking on the same incubator that the user was attempting to book, users accepted this option 93% (27/29) of the time. When given the option to share an existing booking on the adjacent incubator, users accepted this 7% (1/14) of the time. These early results are promising, as they indicate that users are willing to accept the sharing options proposed by LILEE. Even if only a small percentage of potential equipment bookings are avoided due to the identification of sharing opportunities, this still has the potential to have a substantial impact on lab equipment energy use.

The booking logs for this period are also useful in allowing us to investigate how the lab equipment is being used. The average booking duration was 9 hours and 53 minutes; and according to the sharing settings entered by users, the devices were used, on average, at only 21% of their total capacity. As discussed during our insight and innovation workshops, these types of data are valuable, since they can help inform and justify decision making at higher levels of the organisation, such as procurement. In this case, a continued indication of shaking incubators not being used to their full capacity could be used to justify the purchase of smaller, more efficient incubators.

With respect to energy consumption, baseline energy data for the two shaking incubators were collected over roughly 3800 hours[1] between July 2017 and March 2018. Table 1 shows results that were obtained by comparing these data with roughly 1450 hours[2] of data collected over the three-month testing period. The results show that the average energy consumption of both shaking incubators has dropped substantially since the deployment of the LILEE devices. Whilst these

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[1]Data recording failed between November 2017 and February 2018.

[2]Data recording failed over 12 days, and a two week holiday period was removed to avoid positively skewing the results.

Fig. 10. A LILEE device wall-mounted alongside a shaking incubator.

Table 1. Mean hourly energy consumption before and after LILEE deployment

	Mean hourly consumption	
	Before LILEE	After LILEE
Shaking incubator 1	0.34 kWh	0.14 kWh
Shaking incubator 2	0.68 kWh	0.42 kWh

results are promising, they could also be influenced by unrelated decreases in equipment usage owing to factors such as sporadic and seasonal research.

As our test phase continues, additional quantitative usage and energy data, along with feedback from staff, will assist us in further evaluating LILEE. Additional features, such as those described in phases 2 and 3 of our development plan, will also be developed, deployed, and tested in a continued engagement with the living lab.

7 DISCUSSION

In existing organisational energy efficiency research, authors have highlighted the importance of understanding organisational characteristics, and engaging building occupants when designing behaviour change interventions [8, 14, 34]. Unfortunately, there appears to be very little literature investigating or evidencing how this can be achieved in practice. A handful of recent studies are notable for adopting participatory design and user-focused approaches to intervention design in the workplace [8, 11, 13, 25]. However, these studies tend to be limited in one or more of the following areas: their investigation of the organisational context; the extent to which users are involved in the design process; and their ability to report quantitative evaluations of the intervention's impact on energy consumption (especially long-term). Our living lab research set out to address these limitations through a three-phase approach: i) acquiring a detailed understanding of the organisation's socio-technical landscape (insight phase); ii) engaging building users in a long-term process of co-design (innovation phase); and iii) undertaking thorough testing of the resulting intervention (test phase). In this section, we consider our experiences and findings from each of these phases, and discuss how these could be generalised to inform wider research on design for behaviour-based energy reduction. We focus our discussion on three areas: understanding the organisation; transitioning from insights to innovation; and learning lessons from LILEE - our co-designed intervention.

7.1 Understanding the Organisation

The main aims of a living lab's 'insight phase' are to understand and contextualise the living lab, whilst also identifying opportunities for innovation. Openness - one of the key living lab principles - is important during this phase, enabling the consideration of varied viewpoints from a range of stakeholders. In our case, we met with management and members of staff in positions of responsibility prior to engaging with a broader cohort of building users. We found that this top-down approach had two key benefits: i) it allowed us to garner high-level support for the project; and ii) it informed the design of the subsequent insight workshops, and enabled us to facilitate them with a degree of shared understanding.

Our insight workshops were designed to explore links between behaviour and lab equipment usage through the creation of socio-technical maps. This approach bares similarities to the 'system diagram' method described by Lockton et al. [24], where building occupants were asked to draw arrows to connect and attribute responsibility for energy use between various people and groups. Again, we wanted our insight workshops to embrace key principles of the living lab approach -

openness and empowerment. We found that incorporating individual and group tasks empowered all staff to contribute personal ideas and opinions, whilst also encouraging discussion and reflection between colleagues. Openness was achieved using large sheets and cards for participants to arrange and write on, meaning that ideas were exposed for all attendees to view, comment, and contribute. This also brought a degree of materiality and flexibility to the tasks.

The findings from our insight workshops serve as an example of the behavioural complexities of organisational energy consumption. Even with a comparatively narrow focus on lab equipment-based energy use, we discovered a wide range of people and factors that exert influence. These extend beyond the Roslin Institute to incorporate the larger organisation, with the inclusion of university-wide policies and estates management decisions. In addition to this, our interviews and workshops helped us identify specific details about the working practices and motivations of different stakeholders.

The methods employed during our insight phase demonstrate a successful means of capturing context-dependant intricacies of organisational energy use, which could be of value for researchers and designers undertaking similar work. In our case, they provided a strong foundation from which to progress towards the co-design of interventions.

7.2   From Insight to Innovation

One of the main aims of our research was to take a user-centred approach to designing interventions for energy reduction. The living lab approach facilitates this by involving stakeholders throughout both the insight and innovation phases of technology development. However, managing the transition between these phases is not something that we have found to be widely addressed in the literature. In our case, we faced two challenges: i) there was a gap of around two months between the insight workshops and the first innovation workshop; and ii) different insights were collected across the interviews and three workshops. We developed and utilised insight cards, in part, to address these concerns. The cards were effective in both reminding staff of prominent insights, and facilitating open discussion and sorting of insights into themes and issues. Such an approach could be adopted more generally by researchers attempting to progress between insight/requirement gathering and ideation.

During our first innovation workshop, we chose to utilise the existing DwI toolkit to empower our workshop participants (who did not necessarily have previous design experience) to have the confidence to contribute ideas, and to consider less familiar approaches to designing for behaviour change. We found that the cards were successful in aiding participants to identify novel design patterns and concepts that could be incorporated into our intervention ideas.

The basic idea for LILEE emerged in our first innovation workshop. At this stage - as a small, screen-based interface to sit alongside lab equipment - it was seen as a blank slate on which to address the themes of feedback and control that had emerged from insight card and DwI toolkit tasks. The development of LILEE towards a functional prototype was achieved during two further innovation workshops, in which staff took ownership by shaping detailed aspects of the design - from the specification of features, to the layout and wording of individual screens. Each of these workshops incorporated references to the outcomes of preceding workshops, providing a sense of continuity and value in the work undertaken.

In summary, our main consideration during the transition from insights to innovation was to ensure that stakeholders experienced continuity, ownership, and empowerment throughout. Whilst we didn't formally evaluate our approach, staff appeared to enjoy and engage in the workshops, and we could not have progressed to the deployment of LILEE without their involvement.

7.3 Learning from LILEE

LILEE was borne from a desire to develop an intervention that was founded upon an in-depth understanding of the organisation, and a co-design process that involved relevant stakeholders throughout. Whilst LILEE's design is constrained to a specific context, we believe that generalised lessons can be learnt from the co-design process that led to LILEE, and from the themes that are embedded within its design.

Four design themes were identified in our analysis of the first innovation workshop: monitoring, communication, automation, and regulation (see section 5.1.2). LILEE's design embraces all of these themes: it *monitors* lab equipment use; facilitates *communication* between lab users regarding equipment sharing and booking; *automates* the process of identifying potential sharing options; and *regulates* access to its features via its RFID reader. Whilst LILEE's design is constrained to a specific context, these themes could be generalised to inform wider research on designing energy-related behaviour change interventions. **Monitoring** forms the basis for measuring and understanding complex socio-behavioural and technical variables within the organisation; **communication** serves to distribute this information amongst networks of relevant stakeholders; **automation** can save manual work and improve efficiency, and has been show to improve energy savings in previous research [39]; and **regulation** enforces organisational structures, rules, and policies. We would advise researchers and designers undertaking similar work to try using these themes to frame different design considerations, but to also ensure that design decisions are supported by the identification of meaningful motivating factors and an underlying potential for energy reduction. Once again, this comes back to the need for intervention design to be founded upon a detailed understanding of the organisation.

An important benefit of acquiring an understanding of the organisational context prior to the development of LILEE was that it enabled us to identify common motivating factors within the organisation. These were rarely centred upon energy use or concerns for the environment, and were more focused on the improvement of working practices. By bearing an indirect relationship to energy use, these motivations are interesting in their potential to provide incentive for behaviour change, where energy saving is not the core motivation, but is instead achieved as associated impact (or intended side-effect) of the modified behaviour.

These observations resonate with those of Castelli et al. [12], who found that people were interested in energy information that could help them increase their work effectiveness, rather than economic- or environmentally-based feedback. Additionally, in a recent review of interventions for behaviour-based energy saving, Staddon et al. [32] found that the most successful interventions were those that created social and physical opportunities for staff to save energy. The potential merits of a user-centred stance can also be seen in commercial approaches to technologically driven behaviour change. For example, Tesla Motors' success in entering the market for electric vehicles can be partly attributed to them changing consumers' opinions of electric vehicles as golf carts and milk floats, by offering them attractive and high-end features; such as high speed and acceleration, bold looks, and low running costs [17].

8 CONCLUSIONS & FUTURE WORK

Tackling environmental issues, such as the reduction of greenhouse gas emissions, requires input from a broad range of disciplines. While we seek technological solutions to these issues, we must not lose site of the importance of involving and understanding people. The socio-cultural complexities inherent in large organisations make this especially challenging. By adopting a living lab approach, our research investigates whether the in-depth involvement of organisational stakeholders in a process of co-design can lead to the development of effective interventions for behaviour-based

energy reduction. The work presented in this paper documents a successful co-design process, from the inception of the living lab, through to the deployment of an intervention. In doing so, the paper contributes novel approaches, such as the use of socio-technical maps (section 4.2) and insight cards (section 5.1); and highlights methodological considerations at different phases of the co-design process. A major theme of the reported findings is an emphasis on the importance of organisational context: firstly, in identifying appropriate challenges and opportunities for energy saving; and secondly, in establishing widely held motivations that extend beyond both individual- and energy-focused motivations.

The test phase of our living lab is still ongoing, with further development phases planned, and an intention to deploy LILEE devices more widely across the labs. This continued work will enable us to evaluate, both qualitatively and quantitatively, the extent to which LILEE impacts upon energy efficiency within the organisation. We will also continue to review how our experiences and findings, such as the themes identified in section 5.1.2, can be framed more broadly as guidelines and recommendations for the design of behaviour-related interventions for energy saving in organisations.

ACKNOWLEDGMENTS

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