‘A bit like British Weather, I suppose’ Design and Evaluation of the Temperature Calendar

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ABSTRACT
In this paper we present the design and evaluation of the Temperature Calendar – a visualization of temperature variation within a workplace over the course of the past week. This highlights deviation from organizational temperature policy, and aims to bring staff ”into the loop” of understanding and managing heating, and so reduce energy waste. The display was deployed for three weeks in five public libraries. Analysis of interaction logs, questionnaires and interviews shows that staff used the displays to understand heating in their buildings, and took action reflecting this new understanding. Bringing together our results, we discuss design implications for workplace displays, and an analysis of carbon emissions generated in constructing and operating our design. More in general, the findings helped us to reflect on the role of policy on energy consumption, and the potential for the HCI community to engage with its application, as well as its definition or modification.

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Sustainability; Public Displays; Buildings; Energy; Workplace; Visualization

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. As a consequence sustainability, and more specifically energy consumption, has attracted increasing attention from the HCI research communities, with the aim to try and apply interactive technology to address such a challenge.

Much prior work has focussed on *motivation*: persuading individual end-users to change behaviour in order to reduce consumption [16, 21]. More recently, there have been several calls for the HCI community to extend its focus beyond persuasion, mostly through well argued position papers, and literature meta-reviews [11, 4, 19, 25, 28]. Critiques suggest that the role of HCI is to create flexible environments where end-users can understand and critically engage with sustainability, and redesign their practices in response [19]. This may require both profound changes to personal practices that might only be achievable at key “life transitions” [8], and profound changes to the accepted norms in communal settings, e.g. moving from the pursuit of building-wide “room temperature” [34] to allowing occupants in large buildings to pursue individual subjective comfort goals [7]. Our work speaks to this latter opportunity, exploring the application of interactive technology to sensitise occupants to their shared environment – in this case a workplace – encouraging them to understand and critique the way resources are used to maintain working conditions, and ultimately to take action to reconfigure the space. In line with calls outlined in recent literature, e.g. [1], our study does not advocate for interactive technology to be *the* solution, rather for it to be part of the solution – in this case implicating organizational policy, culture, and a number of practical constraints.

Our focus is on the workplace and its occupants as a context for new sustainability research. Much of the HCI research community’s understanding of sustainability and sustainable behaviour is built upon studies of the home, e.g. [6, 10, 36]. In contrast, energy usage in non-domestic buildings has been relatively overlooked [30], and the workplace has been highlighted as a distinct setting that could be a necessary and fruitful target for further research (e.g. [24, 15]). Although some work has been carried out to understand the unique tensions and barriers to sustainable behaviour in workplaces (e.g. [23, 15]), little empirical work with workplace occupants has been reported in the literature to date [2]. While most commonly prior work focussed on the display of energy consumption data, our own research builds on work around the relationship between energy and temperature [2, 7], which suggests that temperature may be a useful frame for engaging office staff in energy issues.

As an endeavour in this direction, in this paper we present the Temperature Calendar, its design process and its field evaluation. The Temperature Calendar is a public display which shows the indoor temperature variations in different parts of a building over the course of the past seven days. It highlights

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compliance with and deviation from the temperature policy, and it leverages the visual metaphor of a diary planner with the aim to be easily legible by users who are not technically trained. The display was developed with the close involvement of stakeholders in the Southshire council, a UK district council (a regional government body), and it was deployed in five Southshire public libraries over the course of 3 weeks. Experimental data, collected through a combination of quantitative and qualitative methods (post-trial interviews, online questionnaires, interaction logs and temperature traces), revealed that the Temperature Calendar was successful in attracting the attention of library staff. Displaying historical indoor temperature information and prompting staff to relate it to the organization policy around it had the effect of encouraging them to reflect on the operation of the building and its infrastructure, leading them, in some cases, to take practical action to lower or raise the temperature in their building. More in general, the findings from the deployment of the Temperature Calendar helped us to reflect on the role of *policy* on energy consumption, and the potential for the HCI community to engage with its application, as well as its definition or modification.

RELATED WORK

Considerable attention has been given within the HCI and Ubicomp literature to "Ambient Displays" – defined as displays "designed to be minimally attended and perceivable from outside of a person's direct focus of attention, providing a level of pre-attentive processing without being unnecessarily distracting" [20]. Hazlewood et al. (ibid) offer a comprehensive review of work on this topic. Our work differs from ambient displays in that it is directed at users explicit attention. Closer to our work, Valkanova et al. [38] report the design and evaluation of *Reveal-it!*, a public display that shows a comparison of self-reported energy consumption. Results from 3 deployments in public locations for a total of 20 days suggest that the display was largely successful in engaging the audience in reflecting about their own energy consumption, comparing it to the consumption of others. Our work is similar to *Reveal-it!*, in that both are public displays related to energy, and both require users' explicit attention. However, our approach is different in several ways: first our emphasis is on sensor data, rather than self-reported; moreover, while our display is also public, it refers to one specific building and its users, rather than the general public.

Public or communal displays have been used to engage inhabitants of both domestic and work environments. There is now a significant body of work that describes interventions that seek to reduce domestic energy consumption, including reviews from academic [14] and policy-maker [9] points-of-view. However, reviews of interventions "beyond energy monitors" highlight the work environment as an under-researched setting [30] - our research closes this gap by introducing a novel workplace display. Some off-the-shelf displays exist for workplaces, e.g. the LEED Dynamic Plaque[1], revealing the performance of buildings against benchmarks. Researchers have also explored displays that incorporate a

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

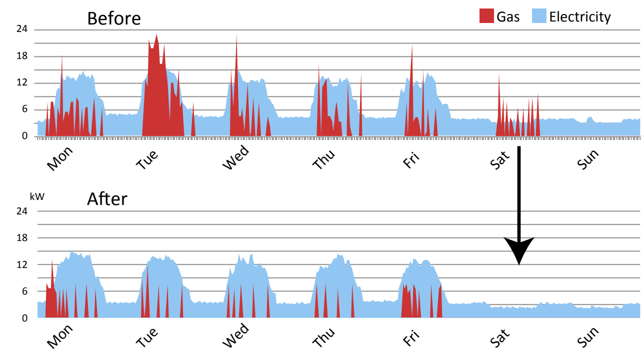

Figure 1. The change in gas usage patterns before (top) and after (bottom) reporting that the building was being heated for an extra day, compared to corresponding electricity usage (from [2], with permission).

range of feedback strategies, including comparing the energy efficiency of teams in a production setting [35], tracking and visualising individuals' resource use in offices [31], and playfully identifying wasteful individuals such that they can be "busted" [37]. As recent research highlights, these displays are limited in that they often target energy consumption related to individual employees and can lack real-world evaluation [2]. The sustainable HCI community has been criticised for a focus on the individual, limiting the potential to address broader energy savings [25]. In line with this, our display reveals patterns in communally-used energy – space heating – via workplace indoor temperature.

Heating accounts for a significant proportion of workplace energy costs – between 20-40% in office-based organizations [5] – and is linked to the comfort of staff. Milenkovic et al. have demonstrated that – using traditional heating controls – staff typically feel low levels of control over their personal comfort, and have developed POEM – a smart alternative [26]. Other smart solutions have been proposed [19, 12], and research suggests that pursuing personal comfort may reduce collective energy consumption [7], but such proposals are complicated to implement and as yet have little hard evidence to demonstrate impact. Indeed, critiques within the sustainability research community encourage us to carefully consider the implications of focusing on new technologies as the solution for sustainability [1]. Specifically researchers have been called to weigh the costs and benefits of interventions [28]. We address these critiques by exploring uses for public workplace displays as a means of encouraging staff to collectively address significant communal energy consumption, and demonstrating how the low energy costs of this new technology is offset by the resulting energy savings.

DESIGN PROCESS

Motivation

Our design was motivated by recent work about energy consumption in the workplace that highlighted *errors* related to energy waste as an under-investigated issue in sustainable HCI, at least in terms of explicit focus [2]. Bedwell et al. (Ibid.) highlighted instances of errors in selected prior HCI work. Examples include participants from a domestic smart thermostat study realizing that their air conditioning was left *on* when they are away from home, thanks to the study interviews [39]. Or researchers pointing out that in some workplace small appliances like phones and task lights tend to be left on out of office hours, and hence showing that savings can be achieved by programmatically turning them off [40]. Other examples include studies of domestic heating showing that misconceptions of heat and heating systems can lead to constantly and inefficiently heating the home, rather than heating on demand [29].

Bedwell et al. (Ibid.) also provide additional evidence from workshops conducted with different stakeholders from a workplace, as well as from the analysis of energy consumption logs. Qualitative data from their workshops highlights the challenges for any members of staff to understand how energy is used in the workplace, because of the complexity of the building infrastructure. Their analysis of gas and electricity consumption data revealed specific instances where energy was wasted because of errors in the heating and domestic water infrastructure. It is worth underlining how such wastage was not related to anyone's *comfort* or *convenience*, factors normally understood as drivers of consumption [33, 7, 34], and often the main target of sustainable HCI interventions, which often aim at convincing end-users to sacrifice their individual comfort in favour of the environment.

Building on these findings, we see potential for interactive technology to help identify and rectify such errors. In this context, we found it helpful to refer to Don Norman's classic work on modelling people's interaction with interactive systems, the "action cycle" [27]. One of the key ideas being that errors can be related to people's difficulty in reading the status and operation of a system, generally because the system is not not legible enough – a situation Norman names as "the gulf of evaluation". The implication then is that good design should reduce such gulf of evaluation, making the system operation and status easily visible and legible. In our context of study, the system is the entire building and its infrastructure,

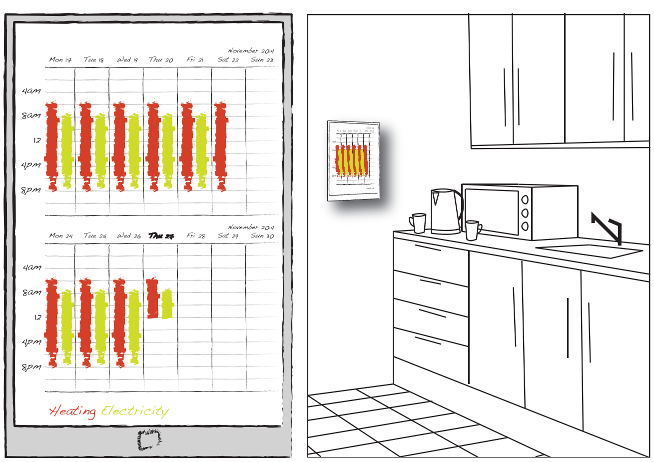

Figure 2. Initial concept sketches for the Temperature Calendar. On the left, the visualization on a tablet, showing electricity and gas consumption data over two weeks. On the right, the tablet on the wall of a communal office space, such as a kitchen.

so we decided to explore the opportunity to make the buildings operation more clear and accessible to its inhabitants.

In particular, our hope is that by visualizing (some of) the building operation, occupants might gain a better understanding, enabling them to detect errors or problems, and possibly act upon them. In some cases such action may not be in direct terms, as often building inhabitants (e.g. employees) may have limited or no control over the infrastructure settings, which may be instead operated by facility management and engineering services internal or external to the organization [18]. Still, increased understanding, or even data to substantiate requests for changes, should be beneficial in supporting the dialogue or negotiations between the inhabitants and facility managers.

Initial Concept

The initial concept for the Temperature Calendar builds quite directly on the analysis of energy consumption logs reported by Bedwell et al. [2], and mentioned above. They reported a mismatch between gas and electricity consumption logs in an office building, as illustrated in Figure 1. It was noticed that electricity consumption followed a standard pattern from Monday to Friday, while being off on the weekend, suggesting that the building is not used on Saturday and Sunday. However, gas consumption was found to be non-zero on Saturdays, suggesting a possible waste. Indeed as confirmation that this was just a mistake, the researchers report that the situation was rectified once they notified the organization, confirming this was indeed an error.

Based on the original report of mismatching gas and electricity consumption logs, we explored a design concept for a visualization of such data that could attract the attention and be easily *legible* by office staff. A key goal was to make the display intelligible to those who may not have technical training (and hence could be put off by traditional time series displays) but who would be familiar with the everyday activities, comings and goings of other inhabitants. We decided to use a representation of time that is commonly found in offices (and office software): the calendar. Like in many offices, staff in Southshire use both personal and communal calendars to coordinate activities, book rooms and equipment, and audit performance. As such, the calendar is a visualization that seems to have an established role amongst our end-users as a tool for critically engaging with the management of their work-life.

The initial concept, illustrated in Figure 2 (left), involved displaying gas and electricity consumption data alongside each other as colourful visual patterns on columns of a weekly planner, covering the most recent past 1 or 2 weeks. Such a display could be installed on a wall in a shared area within an office environment, such as in a kitchenette or near a water dispenser (see Figure 2 right), where it would be easily visible.

Iterating with Stakeholders

The initial concept was then developed with the aid of our partner or "user" organization, the Southshire council. Gas

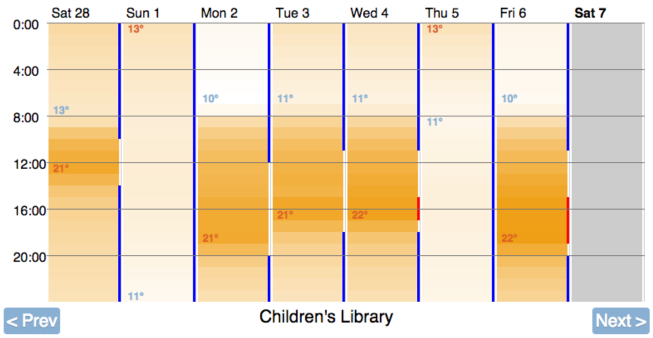

Figure 3. A screenshot from the first prototype of the Temperature Calendar.

consumption can often be difficult to measure, as it generally requires the installation of flow sensors inside gas pipes, or using a camera pointing to a traditional gas meter: discussions with the council highlighted that these would be impractical to set up. The gas information, then, was replaced by indoor temperature. Not only is temperature easier to record, but it can also be more informative than gas consumption, as it relates more directly to occupants' thermal comfort, and it is generally easier for people to make sense of it. Temperature is the experienced "effect" of heating.

We presented our sketches to the council to get their feedback and buy-in, as we looked for concrete opportunities where the display could be deployed and evaluated. In particular, our main interlocutor has been the council's energy team, whose remit includes trying to optimise the organization's performance in terms of energy consumption. The council stakeholders reacted very positively to our suggestion to display temperature, and they suggested to relate the display to their existing "temperature policy". In the Southshire council (as in other organizations [34]) an organizational policy is in place defining what temperature the buildings should be kept at. As such, an additional design goal emerged: to draw attention to the temperature policy, and encourage staff to engage with it locally.

The electricity consumption information is used as a convenient proxy measure for activity in the building: in [2], this data was used to infer when the building was or was not "in use". Alternative, and more direct, measures of human activity could be be used instead, such as information coming from motion detection sensors, which are already installed in many buildings for security. Such alternatives would be necessary in cases where electricity is used also for heating or cooling, or by automated processes unrelated to building occupancy (e.g. server farms).

Setting: Public Libraries

The council highlighted public libraries as locations of interest, based on their own analysis that suggested that local operation of heating, ventilation and air conditioning is attempted in an ad-hoc and somewhat piecemeal nature – potentially affecting both energy costs and thermal comfort – plus interest from library staff towards initiatives to manage working conditions more effectively. It should be emphasized that even though these buildings are (in part) open to the general public, our main focus is in particular on the library staff, given that they occupy the building on a much more frequent and regular basis. The library buildings do not have a resident building manager. This role is held by a central team within the organization. Each library has one supervisor, who is the line manager for all other staff, and is generally responsible for the day-to-day running of the structure.

The Temperature Calendar Prototype

In the process of developing the prototype, a decision was made to begin simply by visualising temperature rather than temperature *and* electricity consumption. It emerged that while electricity consumption is monitored in libraries for auditing purposes, the data is only available through a reporting system one or two days later. As a result, any reflection on the visualised data would be significantly delayed from behaviour that had led to that consumption. The addition of new equipment to collect detailed consumption data was also impractical, requiring significant intervention into the library electrical systems by qualified (and Council approved) technicians.

At the same time, discussions with library staff demonstrated that staff had a good understanding of the daily activities and routines, and could anticipate staff occupancy, without necessarily needing data to highlight them. As such, it was decided to develop an initial prototype of the display based only on the temperature data – a data stream that could be collected without intervention into the library infrastructure – leaving electricity consumption out.

The Temperature Calendar displays the temperature for the past 7 days, hour by hour, with a format similar to a week diary planner, as illustrated in Figure 3. Each column corresponds to a calendar day, labelled on the top, with the rightmost column corresponding to today. Each column is divided into 24 cells, corresponding to the hours of the day, these are labelled on the left at 4 hour intervals. Each cell is coloured according to the average temperature recorded for that hour, on a colour scale that goes from white to orange, corresponding to the minimum to maximum temperatures for the 7 days displayed. The minimum and maximum daily temperatures are indicated on each column with numerical labels in grey or red, respectively. These labels also aim to provide a reference to more easily interpret the colour gradient on the display. Cells are highlighted with a blue or red coloured vertical bar on the right, to indicate that the temperature was respectively below or above the range prescribed in the council temperature policy.

The system can show data from more than one sensor, to monitor the temperature in different parts of the building. Each sensor is displayed on a separate screen/page – the label on the bottom of the screen indicates the sensor currently displayed. Every 5 minutes, the display automatically changes to a different sensor, in a rotation. Users can manually cycle through the different sensors using the "prev" and "next" buttons on the bottom left and bottom right of the display.

Location	Intervention	Staff	Floors	Sensors
Donton	Temperature Calendar	5	1	3
Hiltam	Temperature Calendar	6	1	3
Knotton	Temperature Calendar	8	2	4
Tielby	Temperature Calendar	19	4	5
Wertam	Temperature Calendar	5	1	5
Pulfort	Thermometers	2	2	2
Folton	Thermometers	6	2	3

Table 1. Summary of deployment information.

Technical Implementation

A prototype of the Temperature Calendar was developed using off-the-shelf components. Battery-powered temperature sensor nodes from "wireless things"[2] were used for data collection, together with a Raspberry Pi (RPi) Model B computer, equipped with a radio module from the same manufacturer to communicate with the nodes. A 7-inch Android tablet was used as a display: the visualization was implemented in HTML, rendered through a 'kiosk browser' app (a free application that locks the device on one specific webpage). The tablet connected via WiFi to the RPi on which we run a webserver and a web app developed using the Django Web framework for the Python programming language.

FIELD DEPLOYMENT

Seven of the Southshire public libraries were selected in collaboration with the council, based on a combination of practical factors, which included how many days of the week the library was open, and how easily its location could be reached by the research team. The sample included a range of different sites, details are provided in Table 1. Each library includes a public area, and a number of other rooms, accessible to the staff only. The public area always takes most of the floor space, and it is often divided into a number of rooms, sometimes across different floors – this is where most of the books are, as well as public workstations and reading space. The part of a library accessible only to staff includes at least an office or "work room" (as library staff normally refer to it), where some desk work may be performed, as well as sorting of deliveries for interlibrary loans (this is generally considered a physical activity, rather than a sedentary one), and a "staff room", where staff can spend their breaks, including lunch. In some libraries, a kitchen and meeting rooms are also present. In four libraries (Folton, Wertam, Hiltam, Tielby) the council had previously monitored the temperature using USB loggers, and in one (Hiltam) performed further analysis with an IR thermal camera (details below).

In addition to deploying the Temperature Calendar in 5 libraries, off-the-shelf digital thermometers[3] were deployed in 2 other ones, to provide a contrast for our design. The specific thermometer model was chosen so that in addition to the current temperature it would also display the minimum and maximum values – these extrema are calculated over a period of time that can be manually reset by pressing a button on the device. The detail about which libraries received which intervention is reported in Table 1. For each site the main contact person was the library supervisor, who was also interviewed at the end of the trial.

The deployment took place over 3 weeks across February and March. Each deployment started with a visit to the library, to install the kit. We asked the library staff about where to install the display so that it could be easily visible by staff, and if possible also by the general public, while being secure and not in the way. In all cases except for one, the tablet was installed behind the library front desk. The only exception was in Wertam, where the front desk turned out to be outside the radio range of some of the sensors, so the tablet was installed in the work room, where the library supervisor's desk is located. Three to five sensors were installed in each library, to monitor different rooms, based on the participants' suggestions. In the two libraries where thermometers were deployed, one was placed near the front desk, and the others in different rooms, which the participants identified as interesting.

Data Collection

Measured temperatures and interaction logs (keeping track of any interaction with the touch screen) were recorded throughout the deployment. At the end of the first and the second weeks, an email was sent to each supervisor, with a link to an online *questionnaire*. This questionnaire was designed to draw attention to the displays, and it was kept concise with only 5 questions, asking about the comfort in the building, adherence to the council temperature policy, any measures taken to bring the building back into the recommended temperature range, and about any technical issues related to our system. At the end of the third week we visited again each library to uninstall the displays and to conduct *semi-structured interviews*. The interviews lasted between 15 and 50 minutes, and covered mainly the participants' experience of the displays, as well as any history of heating or temperature issues in the building.

Results

We report findings from the semi-structured interviews and questionnaire responses (through thematic analysis [3]). This data was coded at the paragraph level resulting in 51 codes, subsequently grouped into 4 higher level categories, with a focus on reporting results relevant to the Temperature Calendar display. Where we present information on system usage, this is based on automatic interaction logs and temperature recordings. Where not otherwise indicated, quotes are from the interviews.

Temperature and Comfort Issues

Confirming the expectations from the council stakeholders (the energy team), for all libraries we had reports about issues with temperature and, more generally, thermal comfort. In most cases, the key issue was that different parts of the building were at different temperatures. In many cases, areas were above the maximum recommended temperature of 21 degrees and others were below 19. Generally, the parts of the buildings open to the public would be warmer, and sometimes even too hot because of solar gains, while the areas reserved to staff only, such as the staff room and the kitchen

[2] https://www.wirelessthings.net/
[3] http://tinyurl.com/nusbbrf

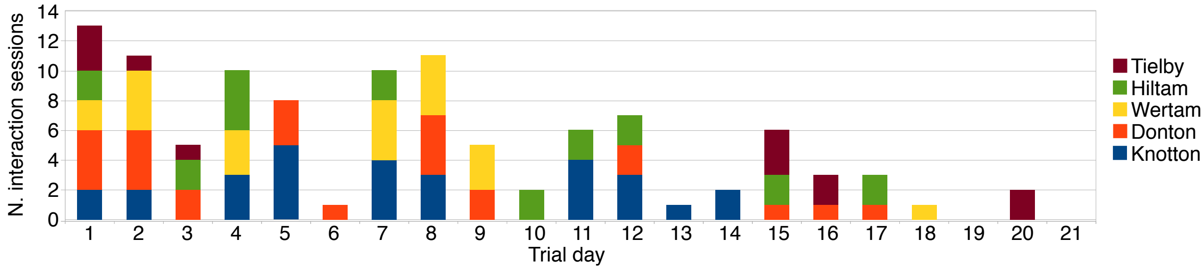

Figure 4. Interaction sessions with the Temperature Calendar over the duration of the trial.

would be unbearably cold. For example, we heard: "..*we don't sit in there [in the staff room] because it's too cold*" [Folton]. These low temperatures were sometimes related to poor thermal insulation, and we learned that the council had previously investigated the issues, using also thermal imaging: "*she brought the infrared [camera] to see for herself why it wasn't getting warm in there, thinking, maybe the radiator had pockets in there that weren't getting warm. Absolutely fine, nothing wrong with the radiator at all, but she put it over the brickwork and she showed me - there doesn't seem to be any insulation in the brickwork at all*" [Hiltam]. Indeed, the sensor data we collected supports such observations by our participants.

Library staff had generally been already involved in discussion with stakeholders in other parts of the organization about thermal comfort. Our interviewees were generally aware of the council policy about temperature. Indeed, only in two libraries were we told that they were not aware of the council temperature policy before our intervention.

Engagement with the Displays

The Temperature Calendar was reported to be clear and easy to understand, this was sometimes in contrast to some other temperature visualizations the staff received in the past from the council own temperature monitoring ("*Yes, I think I did look at it, but didn't quite understand her graph, I don't think. I think that's what probably flummoxed me*" [Tielby]). We had opportunities to observe that the calendar-based design resonated with ways to record information that already take place in libraries. For example, speaking about an earlier autonomous attempt from the staff to monitor the temperature, we were told that a *diary* was used to record the data over time: "*We did it through a year in the diary, yes, we manually wrote things down*" [Wertam]. In a different library we noticed that staff used calendar-based paper notes to keep track of working shifts. The off-the-shelf thermometers were also reported to be clear and easy to understand. In both libraries participants manually recorded the temperature data on a daily basis – this observation further suggests that representing the temperature data over time was a somewhat natural idea for our participants.

For the Temperature Calendar, the interaction logs revealed that participants interacted with the display regularly, as illustrated in Figure 4. In the library where interaction was most frequent (Donton), participants interacted on 11 out of the 21 days of the trial, while in the least frequent (Tielby) on 6 out of the 21 days (these values include days when the library was closed). In one case (Knotton) access was up to 5 times per day. These interaction patterns resonated with what we heard in the interviews. Participants generally reported that they found the display interesting to look at, some being particularly enthusiastic about it:

"*It is interesting to see, because in this building the temperature, you know, hot or cold, has always been a big thing for us to discuss. Because it's quite often not, you know, a steady, comfortable temperature. So it's a bit like British weather, I suppose, you talk about it a lot because it's so different all the time.*" [Knotton].

In five of the libraries we heard that staff (besides the library supervisor who was interviewed) were generally engaged by the interventions (either the Temperature Calendar or the thermometers) and that the display prompted discussion: "*all the staff were really interested, actually, they were intrigued by the different temperatures in the different areas*" [Hiltam]. One of the libraries where that did not happen was Wertam, where because of technical issues (radio range), we had to install the tablet display in a location where not many staff commonly pass by. The interviews also reveal that in the library with the most frequent interaction (Dotton) – despite the display being placed near the front desk, visible to staff – the interaction was mostly from one highly engaged member of staff. Here we were told: "*I think [the rest of the staff] looked at it but I don't think they got really involved with it*" [Donton].

The Temperature Calendar went mostly unnoticed from the general public using the libraries. Even in those locations where the display was visible to the public[4], only in two cases the interviewees reported of having 1 to 3 members of the public asking what the device was. The supervisor in Knotton pointed out that because the display was behind the desk, members of the public could see it, but not easily read it. In cases where members of the public did ask about the display, the staff seemed pleased to have interest in the study: "*We had one member of the public notice it. That's one more than none [laughs]. So we did have one person ask and he is a regular member of our community. So he did notice it, which was quite nice, and he did ask would it make any difference to the way the building is heated - will it be used to change the way the building is heated in any way? We said we don't*

[4]the thermometers were rather inconspicuous

know. But he did ask that question, so that was quite nice that he noticed" [Hiltam].

For the two libraries where thermometers were deployed, no interaction logs are available. However, in these two cases participants reported that staff were interested in the interventions, and monitored the thermometers, noting down the daily values for the temperature.

Induced Reflections

The interventions prompted participants to reflect on the temperature, generally in relation to the 19 to 21 degrees mandated by the council policy ("*at least once a day I always went through all of the different areas just to see what the feedback was and the blue and the red lines*" [Wertam]). During the interviews we asked participants whether the displays led to any surprises. Reactions were mixed. In some libraries the display revealed unexpected values (e.g., "*we were quite surprised at that really, that it was always above 21. It was, like, 24*" [Folton]). In others, the observed temperatures were related to issues that had already been noticed, e.g., "*..the guys weren't surprised that it was 24 degrees at times, yes. There's not much air circulating. We've just got a few top windows to open..*" [Tielby]. The lack of surprises was sometimes considered positive: "*No [surprises], and it was good to see, you know, that it does go down at night, you know, that it's not... you know, the boiler isn't staying on unnecessarily and heating an empty place*" [Donton]. This last quote indicates the only occasion when out of hours operation was mentioned.

With the Temperature Calendar, in some cases emphasis was placed on how the temperature changed over the day and on the effect of external weather: "*[...] in the main library we could see it getting up to temperature, but it's then going over temperature, about 22 degrees, sometimes 23 degrees, on a sunny day when the sun's been shining in the building.*" [Hiltam]. However, other times the temperature was discussed in absolute terms, rather than in relation to the occupancy and use of the building. Participants pointed out that their subjective perception of heat was sometimes in contrast to what the display indicated, and sometimes went as far as attempting to justify such discrepancy. "*..the display was showing 24 degrees, which I know is too hot for a building. It didn't... it didn't actually feel very warm and we had, you know... I don't know if it's the draft coming through the door when it opens. They're automatic doors.*" [Knotton] The subjective nature of thermal comfort was resonant in the comments participants made about their difference in perceived comfort across days even though the temperature was reported as being the same.

"*Because on, sort of, several occasions we've thought, that says 24 but it doesn't feel like 24. It's really weird. And other days it says, oh, it's 24 and you think, oh, I'm roasting. But it just depends, I suppose*" [Knotton]

Taking Action

From four libraries, we had reports of staff taking practical action with their heating system in response to what they learned from the display. In one case staff turned the heating off completely, only to realize that was too extreme of a measure: "*Well, because you said the temperature should be between 19 and 21, I think? [...] And obviously ours were all over that, which was quite surprising. And then we turned the heating off and it got down to about 18, 19 or 18, but then it felt like it was really cold in here.*" [Folton] In another case, the action was more specific, an individual heater was turned off, and later turned back on by another member of staff: "*I did at one stage turn off that radiator that blows heat out because I thought where is that going to go? Right back to the heater, so that's why maybe in the non-fiction area it went over 21 more. So I can't remember what day I switched it off, but I did a comparison in my head anyway and I think it went down a little bit. Then when I was away somebody switched it back on.*" [Wertam] This quote points at the fact that the display was used to verify the effects of the action.

While the two examples above aim at lowering the temperature, in other cases staff reported using extra heaters to increase the temperature to the recommended range: "*We have to use a small heater in the office if anyone is working in there.*" [Donton, Questionnaire]. Or even combinations of the two: "*Using the [electric] heater in the staff room otherwise it remains cold in this area. Opening windows in the main library to try and help reduce the temperature when above comfortable temperatures*" [Hiltam, Questionnaire]. These reports need to be placed in context of the extent of control our participants had on the buildings heating systems. In most cases they could just turn the entire system on or off. In some cases individual radiators could be controlled, while other cases they were able to select one of a number of preset timer programmes (but not to control the programmes definition directly).

A longer term deployment

When asked about the opportunity of deploying the display in the future, participants always answered positively, and often mentioned that indeed it would be even more useful to look at the display when the weather is at its most extreme conditions, such as the coldest days of winter, or the warmest days of summer ("*..July-August would be very interesting*" [Tielby]). We also asked participants about the prospect of having a permanent version of the display installed, and in particular whether such an option would concern them in terms of privacy, with the central offices of the council being able to constantly monitor the temperature. In all cases, participants welcomed the idea of a permanent installation, and thought that more awareness from the council about the local temperature would be a good thing, especially if that would result in the council taking action to improve the situation. Some interviewees, however, also reported scepticism about the council actually taking any action in response to such monitoring.

DISCUSSION

The results of the field deployment revealed that both the Temperature Calendar and the simpler digital thermometers were successful in attracting the building occupants' attention to the indoor temperature. They demonstrate how the Temperature Calendar mobilised staff to take action on heating, and to rationalise about organizational policy. Our results also provide a basis for further discussion around three topics of relevance to the research community.

Visual language and positioning of the display

The way that library staff approached and discussed the Temperature Calendar provides insights into the design of displays that engage users around thermal comfort and heating. In "engaging with the displays" we presented comments from library staff about not managing to make sense of previous temperature graphs they received via email: these comments remind us that just making data available is not enough. The presentation format is crucial to support users who may not have technical training in making sense of the data. In addition – as discussed below – the format has a distinct impact on what form engagement with the data takes.

Generally speaking, the choice of a calendar visualization appears to have been appropriate to our goal – outlined in our "initial concept" – of legibility for office staff, and to an extent in terms of allowing users to relate temperature to the workplace routines. The visual language of the Temperature Calendar was at once familiar and effective for presenting higher resolution data (compared to simply minimum and maximum values, as shown by the thermometers).

The differences between Wertam – where the Temperature Calendar was placed in a staff room – and our ideal choice of position in other libraries (where the display was placed at the front desk) suggest that the position of the display can make a difference in the extent to which it engaged people. When the display was at the front desk staff were more likely to become involved in its use. The room in Wertram, although accessible by all staff, belonged to a particular individual. Our results suggest that displays like the Temperature Calendar, which are tools to be used in and around work tasks rather than actively sought out to solve a particular issue, should be placed in locations where they will be encountered in "down-time" while staff attention is free. This aligns with Pousman et al.'s design challenges for *Casual Infoviz* systems, in particular the need to integrate such visualizations into the "particular rhythms and routines" of the users' lives to capture "fleeting" moments of attention [32].

Our study sheds some light on how the general public might engage with displays like the Temperature Calendar. Libraries – like shops and other public sector buildings – mix publicly-accessible areas and private areas only accessible to staff. As reported earlier in "engagement with the displays", in four of our deployments members of the public could see the display, although not necessarily the screen. We had only minimal reports of interest from the public, and certainly no evidence of the general public initiating detailed discussions about energy or sustainability. Unlike the staff, most public visitors do not spend time waiting at the front desk and are unsurprised by noticing yet another device. However, it is worth noting the response of the Council who were pleased by the opportunity to communicate to the public simply that they are engaging in sustainability initiatives – to this end it mattered more that the staff and building were visibly being "equipped" than whether the public could read the display. It is also unclear from our studies whether the general public would be able to draw useful inferences from the Temperature Calendar, given that all but the most regular of visitors would lack the intimate knowledge of the libraries' routines and the historical issues with temperature.

Beyond thermometers?

Before advocating a technological solution to visualise data, it is worth considering the temperature records that were manually created by staff in the libraries where thermometers were deployed. In "engagement with the displays" we note that staff kept daily records of temperature and that this process seemed natural. We also found that the thermometers were indeed enough to provoke a reaction in one library (Folton). However, we question whether this manual process – which requires additional work from the staff – is sustainable in the long term. The fact that the Temperature Calendar automatically collected and visualised data allows staff to spend spare moments in and around their job of work engaging critically with the visualization, rather than doing the groundwork to generate it. In addition, as discussed above, the resolution of the Temperature Calendar (24 data points per day) was an important feature.

Policy vs. persuasion

Either with the Temperature Calendar or with the simpler thermometers our deployments triggered discussions, and, in four cases, even stimulated the occupants to try and change the way the building is heated, within the tight constraints of control available to them. As is common in workplaces, our participants were already particularly sensitive to temperature and thermal comfort – in interviews some thermal issues were reported as being outstanding for a number of years. Despite these issues being persistent and frequently discussed, this alone was not enough for the staff to take the actions they took in our study, indicating that the technologies empowered them to gain a clearer, actionable picture of the temperature performance of their buildings. Such findings suggest that the deployment of the displays was successful, in that they helped occupants to take action on persistent issues.

It is worth emphasizing, though, that the Temperature Calendar per se was clearly not the *motivating* factor, the council temperature *policy* was. In other words, the displays were successful in drawing our participants attention to the policy, which was one of the original design goals. The displays did not present any indication of the environmental or financial consequences of the temperature levels, nor any health warnings (in relation to the temperature being too high or low). Our displays merely made the existing policy salient, and related it to the reality of the temperature in the specific buildings. The interview responses, as well as the questionnaire, demonstrate that our participants discussed temperature in terms of the Council policy – specifically whether the temperature was inside or outside the recommended range. In "induced reflections" we highlighted staff use of the "blue and red lines" on the Temperature Calendar (out-of-policy indicators), while in "taking action" we presented trial and error approaches to reaching an in-policy temperature: here staff treat the policy *normatively* – linking thermal discomfort to their building performing in "abnormal" ways. Elsewhere, however, our results point to staff rationalising policy as inappropriate to their particular context, sometimes being frustrated – e.g. due to lack of insulation, or to unavoidable heating from sunlight. There was some realisation that temperature does not necessarily map to comfort.

In "temperature and comfort issues" we discuss the common awareness of the temperature policy amongst our staff (prior to our study): speaking more generally, organizational policy seemed a comfortable topic for collective discussions around the display, and to be a natural target for critique. As discussed above, staff appeared to accept that the policy was inherently limited in applicability, and to want to establish how their own building could and should perform relative to this benchmark. Despite its perceived limitations, then, the policy appeared to provide participants with a framework within which to negotiate and enact thermal control. As mentioned in "a longer term deployment", staff also saw policy as a means of engaging decision-makers elsewhere in the organization, hoping that data collected by the Temperature Calendar could draw attention to the plight of poorly performing libraries.

Carbon cost vs benefits

Critiques of sustainable HCI suggest that a common mistake in HCI research is to encourage the deployment of new technology where that technology might embody "an [environmental] impact that may not be outweighed by the benefits" [28]. The life-cycle of a new technology – from production to disposal – can generate significant carbon emissions that should be weighed up against the savings that they empower. To understand how sustainable the Temperature Calendar is, we performed an analysis of its carbon cost, considering both the embedded carbon, and the energy required to run the system. We report this analysis to allow others to replicate our calculations, and – more importantly – to provide an example that others could follow. Calculating the carbon cost provided difficult: very limited information about embedded carbon is publicly available, and the current Temperature Calendar is a prototype rather than a final product. As such, we looked for broad equivalencies of different parts of the system in order to calculate indicative figures.

Our prototype uses a tablet as a display, and a Raspberry Pi device with an additional radio module for collecting wireless sensor data and serving the Temperature Calendar app , a Wi-Fi router is used to connect the two. In the long term, the devices could be integrated for increased efficiency. All the functionality provided by the system, except for the the wireless sensors, can then be modeled as an individual tablet: a tablet includes a powerful processor as well as at least one radio module, which is needed to communicate with the sensors[5]. For practical reasons we refer to Apple products, as the company provides emissions data for them[6]. As such, we assume that an iPad Mini 2 is being used as a display (the screen size is similar to the one in our prototype) and as a receiver for the sensor data; and that there are 5 sensors located around the building. We further assume that the iPad is always on, and that the sensors are sending data at 5 minute intervals.

Given these assumptions, and estimates for component construction and running costs (further details of our calculations are available in the the dataset associated with our paper: `http://doi.org/bbpq`), the cost of constructing the hardware would be approximately 99.63kg COe, and the running cost would be 0.0705kg CO2e per day. To put these figures in context, we compare them with the CO2 emissions saved by detecting and rectifying the error in the heating settings reported by Bedwell et al. [2]. In that case, the building was heated one extra, unnecessary, day each week, amounting to 87.969kWh of gas per week, corresponding to 18.9kg CO2e[7]. In this deployment, the actual saving per week would be 18.4kg CO2e per week after taking the running costs into account, so based on the manufacturing costs the carbon cost of the Temperature Calendar would be paid back within 6 weeks. While the level of savings in this specific building is just anecdotal, these values suggest that an intervention of this sort has potential to be sustainable if staff take action as a result. Further research, however, is required to improve the accuracy of this estimate for the carbon cost of the system, and to determine how quickly the cost of the Temperature Calendar would be offset by any energy savings.

While the level of savings in this specific building is just anecdotal, these values suggest that an intervention of this sort has potential to be sustainable.

LIMITATIONS

It is worth pointing out explicitly that because of the very nature of the Temperature Calendar, its evaluation is particularly sensitive to the weather during the deployment. The specific period when we deployed, winter starting to phase out into spring, might have influenced the results. As reported in "a longer term deployment" participants noted that the weather in other periods might be more interesting, yet extensive (and regular) deviations from the temperature policy were still visible on the Calendar.

As with many technological interventions, and even more so those involving displays, the evaluation might have been influenced by a novelty effect, so an opportunity for future work is to assess such interventions over longer term deployments. These would enable researchers to investigate the impact of seasonality (i.e. weather) on the relationship between staff and temperature policy, but also on the utility of the Temperature Calendar, assessing whether this sort of intervention should be deployed permanently, or as part of seasonal initiatives.

CONCLUSION

In this paper we described the iterative design process and field evaluation of the Temperature Calendar. The Temperature Calendar is a public display showing the variations of

[5] We are not suggesting to use the actual tablet radio to communicate with the sensors, but just to model its carbon cost.

[6] `https://www.apple.com/environment/reports/`

[7] 0.2147kg CO2e per kWh for LPG, based on `http://tinyurl.com/nspuq7u`

indoor temperature in different zones of non-domestic buildings, relating the data to existing temperature policies defined (in our case) at the organizational level. The system was deployed *in the wild* over 3 weeks in 5 public libraries, and a combination of quantitative and qualitative data revealed that it was successful in engaging building inhabitants in reflecting on heating patterns and deviations from their organization temperature policy. In some cases even prompting them to take practical action and changing their heating settings. A cost-benefit analysis for the Temperature Calendar demonstrated how the various components contribute carbon emissions, providing an example for other researchers to critically appraise the impact of technological interventions.

Our findings, together with the initial interest from the council energy team to include policy in the Temperature Calendar, point to a more general issue: the opportunity for sustainable HCI to *engage with policy*. Even though Dourish drew attention to policy in 2010 [11], relatively few projects attempted to go in such a direction – a notable exception is the "Water Wars" project [22] designed around possible water distribution policy changes in New Mexico. Jain et al [23] mention different organization level policies related to energy consumption, but they do not really suggest how HCI can engage with them. While other academic disciplines and domains have a tradition of influencing public policy[8], such as health and psychology in relation to issues such as child obesity and media regulation [17], or tobacco consumption and smoking bans [13], HCI has an opportunity to encourage staff to critically engage with and shape organizational policy. While other displays have focused the attention of individual users on small changes they can make to their personal behaviour – tightly constrained as they are in the workplace – the Temperature Calendar widened the frame of reference to organizational policy, and subsequently participants discussed significant changes to heating systems and architecture, and worked collectively to investigate and instigate building-wide changes to heating.

We hope that by presenting this design process and evaluation our work will motivate others to embrace the challenge of extending sustainable HCI work beyond the paradigm of motivating the individual, and explore opportunities for our work to engage with policy. We believe that opportunities lie not only around helping users reflect on the implementation of existing policies (as we report in this paper), but also in promoting discussion around the introduction of new policies or modification of existing ones.

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[8]see also https://vimeo.com/52408411

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