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“Just whack it on until it gets hot”: Working with IoT Data in the Home

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ABSTRACT

This paper presents findings from a co-design project that aims to augment the practices of professional energy advisors with environmental data from sensors deployed in clients’ homes. Premised on prior ethnographic observations we prototyped a sensor platform to support the work of tailoring advice-giving to particular homes. We report on the deployment process and the findings to emerge, particularly the work involved in making sense of or accounting for the data in the course of advice-giving. Our ethnomethodological analysis focuses on the ways in which data is drawn upon as a resource in the home visit, and how understanding and advice-giving turns upon unpacking the indexical relationship of the data to the situated goings-on in the home. This insight, coupled with further design workshops with the advisors, shaped requirements for an interactive system that makes the sensor data available for visual inspection and annotation to support the situated sense-making that is key to giving energy advice.

Author Keywords

Internet of Things; sensor data; energy advice; non-profit; ethnomethodology; data work.

ACM Classification Keywords

H.5.3 Information interfaces and presentation (e.g., HCI): Group and Organization Interfaces.

INTRODUCTION

The Internet of Things (IoT) promises to provide ‘the right service at the right time’ and in doing so to increase well-being, productivity and convenience [24]. The widespread availability of relatively cheap sensors coupled to networks and computing platforms brings this vision a step closer to reality. It is a vision that assumes people can afford such

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novel consumer devices (whereas the expense may preclude a great many from the IoT vision in practice) and, more tractably, that the data produced by IoT applications can be readily ‘read off’ and acted upon. This latter assumption is turning out to be problematic (just as the former might do), with recent research revealing the difficulties encountered in the use of ‘smart’ domestic applications [39] and the sophisticated reasoning implicated in making sense of sensor-based data [35]. The work presented in this paper chimes with these emerging findings.

The paper builds on prior ethnographic research [13] to support the work of energy advisors through design. Energy advisors typically provide in-home advice to low-income households in a bid to help them manage energy consumption, reduce bills, and deal with problems such as damp and mould. Previous ethnographic observations (*ibid.*) suggested that it might be possible to augment the advisors’ work practices with sensor data, providing useful insights into the domestic environment (temperature, humidity, etc.) to enable advisors to better tailor advice around their clients’ everyday lives. We prototyped a sensor kit to explore the possibility and deployed it concurrently in twelve UK homes.

We adopted an ethnomethodological perspective [16] to analyse the collaborative nature of the ‘data work’ the advisors and their clients had to engage in to understand the data coming out of the sensor kit and to tailor bespoke advice around it. Our analysis reveals that this kind of data work turns upon unpacking the ‘indexicality’ of the data. This suggests that the sense of the data is not found in the data itself, but in collaborative *talk* about the data (e.g., between advisors and clients). Indexicality thus refers to,

“... expressions whose sense cannot be decided by an auditor without his necessarily knowing or assuming something about the biography and the purpose of the user of the expression, the circumstances of the utterance, the previous course of the conversation, or the particular relationship of actual or potential interaction that exists between the expressor and the auditor.” (*ibid.*: 4).

One consequence of indexicality is that the meaning of the data cannot simply be ‘read off’ representations of it (e.g., graphs and charts). Rather, what the data means, what it refers to, what it reveals is, without remedy, wrapped up in the *situated* interaction between parties to its use. Thus,

sensor data requires ‘articulation’ to make sense of it [35] and arrive at an account of what it means ‘here and now’, in this case, *in* the giving of energy advice.

Our study unpacks the articulated character of data work in the giving of energy advice. We describe and document the broad lifecycle involved, where sensor data is *anticipated* during installation, the presentation of data is *rehearsed* prior to home visits, and data presentation is *performed* during in-home visits. Anticipating, rehearsing and performing data are collaborative matters through and through. They reflect the articulated character of the data work occasioned by the deployments and have informed our thinking about future systems to support the work of advice-giving, human and automated.

RELATED WORK

Our work is located at the intersection of a number of topics in HCI, UbiComp and CSCW, including energy and sustainability, sensing, workplace studies, and the home as a ‘wild’ setting, which we briefly review here.

Energy, sustainability and environmental sensing

A significant body of work has been aimed at raising awareness of energy consumption and encouraging behaviour change [10,28]. Electricity consumption feedback [14]; advanced sensing techniques for monitoring use [20], and interactive systems to visualise and annotate this information and promote understanding have all been studied [3]. Advances in sensor technology further allow novel applications based on sensing of air quality [22,23], occupancy [31], and CO₂ data [21]. While our work is not specifically aimed at behaviour change, we apply techniques from sensing and visualisation to augment and support energy advice practice with sensor data. Technical work has been complemented by studies of energy use in low-income homes highlighting relevant social issues, such as that lack of control and ownership can act as barriers to energy saving [8], and that designing for rented properties should engage with conflicts between landlords and tenants [9]. Our work is related to research concerned with how people with few means at their disposal can be supported, and what the implications might be for technology design [6,11]. It also speaks to research concerned with the relationship between sensor data and its intelligibility in a domestic context [e.g., 2,12,30].

Designing for non-profit workplaces

Our research has a focus on *work practice* [1] and draws on fieldwork with a view to inform a co-design process. We note that studies of work practice are not confined to the workplace [4], but this approach has been widely used to study organisations, occupations and professions in CSCW [29], emphasising a social perspective on the development of technological infrastructure [32]. Applied to non-profit workplace settings, related work has for example looked at information management [27], coordination and awareness [7,33], participatory design with community groups [26], fundraising [18], and volunteer coordination [38]. In this paper, we focus on novel work practices implicated in the

conduct of not-for-profit energy advice work that makes use of sensor data in order to feed the results back into an ongoing co-design process.

Deploying technology in homes

A notable difference to the workplace studies literature is that the workplace setting of energy advisors is more often than not the home of their clients. This overlap warrants consideration of some of the concerns that have emerged about the home as a setting for the deployment of technology. Tolmie and Crabtree highlight that deployments are often oriented to by household members as something done *to* them rather than done *for* them, which impacts our understanding of how new technologies might actually be adopted in the real world [36]. Further research has highlighted the extensive work required to make the technology work in the home [19], social and technical, including the work of ‘digital plumbing’ [34]. Our work touches upon all of these concerns. It seeks to exploit technology to deliver beneficial outcomes *for* clients; it touches upon the work of digital plumbing in accounting for salient aspects of the work of deployment; and it unpacks the inherently collaborative or social character of the data work that advice-giving turns upon.

THE PROJECT

This work is part of the CharIoT project aimed at using the IoT to support the work of energy advisors through the co-design of sensor kits for collecting environmental data in homes and interactive systems that support sense-making and the provisioning of tailored advice. The project follows a participatory co-design philosophy, including ethnographic studies of advice-giving work practice, participatory design workshops, cooperative prototyping, real world deployments, and studies in the wild.

Energy advice

This project aims to support the work of energy advisors working for the Centre for Sustainable Energy (CSE), a non-profit charity based in Bristol, UK. CSE’s energy advisors provide advice through in-home visits, particularly to vulnerable households affected by fuel poverty. Fuel poverty is a key societal problem not just in the UK, with millions of people struggling to pay fuel bills in order to maintain adequate heating in winter months, affecting financial, physical, and emotional wellbeing [25]. CSE’s energy advice work involves diagnosing the causes of high bills and health risks (e.g., damp and mould), recommending material and behavioural improvements, and reporting to third parties to make the case for improvements on their client’s behalf (e.g. landlords, councils, and energy suppliers); a detailed account of the advisors’ work practices has been reported elsewhere [13]. The project team consists of three full time advisors and CSE’s senior development manager, who collaborate with a number of interdisciplinary academic researchers. The team collaborates by means of meetings, workshops, shared workspaces, and remote communication.

Supporting Advisors

CSE's advisors currently suffer from a paucity of information about the causes of problems in households, which limits their ability to tailor advice to clients and to provide evidence when acting on their behalf. Our work explores whether and how data from environmental sensors may mitigate this paucity in information and support advisory practice. The key goal is to augment and thereby improve existing advisory practices in homes by enabling personalised, data-driven advice-giving. Prior work [13] suggested multiple opportunities for technological support including:

- **Enhancing advice visits with data**, by providing and discussing data visualisations that show the impact of the client's activity;
- **Supporting remote advice work**, by providing access to the client's household's data prior to the home visit to enable better preparation and comparison;
- **Supporting upward accountability**, by enabling data representations as evidence of practices and property conditions in third party negotiations.

We prototyped a sensor kit for deployment in CSE's clients' homes to explore these opportunities in the wild.

The sensor kit

The sensor kit was assembled using off the shelf components including:

- A wireless temperature, (relative) humidity and light sensor (Figure 1), including WiFi connectivity to send the data to our server via the portable 3G router.

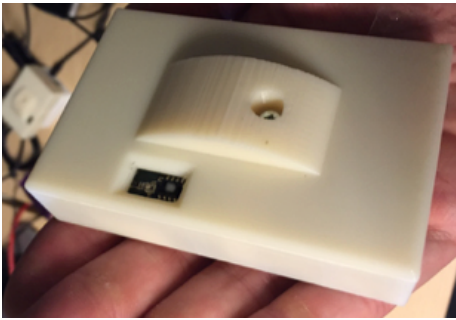


Figure 1. The prototype temperature, humidity and light sensor.

- An off the shelf electricity sensor (CT clamp) which sends data wirelessly over the zigbee to a hub. The hub is connected to the internet via an Ethernet connection to the portable 3G router or broadband modem if available.
- A small form factor 3G mobile broadband router which is preconfigured to allow access from the wireless environmental sensor and off the shelf CT clamp.
- A rudimentary web interface was also developed to enable checking during installation that data from the home was received in our database, and to plot the raw data in simple line charts (Figure 2).

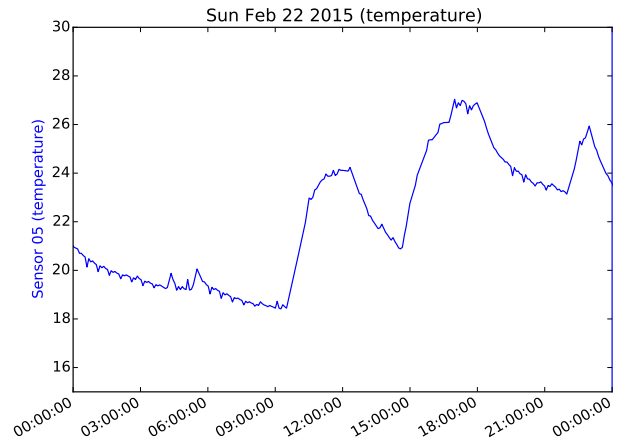


Figure 2. Sample temperature data.

Participants

After approval by the University's ethics committee, we recruited 12 homes as participants. Six homes were recruited via an energy supplier, which was recruiting new pre-paid smart meter customers. Pre-paid meters are prevalent among low-income communities in Britain; the majority of CSE's clients are on a pre-paid tariff. We hoped that there would be participants among the energy supplier's new customer base who would benefit from advice by CSE. Eligibility was ensured on a case-by-case basis, as described below. In addition, our relationship with the supplier provided access to otherwise unavailable gas consumption data.

We took steps to ensure that participants understood the research was not being conducted on the part of their energy company. For example, the company's representatives were instructed to advertise the research project only after new customers had agreed to smart meter installation, and to stress that participation was voluntary and independent of their contractual relationship with the company. CSE advisors then phoned the potential participants after a 'cooling-off' period of two weeks to establish whether they would benefit from a home visit. This interview followed CSE's procedures to establish client eligibility, and included probing whether the client has a cold home in winter, or problems with damp and mould, or sometimes struggled to pay their bills.

An additional six households were recruited from CSE's existing client base. These clients are tenants of council properties in the city of Bristol and were referred to CSE by the city council, which for various and specific reasons identified these households as 'vulnerable', e.g., members include children, elderly or disabled people, or those with long term illnesses. Out of our 12 participating households, two households had people over 70 years of age, four had children below the age of five, seven had a low household income (less than £16,000/year), eight reported their homes were colder than they preferred in winter, five reported problems with damp and mould, and eight reported they sometimes struggle to pay their fuel bills.

Project phases

The sensor kit was deployed in each of the participant's homes for between 4 and 6 weeks. Deployment, use and study of the sensor kit was accomplished over a number of discrete phases. The first of these involved an *installation visit* to situate the sensor kit in participants' homes. The second consisted of a *seed workshop*, where collected data samples were reviewed by the academic researchers and CSE staff. Third, the advisors conducted *in-home visits* using the data to work through perceived problems. Fourth, a *final visit* was conducted by the advisors to collect the sensor kit and offer further advice. Fifth, a *reflective workshop* was held between the advisors and academic staff to review the experience.

Data collection and analysis

In addition to the data that was captured by the sensor kit, we treated each of the phases outlined above as opportunities and subject matter for fieldwork. CSE's operating procedures require two people to conduct a home visit, so a field worker accompanied the advisor and documented the work s/he engaged the client in. Data captured included audio and video, along with fieldnotes, which was transcribed and then initially analysed to identify the sequential organisation of advice-giving work (cf. [5], chapter 6). This reflects an ethnomethodological orientation, which seeks to identify the methodical ways in which the members of a setting naturally and accountably order their activities in interaction [17]. Identifying the sequential organisation of interaction orients us to the naturally accountable order of interactional work and subsequently enables its unpacking.

Thus we focus below on the ways in which sensor data is *anticipated* during installation, gets *rehearsed* before the visit, is *performed* during visits, and how these methodical features of data work impacted reflection on sensor-based advisory practice. While a host of research lenses could be interesting to adopt, we are especially concerned here to understand *the work to make the sensor data work* in support of the advisors' advice-giving practice, both in collaboration with one another (in workshops) and with their clients (during in-home visits). We elaborate key findings by offering conversational vignettes or extracts from the field studies to unpack the work involved in making sensor data accountable in and to interaction.

DATA WORK

Data work occurs across the 3 main stages of deployment, during installation of the kit, the pre-visit workshops where sample data is reviewed, and during the in-home visits where they are drawn upon as a resource in the work of advice-giving. We explicate key features of data work in each of these stages below.¹

¹ It is worth noting that our aim here is not to provide an exhaustive account of data work in each stage; more could be said. What we want to do here is tease out what we take to be the most salient features of the work to design.

Installation: anticipating data work

As a preface to installation advisors first assemble the sensor kit at the offices to check that it is complete and working. At the client's home the advisor explains the project and runs through an initial interview to get a "general sense" of the property and its occupants. The purpose of this interview is to *profile the property* (e.g., fuel type, heating system, appliances) and *the occupants* (e.g., number, type and age of people living in the home), and their *everyday routines* (e.g., how do they use the heating system, how do they dry their clothes, how do they ventilate the home, whether or not they keep doors open or closed), and to *establish the client's main concerns* (e.g., damp and mould, high bills or a cold home).

Deploying the sensor kit is not simply a matter of physically installing it and making sure it works. It also, and crucially, relies upon a process of negotiation that involves introducing the kit to the client, explaining what it does, getting their permission to install it, which frequently involves articulating potential benefits for the client, and figuring out where to place the kit. Placement can be challenging as the advisor needs to balance the desire to equip a room that is frequently used or that has problems (such as damp) with technical constraints, including access to plug sockets, distance between sensor and hub (which affects connectivity), and avoiding direct sunlight or extreme heat (which produces misleading data). Installation also involves accounting for follow up actions (e.g., potential repair visits if the kit breaks down and the planned advice visit).

The following vignette shows something of the work involved in installing the sensor kit:

Vignette 1

After introducing the project, the advisor retrieves the sensor kit from her bag:

Advisor: (Picks up sensor) So this - basically what we'll be doing - this is a sensor - and it records the temperature in a room, and the light, and the humidity.

Client: Yes.

Advisor: And it (picks up hub) sends a signal to this router, and this (picks up 3G dongle) is like a 3G connection.

Client: Yes, it's a dongle. Yes. Yes.

Advisor: And then we can receive the information and we can get charts on those readings.

Client: Yes, not a problem.

Advisor: And then we come back in a couple of weeks.

Client: Yes.

Advisor: And share that information with you, and offer advice about what you might be able to do to reduce your fuel bills.

The vignette makes it visible that the advisor introduces the sensor kit piece-by-piece, explaining the kinds of data that will be collected and how it will be transmitted. It is of note that in doing this the advisor brings up the *anticipated use* of the data - "we can get charts on those readings", and can "share that information with you"; its *purpose* - to "reduce your fuel bills"; and the *projected actions* through which this will be achieved - "we come back in a couple of weeks ... and offer advice". The client's utterances indicate both

his understanding of the kit and the procedure, as well as his permission – “yes, not a problem”.

Communicating the anticipated use (what will be done with the data) and its purpose (why) is essential to gaining the participant’s acceptance and permission to install the kit. If omitted, the client may in turn *prompt an account*. Consider the following vignette:

Vignette 2

The advisor has just clipped the CT-clamp around the meter’s main cable.

Client: So what does that do now, the part you’ve just put on there?

Advisor: That’s on the live electric cable.

Client: Right.

Advisor: And so what that does, that’ll send to the little white box we’re going to plug in now, and that is recording the electricity that you use.

Client: Right.

Here we can see that clients do not simply accept the installation of the kit: reasons have to be given to account for what is being done, and good ones at that. Thus, the client’s requests for an account of what the installed sensor does is provided by the advisor in saying that it records “the electricity that you use”. We can see too that the advisor accounts for the next action she is going to perform in saying that the sensor sends data “to the little white box we’re going to plug in now”. Accounting for installation is critical but it is not sufficient simply to say what something is or does, for what is absent from this kind of exchange is an account of the anticipated use and purpose of the sensor data, and particularly the *relevance* of these matters to the household, which clients are not blind to:

Vignette 3

Client: So when you’ve got all this data and everything, how does this benefit us then? How would this benefit us?

Advisor: So, what we’ll be able to - what it’ll give us is the humidity in the room, the light, and the temperature.

Client: Yes.

Advisor: So say, for example, we could see that there was a sudden drop in temperature. We could ask why that might be, and what that might mean in terms of helping you with your heating? That kind of thing.

Client: OK.

A further important characteristic of note in the installation visits is an attempt to sensitise clients to *the relationship between their activities and the data*. This is most strikingly evident in how the advisors ask for a “diary of unusual activities” to be kept by clients:

Advisor: So if you just record down unusual, out-of-the-ordinary activity - so if you have more people around than normal, just write it there (gestures towards diary) to say tonight there are people coming around. If you dry clothes in there (points to living room), just write that down as well, because when we get the graphs back that will help us to be able to read things. If your humidity levels or the heat suddenly shoots up and you’ve got more bodies in there that will explain that.

Here we can see that the advisor not only provides examples of the kinds of activities or events that might constitute “out-of-the ordinary” – e.g., having “more people around than normal” or “drying clothes” in the living room – but also accounts for the purpose of providing this kind of

information – it “will help us to be able to read things” or the data to be more precise. The advisor also accounts for what being “able to read things” means – “if your humidity levels or heat shoots up and you’ve got more bodies in there that will explain that.” *Explaining the data* is key to data work and, while trading in the “out-of-the-ordinary” here, it is clear that advisors are aware of and anticipate its indexical character – i.e., that what the data means, what it reveals, is irremediably tied to what Garfinkel [16] refers to as the biography, the purposes, the circumstances of data production and the relationship of parties who generate the data to it. Thus, the advisors *presume in advance* of data collection that the data will not account for itself: more will be required to make sense of the data, with the more of the matter consisting of perceptibly salient aspects of the day-to-day business of domestic life.

It is notable too that that none of the participants recorded any information in the diary. This underscores the orientation of participants to the ordinarily *unremarkable* nature of domestic life: that having more people round than normal is not, in itself, particularly noteworthy, anymore than drying the clothes in the living room, bedroom or bathroom is. If you doubt it, try saying such things to your friends and colleagues and see what they make of them. Many aspects of domestic life are deliberately “opaque” [36] and for good reason in that surfacing them opens members up to potential moral account [35]. We might say then that members have a vested interest in making domestic life into a largely unremarkable matter, and that everyday life in general turns upon this mundane matter of fact [37]. A key challenge to data work involves opening the unremarkable up [35].

In summary, the work of installation is not merely about installing the sensor kit. It turns upon a range of practical concerns *with the data*. These include accounting for what data will be gathered and how, the purpose of data gathering and its anticipated use, and the projected actions through which this will be achieved, all of which turns upon accounting for the relevance (or benefits) of the data to the participants. Furthermore, these anticipatory concerns with the data are accompanied by a concern with the indexicality of the data, particularly its relationship to the activities and events that generate it and the need to make the data accountable to these. Much of this work may be seen as incidental to the work of advising, but it is key both to installation and to building a cooperative relationship between advisor and client in the use of sensor-based applications.

Pre-home visit: rehearsing data work

Once sufficient sensor data had been collected, a workshop was organised by the researchers to prepare the advisors for the in-home visits. The researchers plotted and overlaid the raw sensor data from the various sensors (gas, electricity, temperature, humidity and light) in simple line charts (as in Figure 2). One household was discussed at a time, to explore the richness and completeness of the available data.

The advisor who led the installation visit gave an overview of the household (issues, occupancy, routines, etc.) and the property (fuel, heating system, thermostat settings, major appliances, etc.), and the data was then reviewed and discussed. Recalling where the sensor kit was placed was important to understanding what the data might be saying about each home.

The advisors first set about trying to spot *expected patterns* in the data by correlating data streams. As one advisor put it,

Straight away you can see temperature falls, boiler fires up and there's a spike in gas consumption, and then the temperature increases immediately after this.

The advisor here correlates temperature, electricity, and gas data; knowing that the client has thermostat controlled central heating with a combination boiler, the expected pattern of cause (temperature falls) and effect (boiler fires up) is 'straightforward' to read from the data. This, however, is not always the case and the advisors spent a great deal of the time discussing *remarkable* data segments – i.e., data segments that were difficult to interpret or counter-intuitive.

For example, the participants spent quite a while discussing a case in which the temperature one day goes up hours before the gas comes on. The advisors *speculated* about what may have caused the temperature to go up, for example, "bodies in the space might do that" or electrical devices such as the "TV, Xbox, or computer." *Cross-referencing* between days was frequently engaged in by the advisors in a bid to verify unusual patterns, for example, examining the previous days' heating profile.

Temperature data was read for its maximum and minimum values, and temporal range. Time of day also served as a reference for the effect of outdoor temperature. The steepness of the slopes of the line chart gave an indication how quickly the home heats up and cools down, and insulation measures were often evoked in relation to this. Temperature was frequently correlated with humidity (laws of physics prescribe that relative humidity increases as the temperature drops) and gas (indicating the use of central heating). The advisors reasoned that repeating patterns in temperature were indicative of heating *rhythms and routines*.²

The humidity data was inspected for signs of increased humidity. Values over 70% for prolonged periods of time are particularly worrisome, and may be indicative of issues with damp and condensation. Humidity can also be affected by the presence of humans and pets, (lack of) ventilation, or drying of clothes. Peaks and troughs in the electricity data

were accounted for in terms of what was known about appliances in a home, time of day, occupancy patterns, and the *domestic activities* that could have caused them (e.g., cooking, washing, using electric heaters). Both gas and electricity data were frequently related to cost.

The advisors frequently *labelled* patterns to reflect their understanding of the data, e.g., one segment was referred to as 'having the heating on all night'. Based on the workshop, the advisors compiled a "checklist for the advice visit", a sort of crib sheet detailing their inspection of the data and the issues they wanted to explore during the in-home visit. For some visits where the data was particularly opaque, printouts of the data were annotated as well.

To summarise the workshop, data work revolved around identifying patterns in the data, both expected and unusual, and speculating for what caused them and their potential detrimental effects. This work was oriented to understanding the local indexicality of the data and opening up the unremarkable nature of domestic life for inspection and *analysis*. The work of analysis might be usefully characterised as attempting to reverse engineer the data, tracking back from the data through the use of common-sense, local and technical reasoning to the situated activities and events that produced it. While some patterns may be 'straightforward' to detect, this work is not unproblematic and is inhabited by uncertainty. Speculation, no matter how informed it may be, is still speculation. The best it can do is suggesting possible causes and effects, and this is what data work seeks to arrive at here. The next step is to verify these working assumptions with clients during in-home visits.

In-home visit: performing data work

The in-home visit begins with a further interview focusing on the physical condition of the house, whether or not energy efficiency measures are in place (e.g., insulation), if the clients have health problems that might be related or exacerbated by the condition of the property, and how much they spend on energy bills. The advisor then moves on to discuss the data, using a tablet to look at (non-interactive) line charts or printouts of the data. Annotations of the printouts or the crib sheet detailing issues arising from the pre-visit workshop are drawn on as prompts to discuss particular data streams and to establish whether or not there is link between them and the client's potential issues on energy bills, energy efficiency, housing condition, health or well-being. The following extended and edited vignette illustrates data work here:

Vignette 4.1

The client reports in the interview that himself and his children suffer from "coughs and colds all the time". There are also issues with mould and damp in bedrooms, and high gas bills.

Advisor: So this is like a week of your temperature changes, with the time along here (pointing at chart – shown in Figure 2). So that's when you're getting up for work.

Client: Yes.

Advisor: You can see there's a number of peaks - one in the morning, normally, and then one kind of around about three o'clock, and then also continuing a bit into the evening.

Client: It all depends on how cold it is, doesn't it?

² Although the researchers had initially hoped that light data might be indicative of external temperature (brightness), this proved too unreliable in practice; light data was barely brought up in the workshop, nor in the home visits.

Advisor: Yes. But also looking at your charts - for example on the Sunday, yes (pointing at chart)? So the temperature went up quite high, then dropped over a few hours, and then went back up to nearly 28 degrees.

Client: Yes, just before bed.

Advisor: Yes. So 28 degrees is like really, really, really high - like Mediterranean temperature really.

Client: Well we always have - it's just set at that. That box in the hall, I think that's what keeps it at that, whatever it does.

Advisor: OK

Client: When I put it on, I don't change it. I haven't changed it since the day I walked in this house - what we just tend to do is just whack it on until it gets hot, then turn it off.

In the first part of this exchange we can see the advisor verifying his pre-visit understanding of the data with client: e.g., "that's when you're getting up for work" – "yes." We can also see that the advisor suggests there are stable characteristics to the data - "a number of peaks" at distinct times of the day (morning, afternoon, evening). These are not contested by the client, though they are seen as contingent – "it all depends on how cold it is." The advisor draws on the data to make it visible to the client that, contingent or not, there is something problematic about the temperature cycle, that it is "quite high", unusually so, i.e., "Mediterranean". Importantly an account is offered by the client as to why the data looks like it does: we "just whack it on until it gets hot, then turn it off". This account, in turn, becomes a resource not only for understanding the data but also proposing remedial actions:

Vignette 4.2

Advisor: So there's a sort of pattern in your heating - morning time, kind of roughly three o'clock time, before the kids get home from school ...

Client: Yes.

Advisor: ... and then maybe a bit more in the evening as well; people relaxing, whatever.

Client: Yes, it all depends what the weather's like to be honest you know.

Advisor: So that might be one thing to try, to bring your temperature down a little bit, looking at your room thermostat in the hall, seeing if you can take that down a bit.

Client: I just put it - I didn't have a clue how to do it to be honest. So I just thought oh, I'll just put it up to full and see what happens.

Advisor: OK. The timer - you can program it to come on at certain times a day.

Client: I'm not really into that programming thing. I'd rather just put it on when I want it on.

Advisor: OK. It's just a suggestion, so it's set ...

Client: If I want it on, I'll put it on, and if I don't - it's the same with my partner, she's the same. I'm never going to use a timer on it, never. I'll just put it on when we need it.

Advisor: Let's just have a quick look at the other ...

Client: Yes, but it's just easier for us to just put it on when we need it. The way I see it, if my house is cold, and my kids are cold, I don't care if we have to pay, I'll put it on. Because I'm not going to make my kids cold. If I have to put more money on, I will.

Advisor: OK.

Here we can see that the client's account of what causes the unusually high temperature enables the advisor to assert that there *is* a pattern to the heating. This is verified by the client, though still seen as contingent. However, establishing that there is a pattern and its cause enables the advisor to propose a potential solution that would reduce the client's bills: turning the thermostat "down a bit". The

client initially responds to this proposal by saying he doesn't know how to do this. The advisor informs him that the thermostat can be programmed. The client rejects the proposal again: "I'm not really into programming". The advisor recognises that potential for conflict here and tries to mollify the client and then move on to another topic. However, the client provides further accounts for his actions that not only justify them, but do so ostensibly on moral grounds (his duty of care for his children) and with respect to a primordial imperative or priority in family life (ensuring the children aren't cold). This is not to say that the data cannot be acted upon:

Vignette 4.3

Advisor: You might want to have a look at the boiler because ...

Client: The boiler is rubbish.

Advisor: ... that will reduce the temperature of the water that's going into your radiators and will help to improve the temperature.

Client: Yes, OK.

Advisor: You know the thermostat valves on the radiators?

Client: Yes.

Advisor: Do you use those much, or do you just leave them?

Client: No, I leave them on full.

Advisor: So you could turn ...

Client: There's one room where we don't have the radiator on in. That's the room which has got the damp in. There's no point in burning gas having that one on when no one's ever in there.

Advisor: Well yes, actually, what might help is if you put the one in the mouldy room on a little bit, on like a one.

Client: Just to keep some warmth in it you mean?

Advisor: Yes. And then in the other rooms, turn them off completely during the day. So when the girls get up in the morning, tell them to turn their radiators off. Then at night, just before they go to bed ...

Client: Turn them back on again. Yes, I see what you mean there.

Advisor: Because that's going to save you ...

Client: So we put the heating on in the day down here ...

Advisor: Yes, and because also what's going to happen, the heat's going to rise.

Client: Because it's heating upstairs and downstairs for no reason isn't it.

Advisor: Yes, the heat's going to rise anyway, and you could try that, try it for a week.

Client: I will do that, actually.

Here we can see that the heating problem has various aspects to it: it is not just about the thermostat but the boiler and the radiator valves, the settings on each being directly implicated in the problematic heating pattern. The advisor proposes further potential solutions, which might address both the heating and the damp problem. It is notable here that data is *not* appealed to. Its use is confined to establishing patterns and elaborating causes, but with these in hand the business of working out solutions turns upon the further elaboration of current practice and proposing novel future practices that will mitigate or resolve the problems to hand. Importantly the work here turns upon accounting for the consequences of current and prospective actions. So again, just as with installation, it is not enough to account for what is (or in this case could be done), but why or to what end.

In summary, performing data work involves verifying pre-visit understandings, which provides a basis for unpacking the indexicality of the data, particularly the rhythms and routines that provide for it. This, in turn enables the identif-

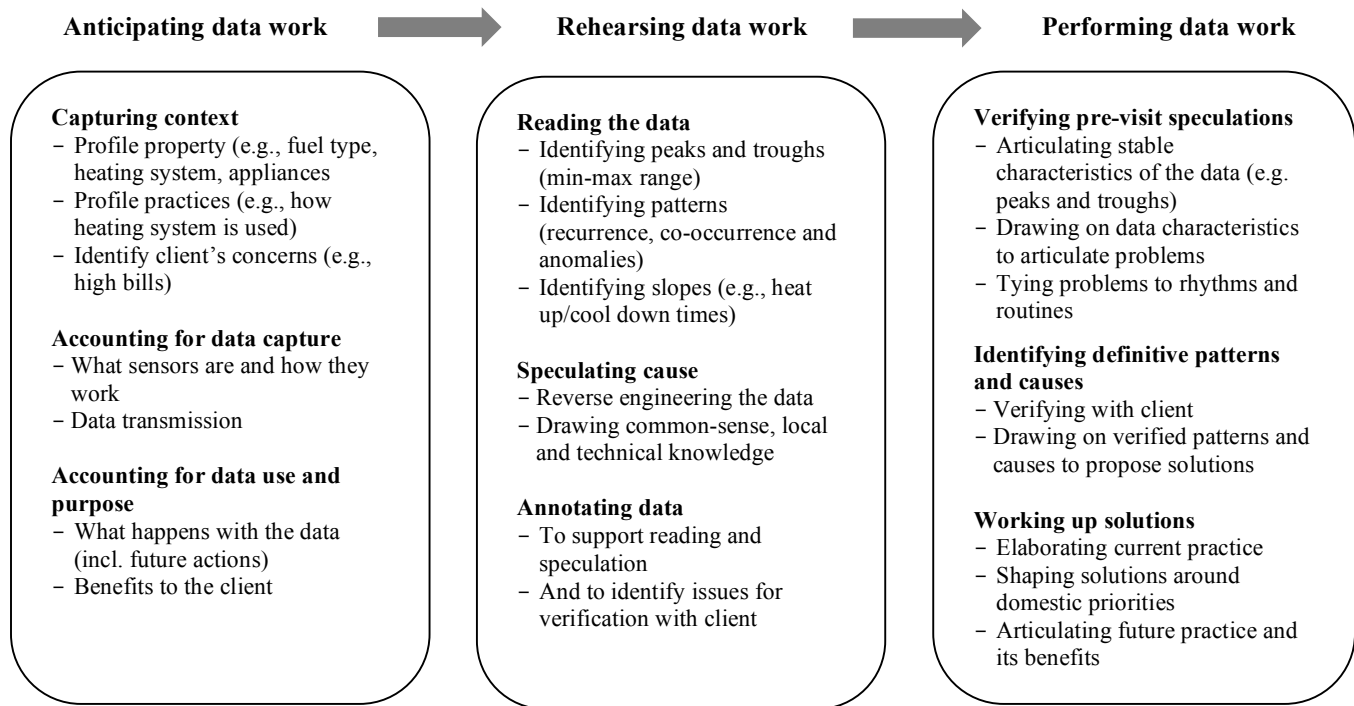


Figure 3. Key stages of sensor data work.

cation of definitive patterns and their causes,³ which in turn provides a basis for elaborating potential solutions. Where the client is in a position to remedy problems, these matters are worked up and out in the course of interaction between advisor and client. Importantly, they turn not only on the data and working out its indexical relationship to human practice, but on the morally accountable grounds on which practice stands. Not anything will do as a solution then, no matter how reasonable it may appear from the outside. Solutions are, evidently, contestable and must chime with the priorities of domestic life.

The naturally accountable order of sensor data work

The vignettes presented above elaborate what Sacks [24] called the “machinery of interaction”. What Sacks is driving at here is that interaction is possessed of generalisable features that order it *in situ*. So while each data set is unique, just as each home is in its problems and practices, the ways in which data work gets done *in* interaction is possessed of stable properties or “procedures” that organise its conduct. These are reflected in Figure 3. They not only consist of anticipating, rehearsing performing the data. Each of these key stages is possessed of its own unique methodical procedures [15].

Thus data work begins with the installation of the sensor kit, which is methodically occupied with the work of

³ Often this is sufficient for the advisor to provide *evidence* to third parties (e.g., landlords) that problems exist and need to be addressed.

anticipating the data. This involves capturing context, which is an important resource in subsequently making sense of the data, accounting for data capture, use and purpose, and the benefits the data will bring to the client. *Rehearsing the data* follows on from this and is methodically occupied with reading the data to identify patterns, their causes and consequences. This involves speculation and draws on various orders of reasoning to “reverse engineer” the data and explain how it could have been brought about, and annotating the data in preparation for in-home visits. *Performing the data* is methodically occupied with verifying pre-visit assumptions and identifying definitive patterns and causes, which turns upon unpacking the indexicality of the data to domestic rhythms and routines. This in turn enables solutions to be proposed and shaped around domestic priorities.

SENSING FOR ADVICE GIVING

The stages of sensor data work bring to the fore its *retrospective-prospective* character. Anticipating the data is oriented to what it will be used for, rehearsal to what produced it, performance to what action can be taken on its basis, all of which turns upon articulating the data and making it accountable to the orderliness of domestic life and the rhythms and routines at work in ‘this’ home. Key to this achievement is the householder or client. Should his or her input on what the data means be absent, what can be done on its basis cannot be definitively established.

It is worth stressing here that our sensor kit seeks to enhance the delivery of advice from an expert; rather than

to deliver information to the householder for them to understand and act upon, or provide information to a remote entity charged with undertaking some form of 'big data' analysis. Thus, we deliver information *in support of a relationship* between client and advisor and the tailoring of bespoke advice. We undertook a workshop with the advisors following collection of the sensor kit from the clients' homes to explore in more detail the impact of this approach and the ways in which the sensor data impacts advice giving. In this section we wish to highlight specific issues that arose for advisors in the use of sensor data and the implications this might have for the design of an improved sensor kit and interactive system for data work.

Data helps build trust

The consensus among advisors was that the data was useful in establishing and supporting their relationship with clients. One of the key problems they have to deal with as advisors is getting the client to listen to them, or "getting close to the client." They found that the data helped build a better relationship with clients, both in terms of understanding the problems that confronted them and being able to evidence their claims, which in turn helped build trust. This was seen as key to being able to get client's to act on advice. As one advisor put it,

"The woman had problems with humidity in her kitchen, and I think that being able to see that on the graphs showed her that I believed her ... gave her a bit more faith in me actually understanding the problem ... and that then helped me to give her further advice."

It was felt that "being able to see" problems in the data increased the advisors' ability to engage effectively with the client and the client's confidence in their advice. The provision of the data allowed the advisor and client to work together to address identified issues, rather than the advisor having to debate the issues with the client and convince them that the phenomena was occurring.

The challenges in elaborating data to clients

The deployment of sensors and the collection of data also impacted the advisors' work practices, changing how they oriented to the task of providing advice. Although recognising the value in enhancing the relationship with clients, advisors also stressed that this was not without issue. They outlined three particular challenges that arose from the use of data as an integral part of advice giving.

Enriching the Data

The advisors drew particular attention to the work required prior to a consultation with clients. Working through and annotating the data in preparation for the in-home visit was time-consuming. Advisors argued that this preparatory work requires explicit support.

"So if there's a way to annotate electronically, that would be good."

In addition to supporting the enrichment of data through annotation prior to visits, advisors also thought that it would be useful to have more sensors including outdoor temperature (to disambiguate indoor temperature fluctuations) and CO₂ (to disambiguate occupancy).

Client involvement

The advisors stressed the critical role of the client in making sense of the data. The data was often made legible by the client in conversation with the advisor as part of the visit. Consequently, the advisors thought more could be done to improve clients' input and aid their recall of events.

"The data we looked at was actually quite old. Often it was a month old. So it's really important to be quite temporally close to the date that you're looking at, because then they will actually remember and say, Tuesday, I did this and that. So you have people that remember and have more certainty as to what actually caused the data that you're seeing."

The advisors argued that the work of "rehearsing data" prior to advice-giving fell too much to the advisor and that some balance, where the client also prepared the data prior to an in-home visit, might be beneficial. They wondered if a deployed system could be enhanced to allow clients to provide self-annotation and develop a range of services and functionality to allow the client to make notes to support their preparation for the advice sessions.

Conveying Savings

The advisors emphasised that giving advice was the principle purpose of their visits and that saving their clients money was the driving focus of their work, rather than data interpretation. Consequently, they thought that it would add value to their dialogue with clients and other parties to convert raw electricity and gas measurements for selected periods of time into monetary values, which in turn could be converted into 'value for money' savings. In addition to being directly useful to advice work with clients, this would speak to the city council's concerns with the affordability of their properties. As one of the advisors put it,

"If it's clear that the house is not enabling the tenants to live comfortably and affordably, and we have evidence, then I would have thought it would go into their decision making in some way."

BROADER IMPLICATIONS FOR IOT SENSING

Deployment of the sensor kit to support energy advice-giving and reflection on its use has raised requirements for future work, including the extension of the sensor kit and development of interactive systems to support data elaboration and articulation. However, our experiences also speak to a number of broader issues concerning the IoT and its use, particularly in domestic settings. Our study demonstrates the way in which data work turns upon *unpacking the indexicality* of sensor data and making it accountable to the temporally-ordered practices that organise domestic life. These practices are manifest as domestic rhythms and routines, motivated by the priorities of domestic life. Their articulation is key to advisory work, both to understanding problems, their causes, and consequences, and to working up acceptable solutions. Advisory work turns upon reasoning through the data in relation to these matters to identify problems and formulate alternative practices that resolve them.

Our findings support emerging ethnographic work that reveals the legibility of sensor data relies upon various

orders of situated reasoning, including reasoning about time, activities, routines, exceptions, people and the moral order of the home [35]. These findings underscore the *essentially* indexical character of sensor data – i.e., that its sense is *irremediably* bound up with situated action and the temporally-ordered practices that organise it. This is not to say that what sensor data means or reveals cannot be inferred – common-sense reasoning along with other kinds of reasoning (e.g., mathematical) can always be applied. It is to say that such readings have the character of speculations, informed guesses at best, and these of course may be erroneous. The inability of a learning thermostat to understand ‘context, situations, and intent’ [39] provides a point in case, and this is but a single sensor.

The essential indexicality of sensor data occasions the need to build people whose behaviour is sensed into the loop, at least insofar as systems are designed to respond to their conduct. System-supported dialogues might enable this, but they will need to be two-way (not just machine to human) insofar as a) inference about practices in the home is necessarily limited by the indexicality of sensed data, and b) the formulation of alternatives is contingent upon the client’s domestic priorities, which are not captured by the data. There is a need then to actively involve data producers in a dialogue a) to understand the action that generates data and the reasoning implicated in it, and b) where remedial actions are required, to formulate viable alternatives.

If sensor data is to be appropriated to augment human action, whether it be in human-human interaction or automated machine-based interaction, it is crucial that sensor-based systems provide ways for collected data to be mapped to local goings-on in much the same way as is apparent in the negotiations between advisor and client in our fieldwork. Here the sensor data is a *resource* drawn upon to support the situated reasoning involved in attempting to answer whichever question is at stake and figure out appropriate responses.

The workshop with the advisors has provided important insight into how this resource may be improved by providing an interactive system that supports the various orders of reasoning implicated in reading the data, and annotating it with speculations about the local indexicality of the data. The purpose of the interactive sensor data system is not to automate sense-making, but to provide people with the tools they need to make sense of the data and formulate appropriate responses. The broader challenge will involve working out how to build such tools into automated sensor-based advice-giving systems of the kinds that large utility providers are beginning to adopt and other help-giving IoT systems in the home. In short, if you want to help the householder, you ought to provide the means to understand what he or she does. Data alone is not sufficient.

CONCLUSIONS

This paper has focused on exploiting sensor data to support the work of energy advisors. It is premised on prior

ethnographic studies of advice-giving practice [13], which shaped the design of a sensor kit capturing energy and environmental data in clients’ homes. The sensor kit was deployed in 12 homes for between 4 and 6 weeks and the data made available to the energy advisors and their clients. The deployment was studied through fieldwork, including studying installation of the sensor kit, pre-visit reviews of the data by advisors, in-home visits between advisors and clients, and post-deployment reflection on the experience.

The study focused on the collaborative nature of sensor data work, and revealed 3 key stages to its accomplishment: anticipating the data during installation, rehearsing the data during pre-visit review, and performing the data during in-home visits. Unpacking each of these achievements through ethnomethodological analysis has made it perspicuous that data work turns upon articulating the *indexical* character of sensor data, particularly the domestic rhythms, routines and priorities that order domestic life and make the data look like it does. These matters drive data production but are not contained within the data itself. Their articulation enables advisor and client to build a collaborative understanding of the problems ‘at work’ in a particular home, their causes and consequences, which in turn provides the grounds for formulating remedial actions.

The advisors have found that the use of sensor data has added value to advice-giving practice, enabling them to get closer to their clients, build trust, and better evidence problems to clients and third parties (e.g., landlords). Their experiences have also raised further requirements for extending the sensor kit and developing interactive systems to better support sensor data work. However, the indexical character of sensor data has broader implications for the design of IoT applications that seek to offer in-home advice. The need to articulate sensor data makes it perspicuous that its factual status *cannot* be established independently of the circumstances of its production; a finding that echoes Garfinkel’s comment on ‘organizational data’ [20:138]. This means that it will be necessary to build support for articulation work into advice-giving IoT systems and enable a dialogue between householders and service providers to establish what the data is really all about and what should really be done in response.

While much may be read off sensor data, either through common-sense reasoning or big data analytics, the veracity of the data in this context inevitably turns upon the clients’ input: the data is indexical to his or her everyday life and the parties they live with. Whether building systems to augment advice-giving or to automate it, there is a need on both counts to *build the user into the loop* and enable articulation of its essentially indexical character if the IoT is to gain traction and deliver the envisioned benefit to users.

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