When Looking out of the Window is not Enough: Informing The Design of In-Home Technologies for Domestic Energy Microgeneration

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ABSTRACT
This paper reports results from an empirical study that explored how people understand, perceive and think about domestic energy microgeneration. With a focus on electricity generation the study highlights future design directions for digital technologies to help people make better sense of microgeneration in their home.

Keywords
Energy microgeneration, solar panels, energy storage, sustainability, smart grid, smart home, energy positive building, human computer interaction.

1. INTRODUCTION
Sustainable ICT and HCI research has had a strong focus on the challenge of reducing energy consumption – ranging from developing smart meters, detailed studies of energy usage, and persuasive technologies to encourage behaviour changes. A recent review of the HCI literature reveals that current work is narrowly focused on a specific set of goals and interventions, namely increasing users' cognitive awareness of electricity consumption and promoting electricity conservation behaviour by means of consumption feedback, particularly by visualizing energy consumption data [1].

In contrast, with some notable exceptions [2–5], relatively little work has been carried out surrounding the practice of *energy production* in homes – a practice referred to as domestic energy microgeneration. More and more people are adapting their homes with energy generating technologies, such as solar panels, heat pumps and small wind turbines, in order to make a contribution to the green energy infrastructure. The energy they thus produce can be used for their own consumption, supplementing traditional centralized grid-connected power while superfluous generated energy can be exported to the grid to be consumed by their neighbours. However, not much is known about the domestic energy practices of people living with energy microgeneration.

From the research into energy *consumption* we know that one of the overwhelming problems underlying people's relationship to electricity is the *invisibility* of energy. Energy, in the form of electricity and gas have been assigned a background role in the home [6] – with boilers and meters hidden in cupboards, and energy bills being presented only very sporadically, in many cases quarterly or annually. This makes it difficult for people to build up a relationship with energy usage. While the invisibility of consumed energy is widely reported, less is known about the visibility of the energy that is *generated* by individual households.

In this paper we report on a qualitative user study involving UK households with and without microgeneration. The aim of the study is to understand how people currently experience microgeneration and how we should design digital technologies to help people make better sense of microgeneration in their home. In the remainder of the paper we describe technical, regulatory and consumer aspects of microgeneration in the UK before we describe the methodology and results of our study.

2. Domestic Microgeneration in the UK
Domestic energy use accounts for more than a quarter of CO_2 emissions in the UK. Traditional approaches to energy reduction look at direct emissions savings through a combination of insulation and efficiency measures, combined with smart meters and in-home energy displays. Microgeneration is seen as an additional way for citizens to help combat climate change with the potential advantage of achieving energy savings without having to sacrifice comfort and to contribute to demand shifting and a decentralized generation infrastructure. Many countries around the world offer financial rewards to citizens who opt for microgeneration installations, easing the burden of the upfront capital cost. On 1 April 2010 the UK government introduced a Feed-in Tariff (FITs) scheme to encourage more rapid deployment of small-scale (less than 5MW) low-carbon electricity generation, particularly by organisations and individuals that have not traditionally engaged in the electricity market. The scheme rewards the homeowner (and whoever they subsequently sell their home to) with a guaranteed inflation-linked 25 year payment for every kWh of electricity generated regardless of whether or not they consume it or export it to the grid, plus a payment for every kWh exported to the grid. The original scheme in 2011 paid GBP0.43/kWh generated plus GBP0.03/kWh exported increased annually by the official inflation indicator for 25 years. The maximum domestic capacity allowed for this scheme is 4 kWh peak production but the average system has about 3.1 kWh peak capacity [7].

The scheme caused a huge take-up of grid-tied Solar PV installations (the most cost effective microgeneration technology). By September 2012 there were over 360,000 residential installations with a constant pace of over 1,200 installations per week [8] which shows no sign of abating. It proved so popular that the government halved the payments for new installs without warning and has been slowly reducing this feed-in-tariff but the rate of new installations is still relatively high (overall domestic generation is still just about 0.1% of consumption).

Although a small minority of domestic generation customers opt to pay for a live display showing the amount of energy currently being generated, they have no idea how much of this they are

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consuming or exporting because export meters are not normally installed: the export payments assume that the home consumes 50% of the generated power and exports the rest. Even where they are installed, export meters simply show a cumulative total number as the consumption meter does (**Figure 1**), so there is no real time or historical data available. Even the quarterly electricity bill does not help as it shows how much energy was purchased from the grid (or the monthly or quarterly estimate) with no information about PV generation, consumption or export. Under the rules of the FIT scheme, consumers read their own generation meter every quarter and send this reading to their electricity company who then send a payment for the electricity generated that quarter. The consumer should see a lower electricity bill in the year after PV is installed, but there is no other indication available to them connecting generation and consumption. Thus there is a strong motivation to use all of the energy generated because the consumer will be paid for an assumed 50% export even if they consume all the microgenerated power and the payment for export is relatively small.

To provide a concrete example of the numbers involved: one UK household we looked at with a 3.3kWh peak system generated 3215 kWh in 2011 and in return received £1543 in FIT payments for generation and export. Yet how much kWh of the generated kWh was exported and how much was consumed is unknown to the household.

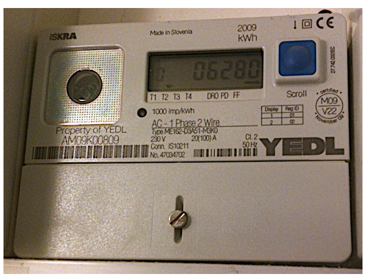


Figure 1: PV Generation Meter (showing total accumulated energy)

3. People and Domestic Microgeneration

Motivations and Adoption. Adoption of domestic micro-generation is still relatively low and not much is known why households choose to buy them, what households think about producing their own electricity, and how they perceive them. A 2006 study by the Open University on the drivers for adoption of micro-combined heat/power systems (before feed-in tariffs came into effect) uncovered that for users of solar PV environmental concerns topped the agenda, with a significant portion of the respondents mentioning "pleasure of using a renewable energy" (31%) [9]. Similarly, [10] discovered that environmental concerns are the main motive for adopting PVs or micro wind turbines. Some household adoption represents a way to reduce fossil-fuel use. For others, this investment is symbolic and provides a way to display environmental consciousness or to set an example. For still others, adoption is a protest against "the system," or a step toward self-sufficiency [11]. Conversely, some households reject microgeneration installations because of financial considerations, respect for neighbors who might object, and/or difficulties finding an appropriate site. Among our participants with PV installations, all had been inclined towards installing PV due to ecological awareness but had hesitated because of cost. Once the feed-in-tariff was introduced, it became, in the words of one participant, "a no-brainer."

Behaviour Change. In 2004 the Green Alliance's Micro-generation Manifesto [12] argued that the small-scale nature of micro-generation means that individuals can play an active part in attaining the UK's environmental goals:

> *'Micro-generation will make the public co-producers of climate change solutions rather than passive consumers of energy, helping to combat the 'what can I do?' apathy that undermines so many well- meaning public education campaigns' [12]*

Indeed the literature provides evidence that microgeneration technologies encourage energy efficient behavior. Keirstead [2] describes microgeneration as delivering a 'double dividend' – that is, not only does microgeneration produce green energy but also give rise to reduced electricity consumption behaviour. A UK study [13] observed that 88% of consumers who installed microgeneration found that household behaviour was significantly altered to reduce energy consumption after installation (including lifestyle changes as well as traditional energy saving measures). Keirstead [2] highlights that some households with microgeneration engage in 'demand-shifting' - a particular form of behaviour change where energy consumption is shifted towards times of the day when production is at its highest.

Other research has noted a heightened *energy consciousness* among consumers, even those merely in contact with microgeneration:

> *"Beyond the sheer excitement and pleasure of DIY energy generation, the impact is seen in householders' shifting attitudes to energy conservation and consumption ... there starts to develop a strong sense of which behaviours are free and self-provided, versus ones that cost money and are supplier-dependent." [14] p. 6.*

Keirstead's study [5] states that "micro-generation provides a tangible hook to engage householders emotionally with the issue of energy use". The emotional resonance appears to be connected to the "sheer pleasure of creation and of self-sufficiency" reported by participants.

Understanding Microgeneration. The reported behaviour changes, especially those related to purposeful demand-shifting, are surprising given the lack of concrete information people have about their own electricity generation. As indicated above, even with currently available energy monitors the generated energy is essentially invisible to home occupants. Users "experience" the energy primarily through a lowered energy bill (only by manually comparing bills for the same period one year after installation). The problem is that a consumer, who wants to shift demand (e.g. the use of a high energy device such as the washing machine, oven, or dishwasher) to a time when free solar energy is available, has no data to base this decision on and is thus left to guess the relationship between demand and supply.

Energy demand reduction and behavior change has been linked to energy feedback systems, such as smart meters or in-home displays [15]. Yet while early studies have speculated about potential synergies between feedback and microgeneration [16], and while households seems to express desire for energy monitors that show consumption *and* production [2], we have no real understanding about the link between microgeneration, feedback and behavior change.

Energy Savings. While some studies have reported net energy savings related to the use of microgeneration [13], [14], [17], other studies question if the theoretical possible savings from installing microgeneration can be realized in practice, and claim that savings are considerably lower than the 'potential' savings predicted by the industry. For example, a recent study of solar thermal water heating in the UK found that the majority of systems surveyed achieved no more than 6% of their potential heating energy savings [18], while [10] claim that the low savings are due to a complex mixture of behavioural, institutional, economic, cultural and technical reasons and the lack of a ‘whole-system approach’ to provisioning microgeneration solutions, resulting in sub-optimal products and installations, as well as a knowledge gap by consumers. Future innovations like domestic energy storage and electric vehicles will certainly complicate the situation.

4. Microgeneration Study

How can people get more out of their own microgeneration installations? How can they better understand microgeneration in relation to their own habits and energy consumption patterns? And how can digital technology help?

In the case of consumption there is a clear case that digital technology can help alleviate the knowledge gap and help people become aware of their own consumption habits – and thus help them to develop more energy efficient practices. Does the same apply to microgeneration? There are several possible angles for the design of digital technologies: A recent study on domestic heat pumps [17] discovered that people who had more information about the working of their pumps were gaining more efficiency from their installation – pointing to the power of information and knowledge. Pierce, in contrast, developed recommendations for default settings on appliances, so that users tend to use them more energy efficiently, even without realizing – essentially arguing for smart design over knowledge [1]. With microgeneration we have no clear indication in which direction to go. Thus we designed and conducted a study with two aims:

1) the first aim is to understand how people currently experience microgenerated energy;

2) the second aim is to understand what roles ICT can play in mediating the relationship between people, microgeneration technology and the energy people generate.

Ultimately our goal is to design novel ways of experiencing energy to inspire a positive chance in energy consumption habits. Answers to these two questions will be a first step towards informing the design of digital technologies for the home that helps people use their own generated energy in a more efficient and effective way. In the following we describe the study design and provide an outlook on the results.

4.1 Study Context

We are working in collaboration with E.ON, a major European energy retailer, who is running a multi-year trial of smart energy home technologies involving 75 homes in a medium-sized UK suburban city. Participating homes have been fitted with wireless electricity and gas meters and room temperature sensors. Participants can access precise consumption data from their mobile phone or through a web application (in-home display are also provided but because of poor design most participants have stopped using them). In later stages of the trial participants’ homes will be set up with additional energy technologies such as electricity storage to store excess solar power for use at night, electric cars, smart washing machines and smart heating controllers (none of these were available during our study). Some of the participating households already have solar panels installed (or soon will have), and most thus have a keen awareness of energy issues and energy bills.

4.2 Research Methodology

For our study we used a two-stage methodology. The first stage consisted of focus group meetings with a large number of participants. The second stage consisted of a one week home study with technology probes.

The focus groups were organised as part of the larger trial and used to discuss various topics including technical problems, people’s experiences during the trial and ideas about novel technologies. Focus groups were run by professional facilitators with us as researchers acting as observers. We used video recordings and written transcripts to analyse the discussions with respect to concerns, attitudes, perceptions, motivation, and requirements of participants.

Insights gained from the first stage informed the second stage in which we used technology probes [19] installed at the homes of a small number specially selected participants. The aim was to let people explore their own attitudes, understanding, experiences and opinions about microgeneration in the comfort of their own home, without researchers being present. The technology probes, a set of interactive displays showing energy data and controls, were intended to stimulate the discussion. Our engagement with participating households comprised four steps: 1) recruitment; 2) installation of technology probes at participants’ households 3) week-long living with technology probes by participants (without presence of researchers) 4) debriefing. After installation of the probes, participants were asked to “live” with them, i.e. to observe and use them and to contemplate their meaning and purpose. A rudimentary explanation of the context and objectives of the study was provided in written form, as well as supporting materials such as audio recorders, cardboard and sketchbooks so that participants could capture thoughts and ideas. A week later a debriefing session took place at the home where two researchers sat down with inhabitants to go over the collected materials (sketches, recording) and to discuss the users’ experience. Participants were prompted to reflect upon their experience with the probes and recollect discussion that took place in the household during that week. Each home visit was recorded for later transcription and analysis.

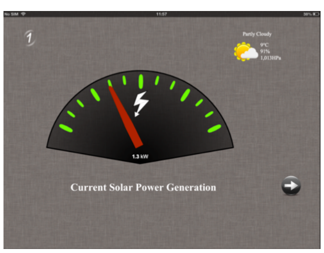
4.3 Technology Probes

As technology probes we used a set of custom-designed interactive displays that provided participants with 16 different data visualisations and user interfaces related to microgeneration (Table 1 and Figure 2). The design of the probes was purposefully kept incomplete and rudimentary: rather than as design endpoints that participants were supposed to criticize, they were intended to spur freewheeling discussions and collaborative exploration by members of a household. The design of the probes explored several dimensions (see Column 5 in Table 1):

- *The amount of energy a household generates*: We used metaphors such as the dial or the battery to represent abstract, concrete, absolute and relative quantities.
- *The locality of energy*: whether energy is available for the whole home or dedicated to specific appliances and uses.
- *Interactivity*: some displays simply visualize energy production while others allow users to influence how this energy is used in the home.
- *Temporal aspects*: Some displays explore the temporal dimension of production and generation while others focus on momentary available energy.
- *Future technologies*: Some displays assume technology that is currently not available in homes. In particular, we explored issues around domestic energy storage.
- *Environmental conditions*: some displays featured icons representing current or forecast weather conditions (Figure 2a and 2f).

Table 1. Technology Probe Design

Probe	Explanation	Metaphor	Focus	Issues that this probe raises
a) Dial	A probe that displays the amount of currently generated energy.	Analog Dial	House - currently generated energy	Probe focuses on momentary availability of energy (here and now), and peek production. It deliberately makes it difficult to see temporal fluctuations in energy generation.
b) Battery (House)	A probe that conceptualizes a house as a battery that can be charged and drained.	Battery	House – available generated energy	Probe focuses on near term availability of energy. Introduces temporal aspects: How long does it take to 'charge' a house? How long does a 'charge' last?
c) Battery (Appliance)	A probe that conceptualizes energy as being available or reserved for a particular appliance	Battery	Appliance – available energy	Probe focuses on every day tasks such as doing laundry. Moves away from whole house issues to appliance-level issues. Uses relative energy measures (full-empty): Can I use this appliance now? Raises questions about future availability: If not now, when will I be able to use it?
d) Potential Use	A probe that indicates how often an appliance (for example, a washing machine) can be used before the available energy is used up.	Analog Dial	Appliance – potential tasks	Probe focuses every day tasks and moves away from abstract energy quantities. It relates energy to family life and accomplishing everyday tasks: "Can I get my washing done?" "How often can I use the washing machine?"
e) Generation and Consumption	A probe that visualizes the gap between energy used by a household and the energy generated by the house.	(graph)	House - total energy generated and consumed by a household	Probe focuses on two issues: 1) the fact that there tends to be a gap between the amounts of generated and used energy 2) the fact that energy generation fluctuates over time. Discussions around this probe might highlight questions such as: "How large is the energy gap?" "How can we minimize the energy gap?" "What factors influence energy generation?"
f) Energy Forecast	A probe that visualizes expected future energy generation.	Weather forecast	House – potential tasks	Probe focuses on future availability of energy. Highlights temporal fluctuation of energy generation: "How much energy will we generate tomorrow/next week?"
g) Switch	A probe that allows users to decide how an appliance is powered: from grid power, from self-generated power, or from both.	Switch	Appliance – energy source	Probe enables users to decide the energy source of individual appliances and thus enables them to use generated energy for a particular purpose. Implicitly enables users to express priorities, importance or values. "Only enable this appliance if there is enough energy available." "Enable this appliance now regardless of availability of generated energy".

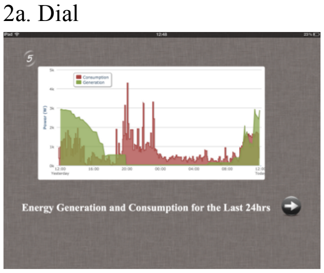


2a. Dial

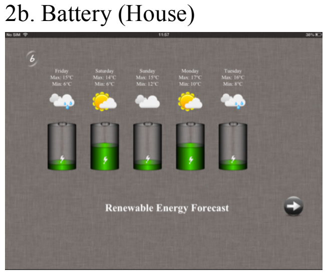
2b. Battery (House)

2c. Battery (Appliance)

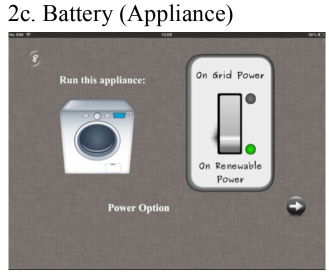
2d. Potential Appliance Usage



2e. Generation and Consumption



2f. Energy Forecast



2g. Switch

Figure 2. Technology Probe Interfaces (displayed on iPad and Android tablets that were placed in participants' homes)

Each household was given two iPads as displays: one iPad was showing information to the house as a whole, while the second display referred to one specific appliance - the washing machine. Participants were invited to place the iPads in locations were they felt they would be most useful to them. We did not specifically indicate where this should be, but did suggest that the one relating to the whole house production/consumption should be in a place where all members of the households would have easy access to them. The display relating to the washing machine was to be placed near the washing machine.

In this study we are using semi-functional technology probes: the displays exhibited realistic data and behaviour but this behaviour was scripted and unconnected to the existing energy infrastructure in the participants household. This was necessary because data feeds provided by the energy company were unreliable and incomplete and because some probes visualised data that assumed not yet existing technology (notably energy storage). In order to minimise discrepancies between energy displays and real world we created realistic simulated data by using historic data from an existing yet unrelated home and by harvesting live data feeds (weather and PV energy production) from other local sources.

4.4 Participants

For the technology probe study we selected six participating households to take part. Four households were also participating in the wider trial, and two households were selected through informal contacts, such as friends and neighbours of the researchers. Four of the six households had solar panels fitted – within the last 6 to 24 months - and two households were actively contemplating doing so and had done much background research into the issues. The six households were all middle to upper-middle class households, with different family structures: some without children, some with teenage children or children who had left home. In total a group of twenty participants were involved, spread out over six households.

Table 2 – Participating households.

	Household set-up	Solar power
HH1	Two parents with 3 children aged 13 to 17	3.7 kWh peak for 18 months, 20% reduction in bill
HH2	Two parents and one 14 year old child	2.7 kWh peak, for 24 months, 27% reduction in bill
HH3	Two parents and two children aged 17 to 19	Considering installation
HH4	Husband (scientist) and wife with occasional visiting grandchildren	1.9 kWh peak for 6 months
HH5	Two adult females	Install pending
HH6	Husband and Wife (scientist)	3.3 kWh peak for 9 months

5. Focus Groups

The focus group delivered a wide range of insights about peoples' energy practices, attitudes and experiences with various energy technologies, some of which was directly related to microgeneration. In particular we were able to identify practices that resemble what [5] described as demand shifting. People reported that they base their decision about if they can switch on their appliances by looking out of the window to see if the sun is shining. Participants in the focus groups reflect on when they use their appliances:

"We now switch on (appliances) when the sun is out – so that's happened with the introduction of solar panels…"

While this is showing that participants are changing their behaviour, there is also uncertainty about what they can or can't do, due to a lack of information:

"the sun was out, so the washing machine was on. It would be nice if I could do the ironing – but I don't know how much …"

"My wife now asks: Can I put the washing machine on? She's starting to think how she could use it separately – not all at the same time, because she know there's not enough coming in…"

While looking out of the window can give an approximation of amounts of energy being generated – it is not straightforward for consumers to work out exactly how much "spare" energy they have to play with. To do this properly they would need to know: (i) *the precise power consumption pattern of the appliance in kW over time* and (ii) *the actual current net exported power from the microgeneration installation (and ideally how long it will be maintained).*

Few participants knew what the wattages of their appliances were, let alone the pattern of consumption. For example, a typical coffee maker might be rated at 2.7 kW but only draws this for the first minute of operation and subsequently draws very little power, which is not obvious.

None of the participants really understood how actual energy production is influenced by the peak capacity of their installation and environmental aspects. Even knowing the peak generation capacity is fraught with problems: the peak capacity of a PV installation only applies under cloudless conditions, around noon for an installation under perfect conditions: south facing roof, 30 degree roof pitch, no shading. As we discovered few installations satisfy all five of these condition. Figure 3 shows one of the participant's homes with a less than ideal PV installation due to partial shading by trees, orientation and roof pitch.

Figure 3: PV panels (2.7 kWh peak) on Participant's roof facing south-east, shaded by trees, at 42 degree pitch

6. Results of the Technology Probe Study

Our analysis of the interviews with six households involved in the technology probe study showed a general high level of engagement with the probes and lively family discussions during the week-long installation. Some individuals had clear favourite displays that they would return to often to look at, pointing it out to other members of the family, while other displays had puzzled them. Most participants had rather enjoyed the idea and look of the shiny iPads in the house although they were also worried that the iPads themselves were consuming energy (in fact this is negligible). In most households there had also been clearly one or more individuals who had interacted with the displays more than the others - comparable to people taking the roles of home technology drivers versus passive users in Mennicken's study on people living in smart homes [3]. Furthermore, visitors such as the children's friends or grandchildren took a keen interest in the displays and were eager to report their opinions to the researchers. Some people were not sure how long the interest would be kept up for such displays mentioning – "after four days we didn't notice it any more", or "the girls didn't even look up to ask what they were, they're so used to all this technology…" But this would be argued against by others saying "I loved walking through the room, and then the display would change, and it would just catch my eye, I'd see it just out of the corner of my eye…"

People were eager to discuss their habits, and discussions went well outside the precise discussion of the displays themselves, and reflected on their own awareness of electricity consumption as well as production. Below we present our findings in terms of a set of themes related to energy production in the home: (i) level of abstraction (ii) locality (iii) information detail.

6.1 Abstractions and Representations

Some of the displays we used were hinting at future technologies such as energy storage, which are not implemented in any participants' homes yet. In particular we had put forward the idea of a battery (Figure 2b/c) – representing the total available energy for the whole house, or representing the 'number of washes' available for the washing machine. The battery abstraction caused the most controversy amongst participants, with them almost holding opposing views from each other.

In HH1, participants were concerned about this display, as it appeared completely wrong to them. When we explained it was meant to be imagined as a future technology, the reaction was:

> *"It's interesting, because I didn't realize that that was now a possibility. We were very early on adopting the solar panels. But one of the first things I asked the guys when they installed it, was where the power was going to be stored. He seemed very surprised about my question. So it's good if you think that that is moving forward…"*

The participants appeared to be struggling with imagining future scenarios with novel features. In contrast, the participants in HH2 were quite happy to imagine the scenario – also knowing that they may have an opportunity to have the technology installed in a few months as part of the wider trial. One member of HH2 particularly liked the battery icon, '*because of its simplicity'*.

On the other hand, for the participants in HH4 it was an almost useless notion:

> *"We didn't quite fathom this one …"*

and in notes written for day 2:

> *"Discussed washing machine display with wife, but can't convince her that a real 'battery' storage would be of any use to us. Failed, probably because I'm not convinced myself. In future, could the display be used so that if enough solar energy had been accumulated in the battery it would automatically start the washing machine?"*

So although the participants in HH4 had grasped that the idea was to think of a future possibility they could not see its usefulness – unless it was tied to automatically starting the washing machine, whereas without this possibility:

> *"At the moment, an empty battery would show me that we'd have to wait to run the dishwasher till the battery is recharged. Well, there is no benefit for us having to do that. Whether in the future there'll be benefit to that I don't know…."*

This view – of there not being any benefit in 'having to wait' - was not echoed among other participants, most of whom considered this to be a very plausible and appropriate behaviour. In HH6 participants were keen to explain how they do their planning – partly referring to the weather forecast displays, but also partly explaining how they do so at the moment anyway. This was the only household with a special generation meter that was displaying currently generated power, on a handy display in the kitchen:

> *"I might think, OK, I'll wait till it goes up to 2kWatts, before I put the washing machine on, because I know the washing machine uses about 2.5 KW at its peak consumption… So if it looks like a sunny day, and I think it will get up higher, I will wait till lunch time, because that's when it might be at that point. If it looks sunny in the morning, and it looks like it will get foul in the afternoon, I might put it on in the morning, knowing that although it won't cover the peak consumption period, I get more out of it. So trying to work out what the weather is doing at the moment, what's going to happen later in the day, later in the week, how much you're getting and what the best time is to put it on…"*

And then continuing to reflect on what the battery display might add to this process, she reflects on the additional pieces of information she needs to make a balanced decision:

> *"Part of the problem is, you don't now how much is being used by other things. We got these smart plugs – but it's too much of a hassle to go upstairs to the computer, and go to the website, and work out what everything is consuming… and then adding it all up, and subtracting it from what you are generating, and by the time you've done that – the sun will have gone in anyway…. So you need something instantaneously…so If we have the battery – that would be ideal. I could see, OK I have enough so that I can do about two washes… that would be great".*

Although this participant was also someone who considered herself to be someone who was very at home with figures (being a scientist), and would always want to see concrete numerical representations – she did not voluntary criticize the lack of numbers on this particular display. Whereas this was a complaint form a number of participants:

> *"The battery one for the house as a whole is lacking some kind of unit – you don't know what full means, or two/third.. Whereas the battery with the washing machine works better – because I can imagine that it refers to a certain amount of wash loads." [husband HH2]*

In common with others, this participant couldn't imagine what a half-full battery might correspond to.

Interestingly, the participants from HH5 could also see an additional side of the potential of this metaphor:

> *"just like battery on phone, I get used to it."*

6.2 Locality

All the participants had placed the 'whole house' displays on the wall or on the table nearby to where they shared meals. All households were happy about this location – feeling that this was the best place to see it, discuss regularly and where it would catch their eye in a natural way:

> *"Having it next to the table is definitely the best place. That's where we are spending most of our time together, and talk about things. Probably on the wall, rather than directly on the table …*
>
> *Having it on this table is good – we always put our cups of tea and coffee here, so you look at it the whole time, and then yes, we'd talk about it."*

The location chosen for display for the washing machine turned out to be more varied. Most participants had either placed the display directly on top of the washing machine or as close to it as possible, but in one household the washing machine is hidden in the garage. They felt that to have better use of the display they should put it in a location where it could be seen, hence they put it upstairs, next to the laundry basket, where dirty laundry gets collected. This variety in locations brought out interesting points of discussion – where some participants felt it was a good idea to have the source of energy displayed immediately near the washing machine, imagining how at some point such a display would be an integral of the washing machines:

> *"I think the washing machine can also be displayed on the one in the living room [showing whole house*

generation/consumption]. By the time you've walked to the kitchen to look at the washing machine, you've made the decision. So having it in a central place, gives you a better idea on planning when to use it."

For HH6, the issue of having several displays and where they should be had been bothering them much – and was the very first thing they mentioned on being interviewed:

"It was too much to have two things! Too much of a faff. I would always look at the kitchen display [showing whole house generation/consumption], which had certain amount of information – and then I'd look at the washing machine display [in the utility room], which had other information... and then I'd decide whether to do a load, and then I'd do it. So there was no point, from my point of view, of having two things - I would have preferred to have it all in one place. All the information there. The only thing I can imagine being useful next to the washing machine would be the switch – to say it is going to be on generated or on the grid. But ideally I'd have one display…"

So it would seem that location and energy use are concepts that are intertwined in interesting ways. The energy can be associated with (i) the particular device – i.e. at the location of the washing machine; (ii) it can be associated with where the planning, and thinking about various jobs in the house takes place, such as the central dining room table or some other central place, or (iii) it can be in the place where the objects associated with the appliance reside – i.e. here the dirty clothes. The dirty clothes can be some way away from the washing machine, or the planning place.

There is currently a lot of interest in designing new interfaces for appliances. Although numerous people have reported on how appliances may require novel displays to take account of different usages, and to influence through different default setting [1] most of our participants felt that centrally visible information was more important than presenting information near the relevant appliance.

6.3 The right kind of information

The displays aimed to create an awareness of generated energy: how much there was, how much there was in comparison with how much was being consumed, and how much useful work (e.g. washing machine loads) could be done with the excess generated energy. In the conversations we tried to get a grip on how well people felt the displays served their needs in terms of information: was this the sort of information they wanted?

Regarding the display that showed 24-hour consumption and production combined graph (Figure 2b) participants in HH1 felt that

"Yes, it would be useful to have that information. Yes, at the moment I do have that information, but I need to go to the garage to see it. But it would be useful to have it in the kitchen to see it clearly. That would be useful."

The participant is actually referring to the simple LCD reading on their DC to AC grid-tied inverter which converts DC power from the solar panels to AC power for the home (usually installed in a loft or garage as it is not intended for consumer interaction). It has the ability to display how much energy has been generated in total for that day as well as the current generation level but it cannot display the energy being consumed or exported, so this participant had a misunderstanding about the data available to her.

However, later she reflects on what the precise benefit is of having this information displayed, and whether they would be more informed:

"if you look at that picture, it does map closely to the picture you have in your mind. You know, that in a lot of big households most of your consumption will be during the evening and into the dark hours. And you know roughly when your energy is being generated. So I don't think that having a picture can change that – you have that picture anyway. And I think if I asked the girls – if you asked them – draw me a picture, of when you think we are using, and when we are consuming, I think you would get this picture. It would be quite accurate. But it is good to have this picture."

Here the participants are reflecting on the models they have – themselves – of their own energy behaviour. However, what is interesting is that we know that much of that information is not actually available to them, as the precise levels of energy generated are determined by the precise roof and cloud coverage that day.

One of the displays (Figure 2a) showed the currently generated amount of solar power:

"That display an instant, or relatively quick, we think .., display of the amount of sunshine, which is interesting in its own right, but it doesn't add anything beyond looking out of the window!"

Clearly this participant felt that he had sufficient information to be able to make informed decisions – and that using common sense was sufficient. Looking out of the window, seeing the sun shining, should be enough information about the amount of generated information. However, as we outlined earlier, this is only a rough indication of the amount of energy potentially being exported or spare. In the focus groups for the wider trial, people discussed a need for more precisely knowing what they can do with the generated energy. *If I have the washing machine on, can I also do the ironing when the sun is out?* So people's perception of the levels of information that they require in order to adjust their behaviour to maximize their energy balancing behaviour is different from household to household.

7. Discussion

The interviews revealed a number of insights that are important for the design of information technologies related to microgeneration.

Microgeneration does change energy consumption behaviour. There is clear evidence that the mere presence of microgeneration in a home make people question their energy consumption behaviour and in many case makes them adjust their behaviour. Some engage on concerted efforts to shift demand to times of peak generation while others alter their habits in a less directed ways. Thus the impact of microgeneration lies not just in the energy that is generated but in the ability to use microgeneration to motivate people and to change their view of themselves from being a passive (even informed) consumer of energy to an active participant. Conclusion: Digital technology should focus on creating opportunities for people to adjust their behaviours rather than simply informing them about the state of energy production in the home. Furthermore digital technology should be designed to support people's changing perception of themselves as active participants and energy custodians rather than supporting a self-image of smart and informed consumer.

*People believe they know, but they don't***.** Although this was a highly motivated group of individuals who had taken the time to try to understand their consumption, there were many misconceptions about how generation is influenced by external factors and how to reduce energy consumption. For example, most people felt familiar enough with the graph display which shows periodic spikes. Most people wanted to see more details and be able to work out exactly when the spikes occur. However, the narrow spikes are almost meaningless for getting a sense of the amount of energy generated. More importantly, however is that some people believed they had a good understanding of how to estimate current generation when in reality they didn't. Looking out of the window is a very unreliable means of determining energy production as seasonal variations (height of the sun above the horizon, shading from leafy/leafless trees) can have a tremendous influence. Conclusion: Digital technology should be designed to help people form an appropriate coherent model of microgeneration, not just inform about individual aspects such as current generation. One way of doing this is by using metaphors that help people understand their role with respect to microgeneration, in the same way metaphors have enabled laypeople to make effective use of computers.

There is a wide variation of how and why people engage with microgeneration. Within this group of highly motivated people there was still a wide variation as to how far they were prepared to go in terms of making adjustment to lifestyles to meet the energy balance. For some people the fact that delaying one action only saves 30 p (by using excess PV energy) is not worth it – for others there are other motivations beside the monetary value, that make them go the extra mile. As with Pierce and Paulos [6] we found a wide range of motivations for engaging with energy. There are those who are keen to think of all of the minute ways in which they can adjust their behaviour – like cooking during the day, when the sun is out, rather than wait till the evening, or buying an electric lawnmower instead of petrol – versus someone else who says "but that battery won't mean anything for me, because there is no advantage!" (HH4). Conclusion: There seems to be the potential to design specialised solutions for specific subgroups of users of microgeneration. However, while we have some rough understanding of possible subgroups (for example detail-oriented vs whole issue oriented) we have no understanding of the specific technology requirements of these subgroups. Rather than looking for a single generic design approach it might be better to focus on each subgroup separately.

8. Conclusion

Microgeneration can be an effective way for people to do their part in living a more sustainable life. Yet microgeneration is a complex technical system that is not easily understood by users. Clearly more work is required to investigate the behavioural aspects of living with microgeneration. As Keirstead puts it "there is a danger that if behavioural responses to microgeneration technologies are not considered now, when consumer technologies and protocols are still being developed, then the industry could find that households become locked into behaviours that may be undesirable in the longer term" [2]. Our study highlights important aspects for the design of digital technologies to help people make sense of and live with microgeneration.

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