Lessons for the Future: Experiences with the Installation and Use of Today's Domestic Sensors & Technologies[1]

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Abstract. Domestic environments are receiving increasing attention as sites of deployment for pervasive technologies, as evidenced by the growing number of studies of homes and maturing technologies in prototype aware/smart homes. The challenge now is to move technologies out of purpose built homes into everyday environments in ways that will fit with existing buildings and the people who live in them. However, there are many aspects of this future vision that people live with right now in the form of sensors and technologies already in the home. We describe findings from three studies – in-home interviews, a questionnaire about home sensors, and interviews with commercial smart home installers – that explore current experiences with sensors and technologies in the home. These lead us to reflect on the implicit assumptions in, and future design directions for, pervasive research for the home.

1 Introduction

The home is gaining increasing attention as a possible site for deployment of pervasive computing technologies [6]. Prototype 'aware/smart homes' such as the Georgia Tech Aware Home [1] and MIT PlaceLab [14] demonstrate the possibilities for sensor and network technologies in home environments. In parallel to, and preceding, this work, there has also been considerable interest in the home as a site of study in its own right, both to understand how the home is experienced and made home, and to identify opportunities for design. O'Brien, for example, has looked at the role of different technologies and how they modulate the social life of the home [17]. Crabtree et al. explored the flow of information through a home, highlighting activity centres with a view to how these could be supported by technology [5]. An implicit notion in much of this work is that there is a gap between the vision of some possible future with an aware/smart home making use of various sensors and complex infrastructures and technologies, and the reality of lived-in homes today with their every-

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day technologies and patterns of social life that are far removed from this vision (as evidenced by the need to build purpose built homes as demonstrators).

Our recent studies of some everyday homes within a UK context, however, show that many aspects of this vision are already a part of many homes. The contribution of this paper is to explore some of the current experiences of living with sensors and technologies and draw out implications for how we might approach future pervasive technologies if they are also to become part of our existing homes.

The studies reported in this paper are part of a larger project concerned with the design, prototyping, and in-situ evaluation of pervasive technologies in domestic settings. Because our approach is to try to design for real homes and involve users as participants in the design process, we undertook a set of initial in-home studies to serve as a baseline understanding of each particular home and family so that we could better tailor our co-design sessions with them. These studies gave rise to findings that, while not overly surprising in hindsight, lead us to reflect more closely on the implicit assumptions and directions in current pervasive technology research. One finding was the ways in which "everyday" sensors in the home are often broken or require various workarounds to be used. Another was the multiple factors beyond just functionality that determine what technologies are in the home and the ways in which these too are often problematic or not well understood. This led us to triangulate our findings through a survey about everyday sensors and through interviews with smart home installers to explore experiences with more advanced technological arrangements in the home.

In this paper we first review some of the background work around studies of domestic environments and pervasive technologies for domestic settings; we then describe three studies we have undertaken exploring current experiences of technology in the home. Finally we discuss our findings and their implications for future efforts to design applications of pervasive computing for domestic settings.

2 Background

Since Weiser [27] first articulated a future of ubiquitous and pervasive computing, domestic settings have been receiving increasing attention from researchers as an application domain.

Sociological strands of work, especially through ethnographic studies, have sought to understand the current nature of the home and, having gained that understanding, to suggest sites and artifacts within the home that might be possible targets for technical augmentation in the manner envisioned by Weiser. For example, ethnographies of the domestic environment have found a strong focus on the flow of information, coordination of activities and presence of routines in the home [5,10,17]. Information-based artifacts that support coordination and routines have been highlighted as candidates for technological enhancement. These artifacts include calendars, family noticeboards, wall-planners [5]; and shopping lists and the kinds of notes that are attached with magnets on a fridge [23,24]. Other work has highlighted the importance of everyday technologies in supporting the maintenance of routines, such as using episode length of children's videos as a timing device [20]. These and other similar stud-

ies make evident the practical accomplishment of home life and provide important points of sensitization when thinking about designing for the home. The studies we present here are somewhat different as we are not so much concerned with issues of how people live in their home but more pragmatically concerned with technology and sensor issues and relationships with technologies. This is similar to Edwards and Grinter [6] but whereas they studied advanced home networks looking at skilled computer people as early adopters, we are primarily concerned with 'everyday' households and their technology experiences.

In parallel, there have been technological strands of work to implement aspects of the pervasive vision for home environments. With recent technological advances, we are now seeing relatively stable prototype developments and some initial in-home deployments. For example, sensor networks are being developed in conjunction with sophisticated inferencing processes to make higher-order sense of continuous sensor data [22]. Component applications are being developed such as SMS messaging displays in the home [23]. One way in which these advances have been both explored and realized has been through the development of purpose-built prototype 'aware/smart' homes, such as the Georgia Tech Aware Home, created as a "living laboratory" with various technologies including location sensing technologies, large-screen projected displays and camera-based eye-tracking [1]; and the MIT "The PlaceLab" at MIT that has its Home-n augmented with over a hundred sensors, including sensors of temperature, humidity, light, barometric pressure, electric current and water flow, "where the routine activities and interactions of everyday home life can be observed, recorded for later analysis, and experimentally manipulated" [14]. These developments have resulted in important advances in understanding and technical sophistication but they tend to do so at a loss of the authenticity of everyday settings and avoid the issues of integration into existing environments.

Other research has sought to deploy technologies into existing homes, as with Beckmann et al's sensor installation kit [2]. Others have used in-home deployments as a form of technology probe to elicit interesting responses to new technologies which may act as inspiration for future design [13]. More provocative installations of technology such as a weight-sensitive 'drift table' have been undertaken by Gaver et al. as part of their curious home project [7]. These implementations in 'everyday' homes complement purpose-built installations by starting to point to issues entailed in realizing the pervasive vision with current housing stock, as noted by [9,19]. There are also increasing efforts to develop toolkits that minimize the time and effort to build pervasive applications [8] and that facilitate engaging household inhabitants more directly in thinking about the applications they want to live with [19,25]. This provided a starting point for our work, where we wanted to explore novel pervasive applications for and with people that would fit into their existing homes and that we could quickly prototype and deploy through use of toolkits. However as suggested by Rodden and Benford [19], and Grinter and Edwards [6], we still have much to learn about the practical realities of engaging in such implementations. The studies to be reported here suggest further that we also still have much to learn from experiences with existing sensors and technologies as well that will help inform the more pragmatic design and deployment of technologies in the home.

3 Overview of Studies

As stated previously, given the substantial and maturing amount of work both in understanding domestic life and in developing technologies, it is timely to think more seriously about how to move from purpose-built homes to augmenting everyday domestic environments. While the potential vision points to homes that could be very different to experiences today, the path to there will be incremental from the base of today's homes and currently available technologies. Below we report on three studies as part of understanding this current base and focus on the experiences that people have with sensors and technologies in the home. The first study consisted of in-home interviews and tours with "average" middle class UK participants in their homes. We then sought to triangulate some of the findings from this study through an online survey of sensors in the home and through interviews with professionals who install current "state of the art" technologies into the homes of the wealthy.

3.1 Study 1: In-home Interviews & Tours

The initial intention of the in-home interviews and tours was to have a baseline understanding of the participants and their homes in order to inform future co-design work with them, enabled by available toolkits for prototyping and deployment. We recruited 12 people from 7 UK households to participate in this study (see Table 1 for an overview of the households). All the interviewees were "middle class" by English standards – they were professionals or worked in clerical professions in support of professionals and had a university education.

Table 1. Profile of participant households (Pseudonyms used)

Household	Occupants (Ages)	Adult professions	Type of home
1.(Chloe & Jack)	Parents mid 30's, children 6 and 8	Teacher, director of technology company	Detached, brick, early 1900s
2. (Emily & Thomas)	Couple late 20's	Admin assistant, software developer	2-bedroom terraced house
3. (Megan & James)	Couple, late 50's	Admin assistant, Teacher	Detached, late 19th century
4. (Charlotte & Joshua)	Couple, mid-30's, children 5, 10, 12	Human Rights consultant, homemaker	Detached, early 1900s
5. (Sophie & Daniel)	Couple, mid 60's	Retired Astronomer, homemaker	Detached, early 1900s
6. (Lauren & Harry)	Couple, late 30's, children 8, 10, 14	Director of technology company, homemaker	Detached, early 1900s
7. (Lucy & Sam)	Couple in 60's	Retired telephone engineer, homemaker	New detached, brick bungalow

A study session with each household consisted of an in-home tour and interview with one or two of the adult family members. Each session lasted approximately 90 minutes and was conducted by two researchers and captured on video. A study protocol was developed focusing especially on the current relationship of participants to the technology in their homes. Participants were asked to give the interviewer a tour of the house and discuss the technology in each room. The participants were asked how each piece of technology came to be there, what it was used for, and if there were any problems or issues with it. If the technology had been bought by the participants they were asked where they bought it and what criteria were used to decide on the purchase. As interviews were informed by previous ethnographic work on the home, questions were also asked about areas of the home and activities and artifacts that had been identified as potential candidates for digital augmentation, e.g., as in [5, 10, 20]. Analysis of the videos was conducted through transcription, repeated viewing and identification of recurring themes and issues.

Findings: In-Home Technologies. As expected, we saw many of the same things that others have noted in studies of home settings. For example the fridge and other notice boards were commonly used as spaces in which information was displayed and through which family life was coordinated [5]. All of the households also owned a diverse array of technologies: every house had at least one computer, at least one mobile phone, and at least one TV, DVD system, and audio system; two homes had burglar alarms; six had broadband internet connections (although one of those had never worked); three had wireless connectivity; and every home had a thermostat and a smoke detector. What caught our attention however was the extent to which sensors and technologies – similar to the component sensors and technologies that would go to make up new pervasive installations in the home – already made up the home, the stories around those technologies, and the issues that people experienced living with these. For the purposes of this paper, we will focus on the following: technology choices, gendered relationships to technology, information requirements, general technology experiences, and sensor experiences.

Technology Choices: How technology gets into the home. In purpose-built aware/smart homes, technology configurations are pre-determined as part of some configurable package, largely by the researcher in an academic context or the provider/installer in a commercial context, albeit modified by consumer choice. In the 'everyday' homes we looked at, there were much more diverse and complex reasons for how technologies arrived there. People received technologies as (possibly unwanted) *gifts* from relatives and they felt a social obligation to keep them or at least bring them out for display when those relatives visited (as did Chloe & Jack with a face spa and sewing machine). Parents gave their financially struggling children *hand-me-down* technology (as was the case with Megan & James' television). Children gave their less-technology-savvy parents hand-me-down mobile phones or computers (as with Chloe and Jack). Of course people also bought new technology but when they did, performance and technical features were not necessarily the primary reasons for purchase. Form and aesthetics also played a factor (as also found when

we talked to smart home installers (detailed below)). *"Has it got the couple of features I know I want? Does it look nice […]I get fed-up with everything else because you could spend months choosing" [Megan, House 3]*

People made trade-offs between functionality and aesthetics. In house 7, Lucy said she was unhappy with the interface to her microwave because it was difficult to use but when asked how she'd come to choose it, it was for aesthetic reasons because it would be the same shade of white as her conventional oven.

If the form and aesthetics aren't right the technology may never be used as was the case with the radio Lauren asked her husband to buy: *"I asked my husband for a christmas present, I wanted a little radio that could sit on the bench when I'm getting dinner and cooking and stuff. And when I opened it this is what I got. I said, this is nothing like what I asked for! And his rationale was that this was just too good a deal to overlook. But I asked for something very small, so consequently it never gets used, hence the dust." [Lauren, House 6]*

Technology choices were also often driven by a strong sense of values. Many of the interviewees saw their choice of technology as a fundamental expression of their beliefs but wanted the technology to fit in with, rather than transform, those beliefs.

"I want to live in a yurt with internet access"[Emily, House 2]

For the 'yurt' couple, Emily and Thomas, almost all their technology choices were influenced by their desire to live an ecologically responsible lifestyle, and they spent considerable time researching products on internet sites that specialized in selling technologies for ecological living. These products included energy-saving thermostatic air-mixing taps, electricity generating solar panels and a fibre-optic "light-pipe". Interestingly, picking up on our 'not-working and not-used' theme, the solar panels had never been installed and were languishing in the spare bedroom and the light pipe, although it was installed, was missing a part and not working.

The very choice of these technologies serves to explicitly convey to visitors in the home what values are held there or what impressions they want to project. *"I printed that out [tide tables] because I wanted people to think that we're the kind of family that goes boating. We're not."[Joshua, House 4]*

Gendered Relationships with Technology. Some of the examples above also point to issues of different relationships to technologies within the home, often playing out on gendered lines. In almost all of the households, women played a key role in deciding what technology was purchased for the home and where and how it was placed. As has been seen in other studies [10], the women also played a large part in the construction and maintenance of domestic routines, handling mail, doing the filing, and managing the family diary/calendar. Calendar management/display has frequently been discussed as one possible application of ubiquitous computing [5]. It is therefore perhaps interesting to note that in many homes the family calendar was either "in the head" of the woman of the house or in a small personal diary, that was carried by the woman in her handbag. For one woman, this control was also explicitly associated with a particular location in the house*:*

"This is my chair and no-one else is allowed to sit here. And that's my work basket, the radio and I always have you can see, the Ikea catalogue [laughs] and my crossword. I sit here and I can see the cooker and I can hear the front door and I can

answer the phone and I'm near the back door and I can see the sink. My poor husband has nothing like this, but then he doesn't do anything like that. I organise the house I run the house, I do all the paperwork."[Megan, House 3]

We saw other examples of men similarly exerting control over other domains in the home. In two houses there was some kind of restriction by the husband on the wife's use of central heating controls. In house 7 Lucy was 'forbidden' from touching the central heating controls: *"I don't touch that [central heating control], it's more than my life's worth"[Lucy, House 7]* In house 2, Thomas had stuck a cardboard flap over the button which altered the thermostat temperature *"…because Emily is always tempted to just put the temperature up when she wants the central heating to come on and that flap is to sort of remind her not to."[Thomas, House 2]*

Information Requirements. An emphasis of many studies and applications is the flow of information around the home and information for coordination, as noted above [5]. Interestingly, amongst our interviewees there were no problems or dissatisfaction with the current (mainly paper) solutions that they used to manage information although one user did express frustration with an electronic calendaring system which he was forced to use as part of working from home. Participants did mention other kinds of information, more to do with values or curiosity than with functionality, that they would like technology to provide. Emily and Thomas (House 2), who were very keen on environmental issues, said they would like to know how windy and sunny it was on their roof. Megan (House 3) said that she would like to know more about the history of her Victorian-period house and the people who had lived in it. She also wanted to know was in the guttering of her three-storey house. Lucy and Sam (House 7) who live in a nearly-new home wished that they had all the documentation (guarantees, instruction manuals, etc) that came with the pre-fitted appliances and a circuit diagram of the burglar alarm.

General Technology Experiences. A recurring theme across the households was the number of technologies that did not work properly and the inadequate or incorrect strategies people had for fixing their non-working technologies.

Networking was a case in point. In house 3 the ADSL broadband internet connection had not worked in the six-months since it was installed. The participants were unable to give any real explanation for why it didn't work, and their only strategy for getting the broadband to work was to buy a new laptop and hope that it would mysteriously work better than with existing computers in the house. Another interviewee [Jack, House 1] was having problems with his second attempt at wireless networking. His first wireless router had "just packed up for no apparent reason" and because he felt that his second was becoming unreliable, he was intending to buy a third wireless networking box. He seemed to be unaware of two of the three main problems that might be affecting his wireless connectivity – using WEP data encryption and interference from other wireless networks in surrounding houses – and seemed to think that the solution would be to buy a "stronger" base station.

Further, many homes had a large number of *technologies that were not used* and were either left to languish in a cupboard or put into a 'back room' to be dealt with at some later time. Some were unwanted gifts. Some were obsolete but the owners did

not feel able to throw them out. Some were devices they wanted to use but were unable to get working properly. In house 1 a video camera was bought to take video during a tropical holiday but it didn't work in the humid conditions and as a result was never used again. Other technologies were missing a part (an extraction hood in house 1, in house 2 a fibre optic "light tunnel"). Yet others were ones that householders thought they wanted but in hindsight didn't, pointing to potential problems in asking people what they want from future pervasive applications.

While there was no scarcity of technology in evidence, there was often a serious *lack of understanding of, and know-how about, the technology*. Only one couple {House 7] had attended computer courses but found that it still didn't help them solve problems such as getting their webcam to work. Lack of know-how seemed to be a strong contributing factor to why various pieces of technology remained broken or unused. Sometimes family members traded knowledge e.g., in how to program the video recorder in exchange for some other household task, as also found by Rode [20]. Sometimes the *presence* of know-how was problematic as when Charlotte and Joshua's (House 4) daughters knew more than they did. Their 12 year old daughter had set up her own website but wanted to take it down because they felt its content was unwise. However, they could only do so with the help of their 10-year-old daughter. We also found cases where the know-how required to fix a problem was not present in the household. In these cases, external help was often sought, but with mixed success. Some accessed informal networks of friends and work colleagues. Others sought help from an advertised PC Repair/Support services. In one case however, this was a fragile solution in the face of subsequent changes:

"I got a man in and he set up all the networking, and that was fine until this laptop got filled up with shareware and other junk and I had to re-install it and now the networking doesn't work."[Joshua, House 4]

Sensor Experiences – Work Arounds. All of the households had at least one sensor-based technology, e.g., thermostat, burglar alarm, smoke detector. Three of the seven homes had problems with these, despite them being commonplace and "mature" technologies. Three households stated that they thought their thermostat was not triggered at the correct temperature, for example: *"That's the underfloor heating, but it only works if you turn it up to 35 degrees centigrade – that's not the temperature that it gets to in here, that's the temperature that the mice enjoy under the floorboards."[Joshua, House 4]*

Burglar alarms also proved problematic. One couple, who did use their burglar alarm extensively, referred to the burglar alarm being falsely triggered during power cuts. Another couple no longer used their burglar alarm after the alarm went off falsely when there was a power cut. It was also difficult to use even if they had wanted to because the control panel had been installed in an under-the-stairs cupboard with no lighting: *"It's a bit difficult to turn that thing on and then get out of the door with two kids in 30 seconds."[Chloe, House 1]*

These pointed to issues people had with not understanding and/or not trusting the ways in which their sensors worked, as well as the practical realities of location and timing and false alarms that render them less useful. Given that the future of pervasive computing within home is often oriented around numerous sensing technologies

acting in concert [1, 14], it is a serious concern that a substantial number of the "everyday" sensors that are found in homes today either do not work properly or, equally importantly, are not regarded by their users as working properly.

In Summary: While it is not possible to generalize from these few households, to the whole of the United Kingdom, let alone to other countries, the findings from these in-home studies do provide some evidence of use and experience of a wide variety of existing sensors and technologies and raise interesting questions around the issues of the multiplicity of ways technologies get into a home, gendered relationships with technology, the different types of information we could be supporting in the home, and the everyday troubles with commodity technologies and sensors and the technical know-how and models needed to make them work. The findings around current sensor-based technologies in particular led us to undertake the following study.

3.2 Study 2: Household Sensor Questionnaire

The lack of understanding of current sensor technologies and the number of supposedly mature sensors that didn't work well led us to question whether or not these were common experiences or particular to our household sample. To explore this we developed an on-line questionnaire that asked about sensors that are commonly found in the domestic environment: respondents were asked if they had a thermostat, smoke detector or burglar alarm and, if they did, whether it worked properly. They were asked to detail any problems they had and also to give details of occasions when smoke detectors or burglar alarms had produced false alarm situations. Subjects were recruited via an email to acquaintances and colleagues who were also asked to pass it on.. 101 people responded to the questionnaire, 48 men and 53 women with an average age of 38 (age range of 21-70). 43% of the respondents were tenants in rented accommodation and 57% were home owners.

Findings: Domestic Sensors. 77% of the respondents had a thermostat in their house. 14% of these reported that their thermostat didn't work properly. Location of the thermostat was a common cause of complaint: *"Temperature always different in different rooms too near the boiler. In a well heated room. Need to make sure boiler door is closed."* Some respondents also complained that the control of the thermostat had a large range of temperature in which it was not responsive: *"The thermostat is just wrong and also has a huge temperature range (10 degrees or so) where it doesn't turn on or off."*

94% of all the respondents reported that they had a smoke alarm in their house, of which 82% reported that their smoke alarm worked properly. However, when asked if their smoke alarm had ever gone off when there wasn't a fire, 71% of respondents who had a smoke alarm (including those who said it worked properly) said it had. In many cases the detailed explanation of when the smoke alarm was triggered falsely indicated that this was a regular occurrence. *"Alarm continually going off when cooking", "The toaster causes them to go off.", "They go off when the room is too hot regardless of there being no smoke."*

29% of respondents had burglar alarms. Of these, 79% said that their burglar alarms worked correctly. However, when asked if their burglar alarm had gone off falsely, 62% of respondents with an alarm said that it had: *"Mistakes entering code", "Detector went of when intruder not present", "It briefly goes off when power is restored after a power cut"*.

Hence, while not universal, these results suggest that alarm-based sensors were often experienced as problematic but that this was not necessarily *perceived* as problematic (as with 82% saying that the smoke alarm worked properly yet 71% had had issues with false alarms).

In summary: The findings from both the in-home interviews and the follow-up sensor questionnaire suggest that users' knowledge of and interaction with everyday sensors, which they regard as unproblematic, is in fact complexly nuanced and not well-understood. There is some evidence in these results to suggest that "false alarms" may play an important role in reassuring the user that a sensor is working: *"The smoke alarm is positioned on the ceiling in the hallway just outside the kitchen. So any smoke coming out of the kitchen goes straight up to the alarm. We just wave a tea towel in front of it to clear the smoke and stops. It's quite good in that we know it is working!"* This phenomena has been observed in the use of sensors and alarms in non-domestic settings [18] but has not been thoroughly discussed with regard to domestic settings.

In working with sensors for more novel outdoor pervasive experiences, Rogers and Muller [21] conclude that sensor performance is too poor to be relied on in "real-world" applications. But neither the field of ubiquitous computing, nor today's home owners, have given up on the use of sensors. In order to design sensor-based applications for the future we need to accept and understand the limitations of current sensors technologies, the lived experience of users with these technologies and the strategies which they adopt to deal with this sensor performance.

3.3 Study 3: Smart Home Installer Interviews

Apart from 'everyday' issues with sensors, our in-home studies also highlighted how much technology people already had in their homes, albeit relatively simple 'stand-alone systems or devices. This led us to think about other homes at the higher end of the market and their experiences with more complex infrastructures and technological arrangements. These were of interest because they represent 'state of the art' commercialization of aware/smart home technologies. As highlighted by Edwards and Grinter [6] the history of technology adoption may in some ways be a useful guide to the way in which technology is adopted in the future. As was the case with television, the technologies that wealthy people can afford to have professionally installed one day may well be the technologies that the rest of us will be able to buy as an off-the-shelf solution the next.

Participants and Methods: Ideally, we would want to interview the householders themselves about their 'smart home' installations. However, the demographics of the

people who are in this category make it difficult to access them as participants – on the characterization of the people who do the installations, they are normally very wealthy people with high pressured jobs, often involving travel, who would not prioritize time for study participation. Instead, we chose to conduct interviews with representatives of companies that install "smart home" technologies as a way of gaining indirect access to a diverse range of customer experiences, albeit filtered through the company interviewees.

We interviewed two people who worked in customer-facing technical roles at two different companies, referred to here as Smith Ltd and Jones Ltd. Jones Ltd is a company with approximately 20 members of staff. It began as an audio equipment stall at record collectors' fair 30 years ago and now offers integrated home entertainment and automation systems solutions. Smith Ltd is a similar company, with 3 full-time staff members. It has been in business for approximately 5 years and was formed by two programmer/engineers who had previously run a company providing technical support services to industry. An example of a recent installation they delivered into a 16th century house was of a video/music server which could be accessed from any room in the house, networked plasma and projection screens, a complex lighting control system, in room web-cams and CCTV monitoring of the grounds.

Interviews with the company representatives lasted approximately 2 hours. The interviewees were asked to discuss the requirements of a typical customer, perceived trends in the industry, which features were popular or unpopular and the common causes of support calls. As part of this we encouraged them to tell us specific stories of customer experiences. Again an interview protocol was developed and used as background preparation while leaving the actual conduct of the interview free to follow leads as they emerged. A content analysis was conducted on the interview notes to identify common themes.

Findings: Smart Home Installers. In both companies, interviewees described very similar pictures of the customers they served, the systems they installed and the experiences reported back to them from customers via their service centres or representatives. One very important difference from the 'everyday homes' just discussed is that most 'smart home' installations begin with an empty shell of the house, or with discussions with the architect before the house is even built. In this way, these homes are similar to the research-based aware homes. None of the everyday houses that we visited, even the one that was newly built, had acquired their technology as the result of one monolithic installation.

Technology Choices: What was or was not in demand. How people choose to prioritize and allocate their money in designing these installations is an important indicator of the technologies they at least think they want to live with (though as we have seen with everyday homes this may not in fact work out to be the case). Both companies reported that one of the most commonly requested 'smart home' components were motion-sensitive lights in hallways to allow night-time navigation to the bathroom. Other components that were popular included an "Occupancy Simulation" – turning the lights on and off in a pattern that might deter burglars – and a bedside switch which allows all the lights in the house to be turned off at once.

Television and entertainment systems, particularly distributed or networked solutions, were also high on people's purchase lists: *"People are really into telly."[Smith Ltd]*. A feature which allows the user to pause a TV show in the living room and resume watching it from another room (typically the bedroom) was a popular request, as was waterproof TVs fitted in bathrooms.

There were also a number of technologies that the installers noted little demand for or that fell low on people's priority lists. Interestingly, these tended to be the ones with more advanced or automated features. In the category of 'technologies which might seem like a good idea and which customers thought they wanted', Smith Ltd cited voice activation as a technology that they no longer recommended. This is because they found that when they did install them, people did not use them in practice: "*Voice recognition stuff, kind of works, it's fun for about five minutes, but it drives you up the wall after two days."[Smith Ltd]*

Other seemingly archetypal home automation features moved from high to low priority, even for the most wealthy of customers, when they discovered how much they cost. *"People like the idea of automatically opening and closing curtains until they find out that it costs about £1600 per large window."[Smith Ltd]*

While talking to these people, we also asked them about their opinion about potential for user-configurable solutions. This is because there has been a current research trend towards the production of toolkits that would allow the user to reconfigure aspects of their digital infrastructure and conduct some forms of end-user programming [8, 4]. Neither company felt that there was a strong demand for this: *"They can't even plug the right cable into the right socket at the back of their DVD recorder to get the best signal for their plasma screens. Reconfiguration will probably happen but only in the IT-savvy/early adopter community."[Smith Ltd]*

Both companies reported a strong gender divide in attitude and approach to the technologies chosen and installed. Men were largely drawn to the technology and wanted it on display but women were much more concerned with the aesthetics of the installations and that they fitted in with the interior décor: *"Boys want all the toys – wives want everything to be out of the way and have the minimum number of remote controls." [Smith Ltd] "This installation has a wall-mounted display and in-ceiling speakers. The woman was wearing the trousers, she wanted nothing on display."[Jones Ltd]*. Smith Ltd reported that, as a consequence, as much as 50% of the cost of many installations was spent on cabinet-making and carpentry to ensure that the technology was aesthetically concealed.

Complex systems, complex infrastructures and controls. The complexity of the installations also entail a number of practical implications. The first is around networking infrastructure – complex integrated solutions require complex infrastructures to support them. However these infrastructures tend to be hard-wired rather than wireless because of practical concerns with current wireless solutions including insufficient data rates for the transport of high quality video. As such, one of the most important services that smart home installation companies provide is designing the layout of cables around the home and laying the cable around the home. Thus installations, once designed and installed, remain relatively inflexible.

These more complex systems also require more complex interactions to manage and control them relative to the more stand-alone technologies of the 'everyday' homes reported earlier. A typical home cinema system installed by Smith or Jones Ltd involves at the very least a control for the projection screen, the screen projector, the DVD player, and also possibly for the lights, the curtains and the sound. The options offered by the companies include: individual controls for each of the boxes (the problems with which have well-documented [16]); a single remote control from which all of the commands can be sent by infra-red as a macro; and, the most expensive option, an LCD panel to control all the devices via RF to a controlling system.

None of these solutions is perfect. The use of individual remote controls means that the user has to identify several remote controls and press the right button while pointing at the right device: *"The [infra red] remote doesn't know what state appliances are in when it sends the signal. If a remote has to send out a whole string of commands the user has to stand there while all the commands are sent."[Smith Ltd]*. The interfaces for the LCD displays are only programmable using proprietary applications and a large amount of systems programming to the proprietary API is required to interface a new appliance.

It is no surprise then that one of the most reported causes of support calls to the companies' service centres were problems with remote controls. The most common problem was that the battery had gone flat but this was often only able to be diagnosed after a time-consuming support call, or even a visit.

There were several hints in the discussion of these smart home controls being a source of dispute, especially where one person, often the woman, found it difficult to perform everyday tasks: *"Hubby [the husband] gets all the kit installed and then he goes off on a business trip and the wife's left alone, sitting on the sofa with all the remotes and she can't put the telly on or turn off the lights."[Jones Ltd]*

In Summary. The reported everyday experiences of living with more advanced sensor and technology arrangements as found in current 'smart homes' suggest similar issues to everyday homes, e.g., in the gendered relationships around technologies and how people make choices about technologies, but also issues that point to more pragmatic concerns when we move beyond simple standalone technologies, e.g., around networking infrastructures, control mechanisms and they models they have for understanding them.

4 Discussion

While the full realization of the aware/smart home is still some way off as the norm for everyday household living (if that is even the sort of home we want to live in, a discussion for another time), there are many aspects of this vision that people 'live' with right now. We argue that understanding these current experiences can provide valuable lessons and insights for the types of issues and troubles people might have with even more sophisticated and complex sensor and technical networks in the home of the future and provide more sobering and realistic filters for shaping future design directions. The lessons reported here provide empirical evidence that at times elabo-

rate upon, and at other times question, lessons drawn out for designers of pervasive technologies for the home in other work: Edwards and Grinter [6] present them as seven conceptual challenges, covering a range of technical, social and pragmatic concerns; Beckmann et al [2] draw out five principles for end user sensor installation, based on in-home deployments of sensor kits in 15 existing homes.

The studies we describe here challenge several implicit assumptions about homes of the future which tend to be embodied in prototype aware homes. Homes of the future tend to be "new builds" where they are constructed from the ground up and fitted with all their technology in a short space of time. In existing homes, technology is acquired in a piecemeal way, as postulated by Edwards and Grinter [6] and evidenced by the findings of our studies.

Where people make purchase decisions about technology, functionality is only one of many considerations, as identified by the themes of "balance installation usability with domestic concerns" [2] and "design for domestic use" [6]. As we saw in both everyday and smart homes, technologies need to fit in: to the power structure; to the physical space; to the values; and to the aesthetics of the home. In this arena, technology choices are often contended along gender lines and can be highly value-laden. For example, the management of the home and its routines was often the domain of the woman; applications which interfere with this power structure or make it more difficult to do the things that she already does are unlikely to find favour. Other aspects of running the home – control of the heating – might be a male domain. This has implications for the types of technologies we develop and the importance of understanding the power structures and values within the home.

Ultimately people will need to be persuaded to purchase these new technologies for the home; seeing where people allocate their spending power and their effort and attention now is instructive for directing attention to what applications might be more acceptable. In the smart homes especially, people were prioritizing safety (in sensor-based lighting choices) and entertainment/leisure (in high-end home entertainment system choices). In neither smart homes nor everyday homes did we see evidence of demand for many, what might be called "typical", smart home features, such as curtain openers, voice control and kitchen automation. Such automation, where deployed, was often experienced initially as a novelty then as annoying. This has implications for what we think people will want or what they say they want compared to what they will actually find useful, fun or are happy to live with.

However our studies also highlight an extra level of complexity in the way technologies are acquired. Not only are people incrementally evolving their own homes with new technology purchases, but in some houses technologies are as likely (or even more likely) to be hand-me-downs, second-hand purchases, or gifts, wanted or unwanted. Some commentators have claimed that the practice of gift giving is in crisis, citing a tension between the need of gift-givers to continue giving and the need of gift-receivers to demonstrate aesthetic control over their domestic environment [12]. While how technology comes into the home needs to be recognized, as per the "accidentally smart home" challenge [6] and it needs to co-exist with older-generation technology (see also the "impromptu interoperability" challenge [6]), there is a further challenge to acknowledge, perhaps encourage, these alternative routes of entry into the home. This has implications for how we think in the future about the

introduction of new technologies into the home and opens up opportunities to support new forms of technology gift giving or sharing.

Another factor associated with future smart home research is that they tend to be constructed and used in environments where advanced technical expertise is always at hand. In everyday homes this is not the case and even "unproblematic" technologies like ADSL broadband and wireless networking are still causing huge problems and may go unused for months because the people do not feel that they have access to proper technical support. Edwards and Grinter [6] phrase this understanding as a challenge to make technologies reliable but even if technologies are "reliable" in the sense intended, our studies suggest that they may still be unusable without access to ongoing technical know-how. Design for reliability may be part of the solution, but it may be that pervasive computing has to recognize and incorporate into its design, the social capital of providing technical support and know-how of friends and family, as well as providing access to a wider community of support. It may be that, as with personal computing, pervasive computing in the home will have to go through a "hobbyist phase". Given the large amounts of money that several of our participants were prepared to spend (e.g., to buy a new laptop to fix a broadband connection, to buy a new PC to fix a troublesome CD Re-Writer) it seems that seeking to understand how best to provide domestic users with access to the required know-how may be a fruitful area of research.

One suggestion for making technologies easier to understand has been for the 'pervasive' designer to "make appropriate use of user conceptual models for familiar technologies" [2] but this implies that correct and agreed mental models exist and can be identified. Our findings suggest that often people do not have such well-developed conceptual models in the first place, as evidenced by the limited understanding of how sensors worked, nor do they have the skills and know-how as evidenced by the inadequate strategies people had for problem solving.

Another suggestion had been to support system inferencing in the presence of ambiguity [6]. The findings here, both of everyday homes and the smart homes, suggest that the reverse is also required: users need to be supported to make inferences in the face of system uncertainty as they seek to trouble shoot problems. Even something as simple as turning a device on or off can become much more difficult with the smart homes, pointing to a need for intuitive easy to use controls and reflective support for trouble shooting (which as discussed is not straightforward the more complex the installation gets).

Future aware home research can also tend to work with particular assumptions about the kinds of information would be useful in a domestic setting, e.g., activity monitoring [14] or coordination information [5]. When participants in our study were asked about information they wanted in their home, they responded with a diversity of answers which reflect the crucial role which the home has in embodying far more than work-like values. For example, "I'd like to know how windy it is on my roof," embodies a desire to express strong beliefs about care for the environment and the use of renewable sources of energy (such as wind power). "I want to know the history of this house, who used to live here," reflects a curiosity and interest in knowing more about (very) local history. Such answers suggest whole new application areas for pervasive information somewhere between utilitarian [1,22] and ludic [7] ones.

A further assumption in much aware home work is that hundreds of sensors can be embedded and networked together in the home, passively and unobtrusively go about their sensing, and, where needed (as in aging in place scenarios), their output can be remotely monitored and interpreted [14]. Yet the studies here suggest that the stand alone 'mature' sensors that we have in home today generate a large number of false alarms and instances of problematic behaviour. At the same time, the people who live with these sensors have developed ways of understanding and interpreting (albeit incorrectly at times) the behaviour of the sensors in response to local conditions, to the point where 'problems' are routine and workarounds are well understood. While reasonable for single simple sensors, this has serious implications if we consider hundreds of sensors possibly not working or sending out false alarms, and where the interpretation of 'routine' problems is removed from the local context and local strategies for addressing them.

5 Conclusion

Significant technical advances are being made that mean that the vision of pervasive computing in the home is closer to becoming a reality. In this paper we have reported on three complementary studies that explore people's current experiences with technologies already in homes in a UK context. These are interesting because the technologies and sensors in everyday homes and in the higher-end 'smart homes' share many of the same sensor and technology components, albeit in much simpler configurations, that will be used to realize these future visions. Our findings around the ways technologies are brought into the home and the everyday experiences and troubles with technologies and sensors suggest that the design issues to be addressed to realize the vision will be much more about the human, social, cultural and marketing issues than the technical issues. They also point to the future work we need to work with people better understand what applications we should be looking at building for the home.

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