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Smart Homes or Smart Occupants? Reframing Computational Design Models for the Green Home

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Abstract

A sustainable home is more than a green building: it is also a living experience that encourages occupants to use fewer resources more effectively. Research has shown that small changes in behaviour in how we use our homes can result in substantial energy and water savings. The design dialogue in the development of efficient buildings has largely focused on energy use simulations, smart automation of the building systems and components for optimal performance rather than on effectively supporting how people use them. In this paper we propose that the challenge to computationally supporting sustainable home design lies in integrating more informative models of occupant behaviour and suggest three foci for developing these models drawn from case studies in sustainable home systems design.

Introduction

A sustainable home is more than a green building: it is also a living experience that encourages occupants to use fewer resources more effectively. Research has shown that small changes in behaviour in how we use our homes, such as turning off lights, reducing heat and uncovering or covering windows, or shortening showers, can result in substantial energy and water savings. But changing the way we use resources is proving challenging. The combination of ubiquitous computing and computational intelligence offers an opportunity to enable occupants to dynamically interact with building technologies for feedback and control regarding performance and atmosphere while empowering the occupant as an agent of behavioural change. These technologies and patterns of use are the focus of recent design research but knowledge of how they should be most effectively integrated into sustainable home design is in its infancy. We still know very little about how to design, situate and integrate the various technologies to support occupants in making more efficient resource use decisions.

Our particular research is focused on how to enable residents to make appropriate resource use decisions in their homes without imposing undue technological complexity or effort: in other words, to examine the potential of optimizing the *use* of the home through computational means. As interaction designers, we are keenly aware of the need to model how people use artefacts as an integral part of the design process. This awareness is only recently arising in the architectural design dialogue. An emerging area of research in the design of sustainable buildings is the extent to which the occupants of that building are engaged and involved with its operation (Cole & Brown, 2009) (Leaman & Bordass, 2001). Cole stresses the need to model this concept of "occupant intelligence" into existing design concepts of intelligent buildings. Buildings designed around occupant intelligence will provide flexible, adaptive task environments, refined control zones and *technologies that maximize occupants' access to adaptive opportunities* (Cole & Brown, 2009). Architects, engineers and system designers are faced with the challenge of reframing design strategies as a co-evolution of human and building intelligence that will encourage as well as underpin sustainable use. This requires new models of design thinking beyond the typical "smart home", encompassing occupant behaviour, motivational strategies, and exploration of how automation can impact occupants' daily rituals and sense of comfort.

The design dialogue in the development of efficient buildings has largely focused on energy use simulations, smart automation of the building systems and components for optimal performance rather than on effectively supporting how people use them. Instead, we propose that the challenge to computationally supporting sustainable home design lies in integrating more informative models of occupant behaviour.

In this paper, we review relevant research, present a case study of the design of two net-zero sustainable homes that highlighted these needs and propose three main foci

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for the development of new models of how people use their living spaces: contextual factors in building use (what affects how people use energy in different situations?), interaction with automation, and the effects of new feedback and control systems in the home. Such foci will be important in extending current work both in simulating occupant behaviour (Clevenger & Haymaker, 2006) (Goldstein, Tessier, & Khan, 2010) and in the design of better interactive, intelligent and embedded technologies for "greening" homes. In particular, we consider that adding this perspective of the resident as *user* will be critical for architects and engineers in exploring the potential issues and affordances of sustainable technologies and building designs.

Motivation

User modeling in interaction design is usually an analytical as opposed to a computational process, and so determining what can be feasibly incorporated to computational modeling is a challenge. The goal of this paper is not to suggest a single computational intelligence model; rather, we propose directions for embedding these human-centred perspectives in computational reasoning for design. What issues do we need to consider in improving the design of "green" homes? While there is significant research on aspects of building performance and its impact on human comfort there is substantially less understanding of what aspects of human behaviour can be effectively modeled for increasing conservation and indeed how these models may be applied. We need to understand this for several reasons:

- Analysis of existing environments (what encourages or impedes saving energy?)
- Design interventions: if we introduce technologies to support or mandate energy conservation, what impacts will they have on human interaction with the living environment and on the resident's comfort and acceptance?
- Operational behaviour: are we using the right conditions to affect automated or intelligent decisions about controlling the residents' environment?

Background

Occupant and energy use modeling

A plethora of engineering and statistical modeling techniques exist for analysis and simulation of residential energy use. Building simulation tools rely on such models to ensure performance and efficiency, particularly with respect to human occupation, Over the past decade researchers and engineers have focused on incorporating aspects of occupant comfort and satisfaction into building performance models, such as the well-known ASHRAE standard for thermal comfort simulation (Peeters, 2008) (Goins, 2010) and the CBE satisfaction index (Zhang, Kim, Arens, Buchberger, Bauman, & Huizenga, 2008). A more recent focus is the need to understand not only how the building performs but how it is used. (Vale & Vale, 2010) stress that when assessing energy use, building performance is no longer sufficient for post occupancy evaluation (POE) of dwellings: it is necessary to ask questions about what the occupants do. While empirical data shows that the energy use of different occupants living in identical residential units can vary by as much as 200-300%, standard energy simulation models such as DOE-2 cannot account for this variability. This has fueled active research in modeling "virtual occupants" (Richter, Weber, Bojduj, & Bertel, 2010) (Pan, Han, Dauber, & Law, 2006),(Akbas, Clevenger, & Haymaker, 2007),(Goldstein, Tessier, & Khan, 2010) (Goldstein, Tessier, & Khan, 2009). However, most of these occupant models are simplistic, relying on simple occupancy/zone schedules to determine building use and extrapolating heat and lighting use from this. As Clevenger points out, this is insufficient to effectively model levels of use in the building (Clevenger & Haymaker, 2006). A recent more promising approach in modeling occupant behaviour in offices has used simple personas differentiated by schedule-calibrated activity to allow architects to explore the energy implications of different building design (Goldstein, Tessier, & Khan, 2010)(Goldstein, Tessier, & Khan, 2009). It is noteworthy that most if not all of this research focuses on office buildings and not home use.

Recent work by (Vale & Vale, 2010) discusses energy use in modern UK households from the perspective of lifestyle factors and highlights emerging trends that promise to significant change the way POE modeling is performed: notably, that the rise in entertainment devices now consumes as much energy as hot water heating in middle-class homes. They emphasise that residential energy use cannot be simply calculated additively; the use of certain devices reduces demands for others, and use patterns rather than singular appliance profiles need to be considered.

Smart homes and responsive systems

The general promise of the smart home – that intelligent operation could be off-loaded to a computational component – has been confounded by the human factor. The single most daunting factors in smart home automation have not been technological capability but complexity and poor usability (Eckl & MacWilliams, 2009).

However, significant research has focused on the power of sensors and ambient intelligence to automate and enable supportive and adaptive services within smart homes. This work has largely been targeted at enabling assistive environments for in-home care such as the PlaceLab (Tapia, Intille, & Larson, 2004) (Intille, 2006). A recent Apple patent extends home automation to support variable control of how devices are powered and provide feedback on consumption at the device level. More recently, similar agent-based sensing networks have been proposed to analyse and react to user behaviour in the environment to optimize power use (Makonin & Popowich, 2011) and enable load shifting (Harle & Hopper, 2008). The focus in these technologies is measurement, analysis and control of power in the home, with automation as an underlying principle. Reasoning about occupants is around presence/absence, activity (via motion), power use spikes or light levels (Makonin & Popowich, 2011). This approach shows some promise, but the model used to evaluate the human's state proved to need refinement.

Human-home interaction and sustainable technologies for the green home

A critical issue in supporting occupant intelligence revolves around how the system is presented to its users and how appropriately the complexity is mapped to both the expertise and the involvement of the user (Leaman & Bordass, 2001). A common observed enemy of occupant satisfaction is when the building control system becomes too complex for its managers (Cole & Brown, 2009). In a home an occupant is both *resident* (not worker or part-time visitor) and *manager*. People engage with their homes in very different ways than with the work environments studied in the research described above. Issues of comfort, identity, and repose are critical. Should one be expected to be an expert building manager?

Woodruff et al. discovered that committed adopters of sustainable building technologies take pride in their expertise around these technologies but emphasize that knowledge and constant management become a way of life in these houses (Woodruff, Hasbrouck, & Augustin, 2008). In fact, many participants described living in a sustainable house as "piloting a ship", demanding constant, active monitoring; course corrections and reconfiguration; and strategies for understanding how occupant behaviour interacts with the desired outcomes (including reduced ecological footprint, comfort, and social outcomes such as influencing others' actions).

Psychological research shows that feedback is a central aspect of motivating resource conservation in the home (Abrahamse, Steg, Vlek, & Rothergatter, 2005) (Stern, 1992). Recent web-based services partnered with power utilities approach this goal. Google PowerMeter™ and Microsoft Hohm™ allow residents to monitor and analyse aspects of their energy consumption using common "energy dashboard" displays and some description of energy use impacts. In-home displays such as Rainforest's EMU™ simply show total electricity consumption in terms of kWh hours and money spent. Point of consumption tools such as the KillAWatt™ are dedicated energy monitoring units attached to a particular appliance or outlet that provide numerical electrical and financial expenditure.

In contrast with these traditional computing displays, a number of researchers have developed ambient monitoring and awareness tools for use in the home. These have the goal of communicating information without requiring analytical attention, such as incorporating displays of energy use into household items such as clocks or power cords (Gustaffson & Gyllenswärd, 2005), personal wear and abstract informative art as ambient visualizations (Bartram, Rodgers, & Muise, 2010). Weiss developed a web-based application for monitoring home energy use that allows the resident to monitor consumption on a smart phone and turn individual appliances on or off (Weiss, 2009) (Gustaffson & Gyllenswärd, 2005).

Research into how technologies may aid or hinder residents in developing more sustainable behaviours within the home is more recent. As several researchers have found, simple data feedback is not enough. Awareness does not equate to behaviour change, and a diversity of motivations exists for conservation. Key issues for residents are the lack of real time information around consumption (Wood & Newborough, 2007) and comprehension of what the energy use units actually mean in terms of behaviour; the complexity of energy-management devices such as programmable thermostats; poor location of feedback away from locations where resource use decisions are made (Bartram, Rodgers, & Muise, 2010); and the need for motivational tools such as goal-setting abilities and social network (Mankoff, Matthews, & Fussell, 2007).

Chetty et al. advocate several design principles: make real-time information visible and comprehensible; design for individual and collective agency for motivation and reward; ensure technologies are attainable; and seek new ways of stimulating discussion and engagement (Chetty, Tran, & Grinter, 2008). Fitting these technologies into the home poses additional challenges. Residents have competing ideas about where visible technology should be located and who controls it. They also feel overburdened by the complexity and inflexibility of home technologies they already use. This can be seriously aggravated by automation: humans have an uneasy relationship with automated control (Woods, 2004) as we discovered in our first house. Numerous additional factors exist, notably architectural and design constraints that factor into technological decisions. Often these last issues adversely affect how the technology and automation are located and behave in the home, designed from the perspective of equipment function rather than resident ease (Bartram, Rodgers, & Muise, 2010).

Perhaps the most immediate example of poor human-house interactive tools is the programmable thermostat. It fails for two reasons. First, the interface is non-standard and invariably complex, so only a minority of users actually configures it successfully. More important, however, is its functional design. Most peoples' lives are more complex and variable than the simple schedules the thermostat accepts. As a result, people tend to program it for the minimum case, and end up heating their homes unnecessarily in periods when they are absent.

Lifestyle and human factors

What kinds of lifestyle factors contribute to residential energy use? Standard demographics identify income level but do not account for variability in use across similar homes (Clevenger & Haymaker, 2006). Ritchie's work shows that elderly people use more energy; women are more conscious than men; and age is not significant,

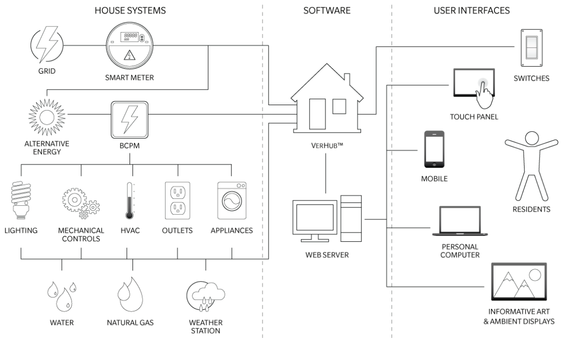

Figure 1. The Aware Living System

although this is an old article. According to Stern, four variables influence behaviour: norms and beliefs; external persuasive forces (community pressure, advertising); personal knowledge and skills; and habit and routine (Stern & Dietz,1994). He goes on to identify that energy use affected by the last is driven by comfort and effort.

Thiese point is reinforced by Steg et al. who discuss energy saving and conservation activities as a result of lowering both cost and effort. (Steg, 2008) (SChuitema & Steg, 2005). In addition, they pinpoint the role of knowledge; many people have incorrect estimations of how much energy is used in hot water and appliances, and their use is influenced. So while demographic factors such as gender and income play a sustantial role, the more malleable psychological aspects of habit, effort and knowledge have a strong influence.

Case Study: Designing for Sustainable Living

Our insights and experience in building information and control systems for the aware resident arise from our involvement in the design and implementation of interactive systems for two sustainable homes: North House and West House. Our system comprises several main components: a control backbone that provides fine-grained measurement and device control that is based on a heavily customized commercial application; automation logic and data logging; a Web services layer that manages data and commands between components; and the Aware Living Interactive System (ALIS) that embodies the resident's interaction with the home (Figure 1).

Design Research

In addition to extensive reviews of existing research and available products, we conducted workshops with people who described themselves as “interested” in sustainable living environments but who had no experience with any such. Participants included students, professionals and blue and white-collar workers. While the motivating models differed (some were more interested in positive financial outcomes where others were more interested in their energy footprint and ecological impact), we found several common threads. The first was *time*: all of our “users” identified themselves as very busy people and were concerned about having to spend too much time and effort in managing the house. A related thread was *place*: people are very mobile, wanted appropriate information and controls accessible from wherever they were, and wanted localized and contextually appropriate access in the house itself. For example, none found the notion of a central control panel and dashboard for lights, shutters, etc. very useful, but liked the idea of information and controls in place. A third was related to *complexity*: whereas several indicated they would be interested in learning more about how the house actually worked, all wanted a simple interface with a low learning curve that would provide quick access to reasonable house configuration while allowing the more expert user to fine time settings. Finally, participants really wanted to know “how they were doing” in the context of their particular *goals* (financial, energy use) and how this changed over time and events.

ALIS

ALIS is built on a comprehensive information model incorporating control and device details, resource-specific production and consumption data in terms of standard units, pricing levels, and standard usage equivalences, personal and shared goals, and a hierarchical model of energy-control settings to enable “one-step” optimization. It currently comprises different forms: a set of variably configured client interfaces run on web browsers in several platforms, including embedded panels in the home; a mobile application; and ambient, “informative art” pieces that can be part of the actual building (including the kitchen backsplash) or separate, decorative displays.

Awareness. ALIS supports a variety of feedback displays and analytical tools. Detailed information on resource production and use is available in real-time and historical views, categorized in different ways (by type of device, by location in house, by time of use).. These detailed views sit behind a Resource Dashboard that expresses resource use in variable terms: as standard units, financial figures, by usage (“Today's water use is equivalent to two baths”) and in relative terms (“25% less electricity than yesterday”) (Figure 2). We are exploring appropriate contextual ways to present the information, as these vary not only by individual preference, but also by location and task: for example, in the garage, the resident may wish to see the power consumed by his/her electric car overlaid on the top-level Dashboard view, and to see it in terms of “kilometers earned”.

We are exploring the use of informative art visualizations in two contexts. The Ambient Canvas is an informative art piece embedded in the kitchen backsplash (Figure 2). It provides feedback on the use of residential resources such as electricity, water, and natural gas. As opposed to typical graphical displays that may use numbers or charts to convey information, the Ambient Canvas combines LED lights and filters of various materials to produce light effects on the kitchen backsplash.

Control. As in standard home automation, ALIS enables the resident to control and monitor lights, shades, and climate settings. In addition, the resident can configure energy-optimizing "modes" as presets in ALIS controls: for example, turning off most lights and lowering the thermostat in a "Sleep mode", or tuning settings and shutting down standby power in "Away" mode. These presets can be activated via one button from any ALIS control interface, or scheduled for planned activation. For example, a smart alarm clock by the bed can wake both the resident and the house (by putting the latter into Home mode). Note that these are presented as examples: modes are entirely user configurable, and coexist with individual control settings for fine-grained control when desired.

Mobile. A mobile application for the Apple iPhone and iPod Touch offers a subset of the features available in the web application. The controls available from the mobile emphasize ease of use through logical groupings. These "master" controls allow the resident to adjust the lights for a whole room, or shades for a whole house façade, with a single control. More fine-grained control of individual fixtures is still available, but a hierarchy of control makes the most used items easily accessible.

Motivation. Residents can set personal milestones and challenges that can be measured by the system – for example, "use 10% less energy than last month." ALIS then tracks and reflects progress toward these goals.

North House

North House is a small solar-powered home that recently placed 4th overall in the 2009 Solar Decathlon. With the objective of achieving net-zero performance (producing at least as much energy as it consumes) in the challenging Canadian climate, North House incorporates sophisticated custom energy systems, adaptive intelligent building envelope technologies, specialized lighting and climate systems, and automated optimization behaviour. During the 10 days of the Solar Decathlon, North House saw more than 60,000 visitors.

The control system in North House employed several optimized subsystems with intelligent behaviour, notably the external shades that tracked the sun for efficient heating and cooling. The North House architects used ESP-r simulation to tune the behaviour of the intelligent shading in their original model (Velikov & Bartram, 2009). This proved insufficient in the later stages of design. The interaction design team came relatively late to the final controls specification and deployment of the house: about 8 months before the competition. We immediately identified a problem with the shade automation that involved a standard house use scenario: what if the resident wanted to alter the external shades for comfort, privacy, and natural light? To the system, this potentially put North House into "non-optimal" mode. Interface modes that indicated the shades' mode and a time-out function to return to optimization were required. Our anecdotal experience in North House was that visitors (our potential users) struggled with a model of how the system worked, with what "optimal" and "non-optimal" modes represented, and with how they might balance their needs with the apparent state of the system.

Placement of the interactive interface controls was equally constrained by the building envelope and materials. Because the facades of North House are almost entirely glass, there were few places to embed controls for lights, thermostats, or other devices. A digital touchscreen panel provided the only means for the resident to control, track and manage energy performance in the house, and the only place to put it was over a deep kitchen counter. High levels of natural light during the day made it perceptually difficult to see. In addition, an iPhone™ application served as a remote control for lighting and thermal controls. While this was interesting and provocative as a design piece, many visitors noted the issues of *needing* a remote control for the house so that one did not need to get up and move to a central location simply to turn on a light. This reinforced our own research.

West House

While North House was, in essence, conceived as a design showcase rather than a "useable" home, it served to extend our understanding of the disparate issues addressed and faced (or not) by the different stakeholders and the disconnect between those stakeholders. West House, our second and current project, addresses a different set of goals. Conceived as a sustainable, "near net-zero" home, it is a small, passively efficient house that uses electricity from the grid, natural gas for heating, and solar energy to augment heating, hot water and electricity production. We built West House as part of our ongoing collaboration with the City of Vancouver, whose policy makers are keenly interested in how information technology, social media, computational intelligence, alternative energies and building design can be combined to foster more sustainable living practices in "typical" houses. The process was substantially different. We began with a standard building design but worked with the engineers and builders from the beginning to augment it with the interactive systems. All of the stakeholders were local in Vancouver enabling easy access to early physical models of the home. As a result, we had more relaxed constraints on where we could place the ALIS controls and display components. West House is presented as a conventional home, and typical controls (light switches, thermostats and security systems) are included throughout the house, so that digital and physical controls and feedback are intermingled. Nonetheless, we faced certain challenges in determining locations for the displays in particular to do with perceptual efficiency, legibility and natural light angles. Human factors and task analysis helped us determine general location for the devices (e.g., that there should be a control panel at the entry point in the garage) but we used trial and error and walkthroughs with the example full-scale model to gauge the best possible placement for perception.

Given the issues with the intelligent North House operation, we chose to delay computational intelligence for the first installation of ALIS in West House. We currently use no automated intelligence for climate control beyond the standard schedule-controllable thermostat: we are experimenting with leaving energy optimization in the hands of its occupants, supported by contextual feedback.

65,000 people visited West House during its demonstration at the Vancouver 2010 Olympics. We conducted opportunistic anecdotal interviews with several visitors each day. Reponses to the interactive system were extremely positive but there were many questions raised about the potential and pitfalls of adding more adaptive control based on sensed activity in the home. This often provoked discussion on what appropriate levels of automation were with common anecdotes of poor automated control in other environments. Both the desire for more assistance and the sensitivity to poorly reasoned dynamic system behaviour were consistently emphasised, often by different people in the same family, highlighting the need for flexibility and seamless integration between user control and automation.

West House is currently installed on a permanent site where it is to be occupied as a living lab and a technology research space. Over the next year, our plans are to evaluate the efficacy of the house systems from the users' perspective. We will be exploring the use of intelligent agents in aiding house operation for resource efficiency: see the section on Future Work.

Discussion: Lessons Learned, Questions Raised

Our research and experience as interaction designers on these two projects highlighted several important lessons and questions around how to design environments that will be used sustainably: that is, how to design for the (reluctant or distracted) sustainable human.

We need more sophisticated models of behaviour. The first lesson is that there is a dearth of models of how humans use resources in the home, and the current promising approaches in simulation research (notably the personas work of (Goldstein, Tessier, & Khan, 2010)) rely on very limited scenarios of behaviour that are not sufficient to explain residential activity. There is a gap between the scientists studying the factors that influence behaviour and those building the models. Lacking the insight of human motivations and activity can skew design decisions: for example, the resident who leaves all the lights on because the only remote control is missing belies the goal of efficient lighting. This was particularly pronounced in North House. We discovered early in our design process that we needed evolving calculations of how much *effort* was required to use the house systems to optimal performance.

Most bottom-up models are based on occupant presence and some reasoning about the energy use implied by presumed activity. However, as Clevenger points out in her study of school use (Clevenger & Haymaker, 2006), activity can be zone sensitive, task sensitive, and time sensitive. When we look at research in home energy use (Vale & Vale, 2010), we see that modeling resource use requires understanding of how one use affects another (e.g. lights turned off when entertainment devices are turned on.) And while newer models from this research may help us reason more precisely about the energy consumption of the family they are more limited in exploring what kinds of technological interventions might improve conservation. Insight from research on lifestyle and demographic factors suggest that we need to construct more nuanced options of modeling a "resident", with gender, knowledge, motivation, habit and time/busyness as attributes. (This also indicates that we need to distill and collect data from various sources to serve as the baseline against which these synthetic models are validated.) In parallel we need to determine veridical scenarios of resource use in the home that recognize zone-, task- and time-specific activities.

How smart is "smart"? The second lesson was that "intelligent" operation and automation introduce new behavioural constraints that often reduce the efficiency of the intended function and can indeed cause discomfort in the resident. Unintended side effects can only be explored by incorporating scenarios of common use. The North House shades were a notable instance. Distributed intelligent control relies on assumptions about what sensed data indicate that may be simplistic (Intille, 2006) (Makonin & Popowich, 2011). At the same time, the complexity of fine tuned control and awareness systems (see the next point) suggest the potential of properly "tuned" adaptive home interaction. There is a fine line between disruptive automation and intelligent assistance. Designers need tools to explore this gamut before imposing it on residents.

Technology carries extra costs we must include in any behaviour calculation. Finally, when we introduce additional awareness and control technologies in the home, we also increase the complexity of use. Traditional usability analyses around each component concentrate on the operation of that component or appliance (only 6 steps to program the thermostat!) but do not model overall complexity, and it is the latter that we need to consider in how effective these systems can be.

Designing for the Human Point of View: The computational intelligence challenge

Human-computer interaction designers continually use several different types of models, almost always painfully built by hand and applied as analytical and evaluation tools in exploring how a system or artefact is used. We rely on the following to explore our designs and enhance our analysis of resource use cases. Developing computational versions of the following tools will aid designers in simulating more veridical behaviour by customizing and diversifying resident behavior.

Effort and Complexity

Our design "grounding equation" is: $E_p > B_p \neq change$: If the perceived effort is greater than the perceived benefit then the resident is not likely to change behaviour. From the perspective of reducing the impediments to conservation actions, we believe an essential part of a model of energy use has to include an "effort parameter" that weights how much effort is required for the resident to use it most efficiently. Our current "manual" approach to this quantifies it in hierarchical terms of steps required and complexity of step. For example, turning off the lights when leaving a room counts the number of switches or lights to be physically manipulated (simple); turning off the lights in another part of the house before going to bed includes checking where lights are left on (simple, but steps to each room) and turning off the lights in each room. Actions become effortful and complex quickly when extra steps are needed for information (understanding why the energy bill is high) or for compensating for extra technological overhead (resetting the programmable thermostat). Standard usability measures of task completion and task steps for evaluating how well technology performs can be easily accommodated in this approach.

Contextual patterns of use

Personas. Critical factors that affect resource use are age, gender, knowledge, habit and available time (busyness). Household income is important but not individually differentiated. One issue that we have heard frequently and anecdotally concerns how receptive a person is to technological intervention, and we are investigating this further.

Scenarios. In HCI research, a scenario describes activity in a set of preconditions, goals, actions and resulting conditions. In the simplest forms scenarios can be schedule- or single activity-based, as in sleeping (Makonin & Popowich, 2011). Scenarios help identify unexpected side effects and design inconsistencies. For example, applying a way-finding scenario to the layout problem discussed in (Richter, Weber, Bojduj, & Bertel, 2010) resulted in a better solution from the users' perspective. As we are particularly concerned with how the introduction of new technology affects complexity and activity, scenarios are essential to helping designers "walk through" the implications of the design.

Appropriate Intelligence Requirements

In line with Intille and others, we advocate for technology that assists humans to behave appropriately rather than relieving them of any operational involvement with their homes (Intille, 2006). Issues of trust and customization are important (Noy, Liu, Clements-Croome, & Qiao, 2006). The advantages of smart homes to date have tended to be outweighed by complexity, but it is clear that context-aware systems (Intille, 2006), distributed smart sensor/agent networks (Makonin & Popowich, 2011) and adaptive behaviour hold substantial promise. However, given the simplistic conditions that may guide behaviour, we posit that two factors may influence the efficacy of these approaches and need to be expressly modeled in design. First, the "cost of being wrong" needs to be taken into account (what happens if all the lights turn off because you fall asleep on the couch?) The cost of being wrong may simply be the effort required to recover a desired state, but may also implicate additional technological interventions such as the need to include extra information in the interface about reducing performance (the case with the North House shades). Second, the appropriateness of a "smart" intervention may be highly contextual. For example, we are currently exploring adaptive approaches to night lighting, that when someone gets out of bed we avoid disturbing her Circadian sleep rhythms while providing adequate light to navigate. Similarly manipulating light levels during the day may prove intrusive. Designers who wish to explore the affordances and potential of these systems will need to be able to simulate them with a variable degree of automation. Coupled with feedback systems, the challenging design question is to balance the appropriate responsibility between prompting for action on the user's part and assisting them by carrying out that action automatically.

Conclusions

Understanding how residents use energy in the home is an emerging area of active design research. Current design tools help architects and engineers evaluate building and technology performance but are limited in their models of how occupants behave. Computational intelligence tools hold great promise in opening the space of design possibilities for more efficient residences that encourage people to use fewer resources more effectively, particularly with respect to simulation and to context-aware smart home operation. Designing for humans, however, requires a user-centred approach. We have proposed three perspectives that need to be incorporated into more informative models of resident behaviour: context, the complexity of technological intervention, and appropriate interaction with automation.

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