PORTS: an interdisciplinary and systemic approach to studying energy use in the home

Garrath T Wilson
Loughborough University
Loughborough, LE113TU UK
g.t.wilson@lboro.ac.uk

Kerstin Leder Mackley
Loughborough University
Loughborough, LE113TU UK
k.leder@lboro.ac.uk

Val Mitchell
Loughborough University
Loughborough, LE113TU UK
v.a.mitchell@lboro.ac.uk

Tracy Bhamra
Loughborough University
Loughborough, LE113TU UK
t.bhamra@lboro.ac.uk

Sarah Pink
RMIT University
Melbourne, VIC 3001 Australia
sarah.pink@rmit.edu.au
Loughborough University
Loughborough, LE113TU UK
s.pink@lboro.ac.uk

Abstract
In this paper, we present an alternative and novel approach to identifying energy demand reduction opportunities in the home. Through the creation of detailed narratives informed by our interdisciplinary research team of social scientists, designers and engineers, we employ a systemic view of how energy is consumed in the home. By interrogating clusters of people, objects and resources through time and space as they come together within our qualitative and quantitative research, we have identified opportunities for sustainable HCI design. This paper outlines our approach and presents an example product concept in relation to laundry.

Author Keywords
Interdisciplinary research; sustainable HCI; energy; domestic; design;

ACM Classification Keywords
D.2.2 Design Tools and Techniques; H.1.2 User/Machine Systems; H.5.2 User Interfaces; J.4 Social and Behavioral Sciences; J.7 Computers in Other Systems

Introduction

On the path towards sustainable energy consumption people are often conceptualised as problematic, either because their 'behaviour' is unpredictable or counterintuitive, or because they are too 'set in stone' in their habits and routines to enable change. While technology-driven studies risk isolating and narrowly defining instances of 'bad' behaviour that need to be rectified, people-centred studies often lack detailed understandings of technological processes with system boundaries set too broad [1], leading to misdirected or short-sighted opportunities for change. Within this complex set of challenges, there are also competing theoretical models concerning the nature and significance of people's psychological, social or sensory-embodied competencies and identities, in addition to their agentive role in relation to wider technological and socio-economic structures [2, 3].

Sociological studies have begun to problematise approaches to behaviour change that solely engage with the psychology of the individual; exploring their motivations and attitudes, in order to effect change [4, 5]. Such studies paint, and often attempt to predict, a complex picture of the habits, technologies and structures that determine how energy is consumed; leading, however, to a displacement of meanings and elements of behaviour from the context of everyday life where energy-related activities are situated and intertwined. Furthermore, sociological approaches can also abstract change into practices and away from the processes of individual innovation and appropriation where they are played out [2, 4-6].

The LEEDR (Low Effort Energy Demand Reduction) project is taking an interdisciplinary approach to investigating energy and digital media use within UK homes with the aim of developing ICT based interventions to help householders reduce their energy demand. Building on interdisciplinary knowledge informed by detailed ethnographic work, qualitative design studies and longitudinal energy monitoring with 20 UK families and their homes, our approach seeks to reframe human activity, energy consumption and design opportunities to consider a range of direct and indirect routes towards domestic energy reduction.

People, Objects and Resources through Time and Space

LEEDR has demonstrated how different types of human action, some of which save energy and some of which consume it, are in real life interwoven and inseparable [2, 7]. Our work has led us to consider how these actions are brought together in a range of key routines and clusters of activity that are fundamental to everyday life in the home. We suggest that it is plausible to address a 'problem' not directly by seeking to change an isolated behaviour, but instead by considering the complex mesh of activities in which that problem is embedded. For example, showering (a practice) for twenty minutes (a 'bad' behaviour) is part of a series of activities and things that come together at a moment in time and space. Rather than only seeking to design a shower based intervention, our systemic approach leads us to seek out new possibilities elsewhere within related routines, which might be the key to creating shorter showering times.

We propose that by understanding the intersections and impacts of people, objects and resources through time and space [PORTS] suitable sites for intervention

can be identified and explored. The building blocks of PORTS are as follows:

- *People* are defined as meaning-making, reflective, habitual, social, experiencing and sensing subjects who employ different kinds of tacit and explicit knowledge to go about their everyday activities [8]. They are only one element in how energy consumption happens and how it comes to be meaningful in everyday life.
- *Objects* encompass domestic structures, materials and technologies (ICT, appliances, media, and laundry for example). Objects are not necessarily meaningful in themselves but become meaningful and relevant in their interaction with people and resources.
- *Resources* include not only the tangible consumables of gas, electricity and water; but also (flows of) air and (natural) light. Resources are only significant to energy consumption in the ways in which they intersect and relate to people and objects.
- *Time* follows two conceptions; as a quantitative sequence of activity and as a qualitative influence. Time within this second definition creates different temporalities [9]; in that 'felt' time is different to the chronological order we use to situate activities (it can be relative, feel slow or quick etc.). Time may be the expectation of when laundry will dry or the pressure of putting a wash load on before a dance class.
- *Space* is the environment in which each of these building blocks are situated and where they intersect. Space, like time, can shape the interrelation and meaning of people, objects and resources [10]. Within this framework, space can span multiple environments simultaneously (for example, shirts required for the workspace are washed in the homespace; both environments are relevant).

Defining our PORTS framework, we identify four potential sites for intervention, as illustrated in Figure 1.

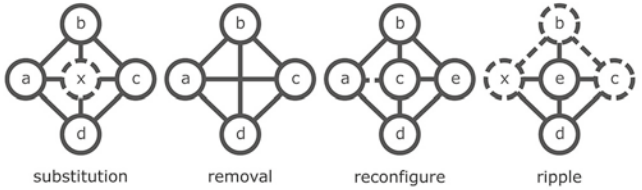

Figure 1. Interrelations and sites for intervention.

By substituting one of the elements within a cluster of activity, it may be possible to make the cluster as a whole more energy efficient. This may be achieved through a replacement of one (or more) of the elements, or through a nudge or other design techniques [3, 11] to change its direct interrelation to other elements. It may also be possible to remove one of the elements within the activity cluster to create new interrelations between previously unconnected elements. The elements within a cluster of activity could also be reconfigured, in effect bypassing elements and connections to create new interrelations.

Finally, we propose that ripples could be purposefully constructed to reduce the energy consumption of an activity. By ripple, we mean the changing of a directly interrelated element to purposeful affect an indirectly associated element within the same activity cluster. Opening up the cluster as a whole for examination could help facilitate lateral thinking as we attempt to bypass or disrupt existing elements. What are the ripples if we disrupt the current definition of the

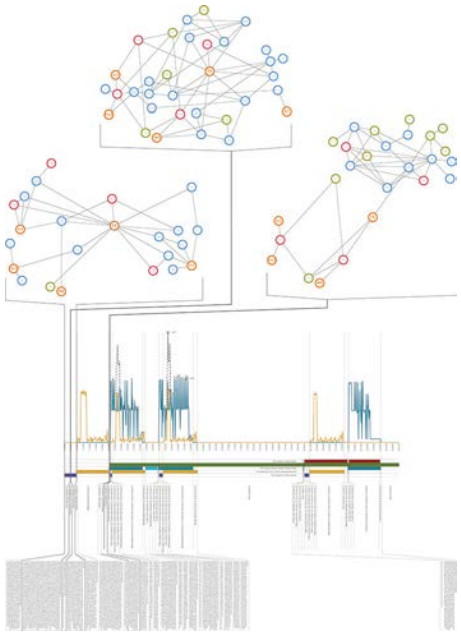

Figure 2. Illustrative layout of H01's laundry PORTS narrative. The ethnographic narrative runs horizontal along the bottom with the monitoring data running parallel across the centre. At the top are the activity clusters for key freeze frames.

weekend or work clothes; can we bypass decision processes and go straight from the washing machine to hanging clothes in the cupboard?

Methodology

Energy use happens at the intersections of people, objects and resources within specific contexts of time and space. Based on our varied data sets, we seek to draw out real-life narratives of how these elements correspond across empirically derived clusters of activity. The series or processes of activity that form the basis of our narratives derive from intersections between our ethnographic insights and their relations to energy monitoring analysis. Narratives may focus on how people intersect with objects and resources in temporally and spatially contingent ways, or may also focus on sets of activity as they play out within relatively short or longer time frames. Within given narratives, we apply 'freeze frames' to study intersections of people, objects and resources in more detail (clusters of activity), thus exploring how they become meaningful or relevant within situated moments of domestic life. Existing data sets, generated in the first two years of the LEEDR project, form the basis for interdisciplinary narratives and the in-depth exploration of intersections:

- *Engineering* monitoring data includes electricity at meter, circuit and appliance level, hot water flow, gas consumption, room temperatures and occupancy across all 20 households, as well as weather data. Engineering data analysis and modelling seek to understand immediate contexts and impacts of energy consumption as well as longer-term significance and use.
- *Social Science* visual ethnographies (audio-visual materials) and detailed ethnographic accounts were generated through home video tours (with all 20 households) and detailed everyday activity studies with just over half of the sample. The former explored how energy consumption is implicated in the creation of the home as a sensory environment, involving a range of re-enactments of everyday routines [2]. The everyday activity visits focused on sets of activity relating to laundry, cooking, bathroom use and digital media engagements.
- *Design*-generated data with all twenty households include audio recordings, transcripts, thematic analysis of semi-structured interviews and participant-led routine-mapping activities on household floor plans. Interviews explored families' everyday lives, interests and values, as well as their existing thoughts on energy consumption and sustainability.

A first stage of the research was to identify key routines and processes in participant homes, and draw out, through detailed narratives, how people, objects and resources come to relate across sets of activity. As an initial investigation, we focussed our attention upon the laundry activity of one household, coded H01, for a specific day (18th March 2012) as illustrated in Figure 2. By positioning and analysing the energy data of H01's washing machine and tumble dryer alongside an in depth ethnographic account for the same period, we could further our understanding (and debate the relevancy) of each data set to create a proportionate narrative timeline, granulated according to energy related activity. Thus, we segmented the narrative into freeze frames, as illustrated in Figure 2, at points that our research showed to be key decision-making moments within laundry, such as dirty laundry prioritisation. With the freeze frames identified, the

Figure 3. Detail of the tumble dryer loading activity cluster (taken from Figure 2). Orange spheres represent people; blue, objects; green, resources; and pink, spaces.

meanings, relevancies and implications of the specific intersections of people, objects and resources were explored in detail through an interdisciplinary workshop; resulting in the construction of complex assemblages of PORTS elements within these clusters of activity (for example, Figure 3).

However, attempting to address and design to 20 different problem and solution spaces in this manner would not be feasible, especially if scaled up. Personas in this respect are ideal, as they are distilled surrogates to focus attention on key characteristics [12, 13]. Personas are not averages (a persona, like a real family, cannot have 2.4 children), but a considered and intelligent extrapolation and selection of observed behaviour patterns, telling a cohesive 'real world' story about the fundamental characteristics of a type of person or group of people. They are designed to elicit empathy in a way that we can relate to, that we can design to, not as a series of abstract and dry characteristics [12]. The set of six personas constructed span the breadth of unique behaviour patterns and (sometimes contradicting) goals observed from our 20 participating LEEDR households. The six personas are The Child Constrained Family; The Principled Sceptics; The Wholesome and Frugal Experientialists; The Multi-Generation Prolific Consumers; The Young Good Lifers; and The Mature Good Lifers.

Each persona had three boards. The first board was primarily a context board (Figure 4), including a short background to the persona; relevant goals (basic, end and experience); 'about the family', 'home', 'sustainability' and 'energy and technology' context points with reinforcing quotes (edited versions of real participant quotes). The second board gave an overview of the relevant technologies, systems and consumption statistics; again not averages but intelligent, bottom up selections from real monitoring data. The third board (Figure 4) was a concise summary of a PORTS laundry narrative for that persona family, incorporating and making sense of the data from all three disciplines. The graphs are visual representations based on monitored data profiles for appliances, selected and manually manipulated in line with data from SS and DES; again a bottom up selection and synthesis process. The quantitative data here is, in effect, as archetypal as the qualitative, used only to convey the persona family's laundry characteristics in a tangible and believable way.

The six text boxes, anchored to freeze frame moments of interest, capture some of the complex clusters of activity to give specific insight. One of the weaknesses with the initial depiction of clusters of activity within H01's laundry (Figure 2) was the lack of explanation as to what the exact relationships are between the elements. These cluster maps, therefore, do not provide simplified answers or act as a standalone device, but act as a detailed investigatory tool to be used alongside the narratives and quantitative data. Forcing the researcher to look for connections within these clusters and then look back through the narrative/monitoring data for the deeper, richer meaning helped to generate new persona insights, as developed and captured within the six boxes.

The following is an example concept that emerged through taking this systemic approach to generating insights.

Figure 4. The Context and PORTS boards of The Child Constrained Family persona.

Kairos – Creating Opportune Moments

Kairos, a term the ancient Greeks used for the *opportune moment* [14], is a mobile app concept that allows the user to set a delayed end time and intelligent profile for their appliances and heating system that is grounded and situated within their daily lives. The concept has been developed so far using the washing machine as an example.

Kairos represents activities and time qualitatively, eschewing traditional approaches to time and activity management (Figure 5). There are no quantitative metrics of time displayed, other than the dial representing a 24-hour day, with activities positioned in relation to other relevant activities (the coloured arcs) and to the present moment (the red arrow). The present moment is constant (it is always 'now') with a fixed position across which the Kairos dial rotates in real-time counter clock wise, introducing new activities ahead and discarding activities that have passed.

Activities can be selected to build unique Kairos profiles, as an individual or as a family, with user created digital flows (using IF/THEN conditional statements) to make new interrelations of activity, embracing the notion of people as everyday innovators and directors of flow [7, 15]. This concept also builds upon Taylor and Swan's vision for ubiquitous computing, that states that "*technological infrastructures for the home should allow for the use of multiple, mobile and embedded, information devices that can be combined and interconnected in ad-hoc*

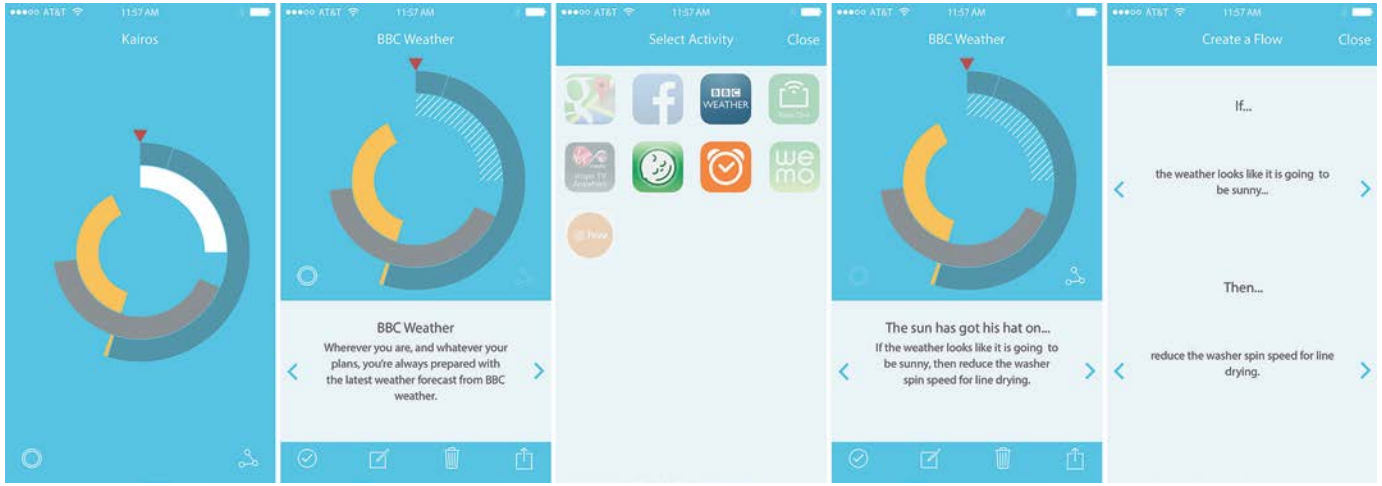

Figure 5. Kairos app screenshots. Screen one, overview of activities with snapped washing machine cycle (dark blue to orange arc); screen two, flicking through the activity carousel and selecting an activity (white arc) for further details; screen three, de-/selecting activities; screen four, flicking through the flows of the selected activity; screen five, creating new flows with conditional statements.

Potential new interrelations:

- Baby's cot (monitored via an in built accelerometer) to washing machine. *IF the baby is in light sleep, THEN reduce the washers spin speed*. Noise generated by objects within the laundry process was an identified constraint on when laundry could be performed. This new interrelation connects spin speed (and noise) to activity, opening up time available.
- Weather (monitored via a local weather station) to washing machine. *IF the weather looks like it is going to be sunny, THEN reduce the washers spin speed*. Weather as a resource can dynamically change, which this new interrelation monitors and adjusts to, helping replace energy intensive tumble-drying with line drying.
- Family events (monitored via social media, NFC/iBeacons, WeMo etc.) to washing machine. *IF I am approaching home THEN start the washers final spin cycle*. Washing machine end times do not always synchronize to dynamic family events, e.g. going to the shops or lunchtime. This new interrelation presents the washed articles when the user is ready to re-engage with the laundry process.

ways" [16 p.648]. The endpoint of the wash cycle can, for example, be 'snapped' to the start or end points of these activities, which may be static (e.g. synchronizing to the TV schedule) or dynamic (e.g. entering/leaving the home), completing the wash cycle when it is the *opportune moment* for the user to engage with.

By setting a delayed end time, the washing machine can determine the most efficient settings to complete the task, adjusting dynamically to the anticipated activities and the energy load of the home/grid. Additionally, Kairos promotes conscious decision making and planning, especially towards the identification of potential activity conflicts (for example, user location and wash load end time) thereby reducing post-wash dwell time and the need for rewashing due to smell or creasing, as identified in our research [17]. Parts of the laundry process can be optimised towards the situated activities of the user in addition to any surplus in the energy system, rather than driven by inefficient speed based priority settings.

Conclusions

The originality of our approach to studying energy use in the home lies in drawing systemically on ethnographic findings and energy measurements surrounding situated everyday routines to create new categories and sites for intervention, as well as generating new ways of thinking about indirect interventions and their potential success. It is strengthened by an ongoing interdisciplinary dialogue that allows for a dynamic and iterative framing of problems and solutions.

An on-going challenge is the need to find ways to manage the complexity of the resulting interdisciplinary data sets. The use of personas is a step towards addressing this issue and we hope to expand the scope of the archetypal qualitative and quantitative data encapsulated within each persona. However it is the reflexive meaning making activities [18] and inter-disciplinary exchanges implicit to the construction of the PORTS data sets that has so far been the richest source of insights and therefore we hope to further examine and refine this process.

We are attempting to generate in-depth knowledge of how energy-related activities are situated in people's everyday lives, that is, how people, objects and resources come together in specific contexts. We set out to restructure data to identify and redefine relevant categories of human activity, the intersections of which may become sites for direct and indirect intervention towards the reduction of energy consumption. Our approach allows us to explore the range of people's experiences and engagements with their environments, circumventing the value-behaviour gap problems by exploring how activities become meaningful and relevant in everyday life; meaning and significance become situated and dynamic, not abstract or externally specified. The PORTS approach is not about isolating instances of (bad) behaviour, but about facilitating new processes, or old processes in ways that are more efficient, as illustrated in this paper.

Acknowledgements

The interdisciplinary LEEDR project, based at Loughborough University, is jointly funded by the UK Research Councils' Digital Economy and Energy programmes (grant number EP/I000267/1). For further information about the project, collaborating research groups and industrial partners, please visit www.leedr-

project.co.uk. The author would like to thank all the households who have generously participated in this research.

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