ENERGY IN THE HOME:

EVERYDAY LIFE AND THE EFFECT ON TIME OF USE

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ABSTRACT

The application of building simulation and modelling is becoming more widespread, particularly in the analysis of residential buildings. The energy consumption and control of systems in residential buildings are tightly linked to the behaviour of people, arguably more so than in commercial buildings which have traditionally been the preserve of building simulation analysis. The input profiles used in simulation pay little attention to the link between numerical characterisations of observed 'behaviour' and the way people actually live in the home. Understanding this is important if we are to improve the modelling of buildings, gain greater insight into energy consumption and make better decisions about future energy production and generation. This paper explores this link by combining conventional numerical analysis of appliance data with insights from the ethnographic study of families in 20 UK homes. Ethnographic insights provide a context to the analysis and understanding of monitoring data that would not otherwise be possible. Importantly, this paper highlights the need to rethink previously static notions of simulation input, such as occupancy and individual appliance use.

INTRODUCTION

There is now a growing body of work that applies building simulation and modelling tools to the residential sector (Dong and Andrews, 2009). With UK homes currently making up 26% (of Energy and (DECC), 2011) of the countries overall energy use, a specific interest has emerged in demand reduction and load shifting models. Energy consumption and the control of systems in residential buildings are tightly bound up with the lives of their inhabitants (Malkawi, 2004; Firth et al., 2008; Zimmermann et al., 2012; Kashif et al., 2013), arguably to a greater extent than in commercial buildings, traditionally the preserve of building simulation analysis. It has been recognised that the input profiles that drive simulation are currently poor, and these are beginning to develop (Bourgeois et al., 2006). Thus far, however, little attention has been paid to the interrelations between numerical characterisations of observed human behaviour and the way people actually live in the home environment and what this means to them. For energy models to become more sophisticated, there is a need to move beyond controlled activity profiles and predefined scenarios towards prediction tools that account for the complexities of everyday life. One way in which human behaviour has been accounted for in simulation studies is through the notion of 'lifestyle constraints', considering individuals' energy consumption behaviour as determined by a range of contextual factors, such as building types, appliance characteristics, lifestyle choices (Kashif et al., 2013; Haldi and Robinson, 2011) (relating to work, school and leisure), and the social and cultural values that are placed on activities (Wall and Crosbie, 2009; Porteous et al., 2012; Wilhite et al., 1996). A consideration of lifestyle constraints already has important implications for understanding the domestic context, given that it shows the complexity and number of variables that might intersect to determine how energy is consumed. Recent developments in the social sciences, however, paint a still more complex picture, suggesting that a focus on common-sense definitions of behaviour and behaviour change is misplaced (Strengers, 2012; Shove, 2010). These approaches focus instead on practices and routines, and show how the ways people consume energy in everyday life are, to a certain extent at least, driven by the need to satisfactorily accomplish these routines and practices. This paper reports on work being carried out on an energy monitoring project in the UK that is generating high-resolution whole house energy data from residential properties. The approach has been to combine monitoring data with social-scientific analysis of the practices through which energy is consumed, in order to generate a greater understanding of how energy use is implicated in the rhythms and activities of everyday life. In this paper the monitored data is used to build pictures of appliance use across the day and, building on existing data based on time of use, to demonstrate differences between households, week days, and seasons. These patterns of consumption are then analysed in relation to the complexity and detail of ethnographic insights about how family life is actually lived in two sample households. Connections between monitoring data and ethnographic insights have developed in a range of ways to create an unprecedented level of interdisciplinary integration. Here we focus on the implications of developing a detailed understanding of mundane household routines and practices as well as special events as constitutive of the patterns of energy monitoring data that is equally detailed. We argue that although energy monitoring can identify when use occurs and where potential savings might be made, understanding the dynamics of energy consumption in households does not only require a focus on appliance loads/numbers or simplistic models of occupancy but a consideration of how everyday life is played out in the home, and the nature and significance of people's activities. While the novel step of bringing together highly detailed monitoring data with in-depth ethnographic research knowledge is in itself not an easy task, we argue that this step needs to be taken in order to advance knowledge in this field.

A CROSS-DISCIPLINARY APPROACH

This paper presents results from an ongoing home energy monitoring project in the UK, which explores residential energy use and the interplay with how people live and carry out their day-to-day routines, with the ultimate goal to reduce energy consumption through digital innovation. The LEEDR project takes a cross-disciplinary approach with expertise from designers, social scientists, computer scientists and engineers from mechanical, electrical and systems engineering. The study focuses on a sample of 20 homes, combining high-resolution monitoring of appliance use, gas and electricity consumption, hot water production, occupancy and building and system temperatures with rich, narrative and other qualitative insights from researchers in design and the social sciences. Energy and measurement data provides a representation of human behaviour as it manifests itself in the use of appliances and services. Value is placed on repeatability and on understanding the overarching relationships that can be compactly represented, so that others can reconstruct the approach and apply it elsewhere. A good example for this is modelling and simulation, which uses the measurement of data to create models that others can apply in their analysis. Within the social sciences, 'behaviour' is understood and investigated as an array of practical activity with different characteristics, temporalities, significances and values. Within the context of this study, the purpose of the social research has been to explore families' domestic activities through a range of video ethnographies and related methods that have been informed by sensory and phenomenological theories of how people experience, create and maintain their social and material environments (Pink and Mackley, 2012), (Pink et al. forthcoming). The approach has moved emphasis away from direct energy or appliance use to consider how energy use is implicated in a range of more or less conspicuous everyday activities, and across (often interrelated) practices and appliances. The detail of ethnographic description in conjunction with that of time-based monitoring data allows us to introduce hitherto underexplored complexities, and to frame questions of energy consumption in new ways, for instance by tracking energy use through people's movements (Pink and Leder Mackley, under review) and by following practices as they are dispersed across time and space. These insights are important to develop better models of how people behave in terms of understanding and interpreting the results of analysis that incorporate prediction.

The dwellings in the LEEDR study are all owner-occupied houses, 9 of which are detached and 10 semi-detached; one home is mid-terrace. With the exception of two three-storey buildings, all dwellings are made up of two storeys. Buildings were built between 1900 and 2002. Wall construction types vary from solid construction to cavity wall; some of the walls not originally insulated have since been filled. Some of the modern dwellings have insulated cavity walls. All homes use hot water provided by a central gas-fired boiler heating system, and 8 of the houses have one or more electric showers. The building heating systems in all dwellings are typical LTHW (Low Temperature Hot Water) boiler systems, more than half of which have had a significant overhaul within the last four years. The electrical systems in all the houses are typical of the UK, although two properties are fitted with photovoltaic panels. All homes have some CFL lighting, but only four have CFL light bulbs throughout the property. The dwellings are occupied by families that are mainly comprise of two adults and two children (the age of the children ranges from new-born to young adulthood). The main exceptions are one single-parent/single-child household and a three-generation family of three adults and three children. Families have a range of educational backgrounds. Incomes range from £20,000 to over £50,000.

METHOD

To demonstrate the approach used in this paper, two homes were selected. H43 is a two-storey detached 1930s building which has undergone extensive building work to now contain a large kitchen diner, office, two sitting rooms, cloakroom and integrated garage on the ground floor, and four bedrooms, one family bathroom and separate en-suite shower room and toilet on the first floor. The majority of the home is heated via gas-fired central heating; a detached garden studio is heated by an oil electric radiator. All the kitchen appliances, including a gas cooker, are relatively new. The family comprises of two adults and two children. H43FA is an artist who mainly works from home. H43MA holds a senior position at an IT firm. The children are aged 11 and 13. H05 is a slightly smaller, two-storey semi-detached 1930s building which, like H43, has been extended to contain a large kitchen diner, two sitting rooms and a cloakroom/utility space on the ground floor, and three bedrooms and a bathroom on the first floor. One of the ground floor sitting rooms doubles as home office. The garage is detached and contains a tumble dryer and additional freezer and fridge. Most appliances are relatively new like in H43. The family comprises of parents and a teenage daughter; an older sibling has recently left home. H05FA works in a senior position in a higher education environment; H05MA's job as a third-sector grant manager is split between travelling and working from home. Overall, the number of appliances in H05 is lower than that in H43, with the H43 family owning a particularly high number of media devices. However, both families' relatively active engagement with digital media reflects a growing trend in the UK (Ofcom, 2011; Coleman et al., 2012). Numerical and ethnographic data was collected and analysed to investigate the mains consumption and the consumption associated with domestic practices of laundry and digital media use. Table 1 gives the annual consumption of both homes and the relative proportions of that annual consumption associated with the practices of interest. Laundry practices and digital media use were found to play a significant role in the families' overall energy consumption, with some seasonal variation. Within energy studies, these practices are of specific interest, partly because laundry has been highlighted as a quick win for automating load shifting for demand side management (Molderink et al., 2010) and partly because the increased proliferation of electronic devices is seen to constitute a key challenge for energy demand reduction (Zimmermann et al., 2012).

Table 1: Electricity consumption attributed to practices.

Description	H05	H43
Annual consumption	1228.78 MJ	2928.46 MJ
Laundry	5%	6%
Digital media use	8%	15%

The monitoring equipment used to collect electricity data in the households was a non-research grade system of devices that communicate with a central hub in the home using a Zigbee wireless network. The data is uploaded to servers where it can be accessed for analysis. Appliances, circuits and incoming mains are monitored at a frequency of 1 minute using smart plugs and CT devices. The ethnographic materials were produced through in-depth one-to-one investigations of the homes and the ways in which participants performed everyday tasks. These encounters with participants were video recorded and the recordings were used to produce narrative accounts to represent the activities and meanings that were involved. The approach taken here has been to take a three stage approach to the analysis by looking at:

- mains electrical consumption representing low, medium and high power levels.
- practices in terms of appliances time-of-use ;
- cross-reference numerical and ethnographic findings.

Electricity consumption in H43 and H05

Figure 1 depicts H43 and H05 next to average values derived form a national study in the UK undertaken by DEFRA (Zimmermann et al., 2012). The DEFRA report was based on monitoring data for 251 households where 26 were monitored for a period of one year and the rest were monitored for periods of one month at intervals throughout the year. 78 households of the study are households with children.

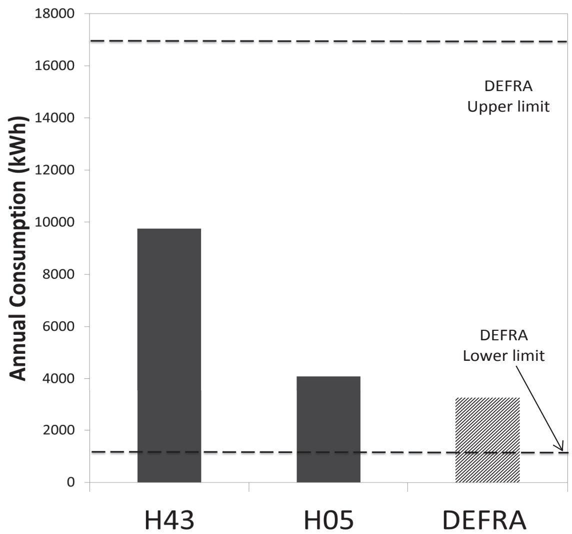

Figure 1: H43, H05 and the UK national average annual electricity consumption.

H43 and H05 fit into these classifications and the values in Figure 1 have been based on 8 months of data collected from April to December 2012. Figure 1 details the average consumption from the DEFRA report, for family homes with no electrical heating. The upper and lower limits on these averages are noted as dashed lines and these give the maximum and minimum consuming homes reported in that category. H43 and H05 fall within the ranges as would be expected, although they have a higher consumption than DEFRA average without electrical heating. One of the reasons for the higher electric consumption is that in both homes there is partial or total occupation during weekdays due to one or more householders working from home for some or all of the monitoring time. As will be demonstrated below, this changing state of the occupancy of homes is an important consideration that is increasingly becoming typical of homes, which is masked by larger statistics-based assessments of energy consumption. The second observation is that H43 is a much higher consumer that H05. This is not proportional to number of occupants, or the daily occupancy pattern as has been reported in other studies (Zhang et al., 2012). H43 use more than twice the electricity consumed in H05, even discounting the electric heater used in H43. These two home have been selected for this study because of this difference.

RESULTS

In order to investigate the differences between the total electricity consumption numerically, it was deemed useful to band the levels of consumption. 4 levels were defined in order to identify power distribution across the day by taking a sample load and defining levels that relate to:

1. background consumption, typical fridge/freezer load at night (<300W);
2. either low activity due to usage of lighting, media, bathroom devices etc., or use of lower powered devices (300W → 1kW);
3. use of a high consuming appliance, i.e. tumble dryer, oven, washing machine, dishwasher, etc or the combined use of multiple lower consumer appliances (1kW→ 3.5kW); and
4. use of high consuming appliances combined with the use of several lower load appliances (>3kW);

Figure 2 depicts typical daily electricity consumption from a typical week for both homes with the band levels shown with the dashed line. Note that neither house made use of an electric shower which would typically have a load in excess of 8kW.

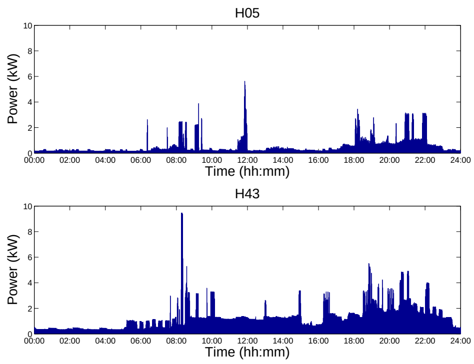

Figure 2: Mains power banding levels.

What is interesting is that because household appliances are more or less the same power level, these bands are quite robust and can be applied across homes. These levels can then be used to alter the number of occurrences when the power level falls within each band. This was carried out for every 1 minute, Figure 3 depicts this for both homes. Each plot in Figure 3 shows the frequency of occurrence of that load band for every minute in the day between April and December 2012. There are significant differences: The loads in H05 are most often less than 300W, only in the evenings between 20:00 and 22:00 are the loads in the 300W-1kW band dominate. For H43, the probability of there being a load of less than 300W is very small; The home operates between 1kW and 3.5kW almost 50% of the time, which is related to the higher number of media devices and the use of an electric radiator in the studio which is programmed to maintain the room between 13 and 15 ℃ .

Media use in H43 and H05

The digital media devices or ICE [1] use for H43 and H05 are detailed in Table 2, these appliances were monitored and the time-of-use for summer and winter for both homes is shown by the solid colour in each plot in Figure 4. The solid colour is counted if any digital media device is used at all. There is actually little difference between the seasons in both homes which are related to number of devices on and which can be seen in H43. The line above this, shows the number of digital media devices being used. In H05, the plot shows that there is typically one device being used, the TV. In H43 many devices are used simultaneously and this varies through the evening. In the winter, the rate of switch on of devices in the evening is nearly twice that of the summer, suggesting that the darker nights mean that family members settle down to use their devices in the evenings. This is explained since H43 is occupied by four people who use 5 TVs around the house as well as computers, game consoles and mobile equipment (a total of 9 media devices), whereas H05 is occupied by 3 members with 2 TVs and a total of 7 media devices.

Table 2: Digital media devices and active power.

Description	H05 (W)	H43 (W)
TV 1	>50	>1
TV 2	>4	>30
TV 3	-	>20
TV 4	-	>30
TV 5	-	>5
iPod dock	>1	>1
Computer/laptop 1	>1	>15
Computer/laptop 2	>10	>15
Computer/laptop 3	-	>1
Games Console	>10	-
Mobile charger	>1	>3

Laundry practice in H05 and H43

Combined washing machine and tumble dryer use make up a similar proportion of the respective annual energy use in both houses. However, the energy use for the washing machine in both houses is almost equal, whereas the energy use of the tumble dryer in H43 is 10 times the energy usage in H05. By breaking down the time-of-use of these appliances over the monitoring period, the analysis can be applied to explore the difference in use patterns between households as well as seasonal variation in the homes. For this analysis, a threshold was applied to the power data and a boolean operation used to determine whether the appliance was running or not. Any standby loads were neglected. Figure 5 depicts the frequency of use in the day for the washing machine and the tumble dryer for both homes and for 'summer' and 'winter'.The dis-

[1] These devices are Information, Communication and Entertainment (Coleman et al., 2012) and include TV, gaming and computing devices.

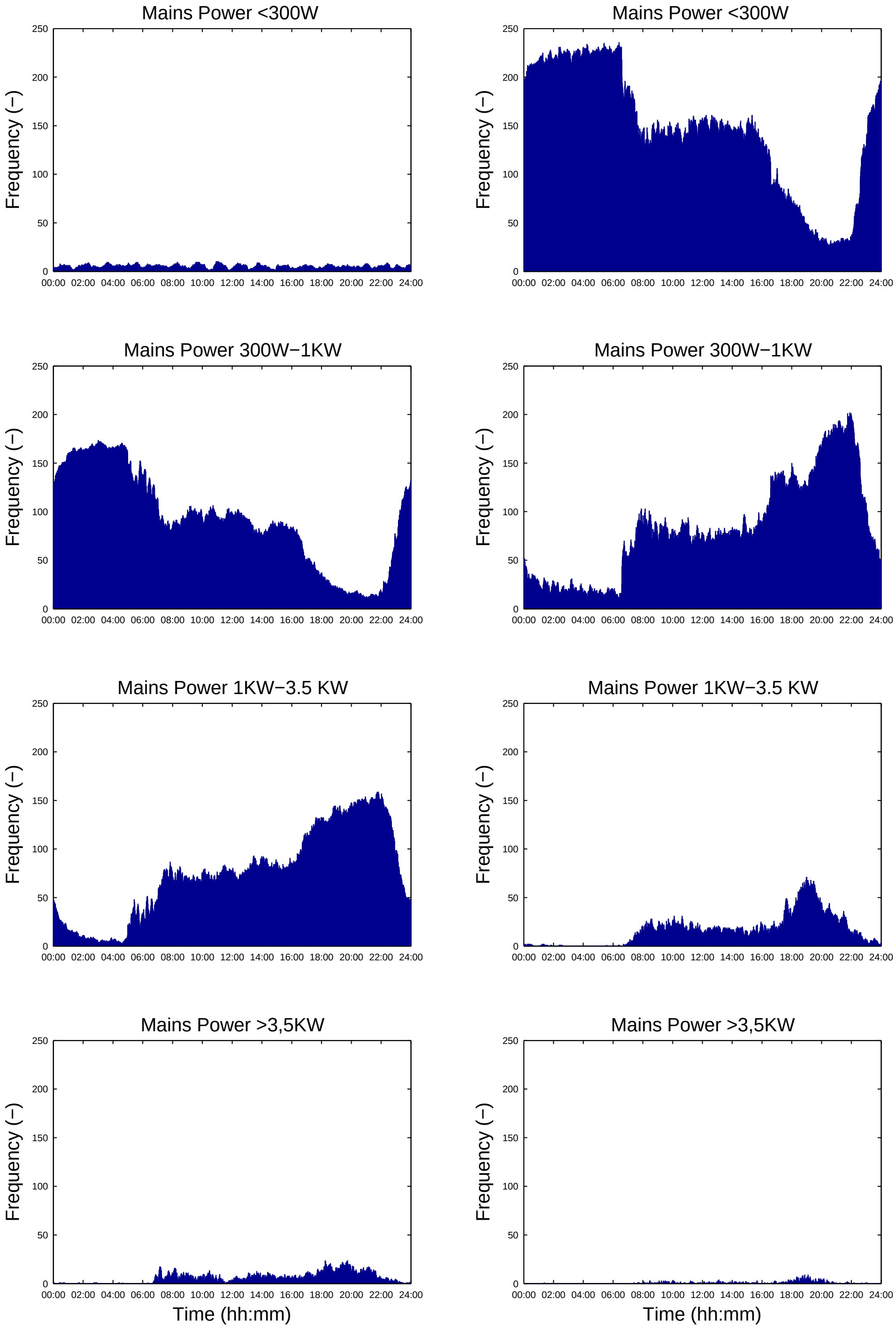

Figure 3: Banded mains power levels, frequency of occurrence, H05 (right) / H43 (left).

tinction was made on the basis of heating usage; heating off = summer, on = winter. There are a number of observations: in H43 the use of both washing machine and tumble dryer varies little throughout the year, and in addition, there is a propensity for the tumble dryer to follow the washing machine use. In contrast, H05 shows special infrequent tumble dryer usage, particularly in summer. The washing machine use also varies, which is mostly during the morning in winter and tends to be more spread-out during the day in summer. Considered on its own, the monitoring data seems to suggest that members of the H05 family respond to the availability of outdoor drying opportunities throughout the year and utilise alternative methods (e.g. radiators) when needed, whereas the H43 family have a routing which gets followed regardless of the availability of other options.

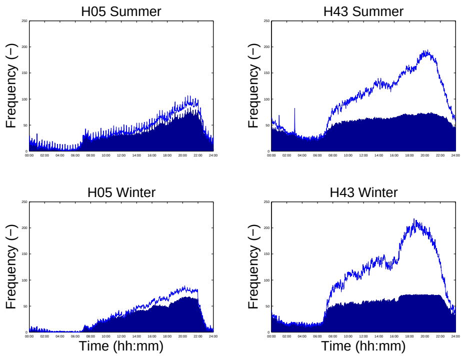

Figure 4: Media use in H43 and H05.

DISCUSSION

There are clear differences between H05 and H43 in the appliance and energy use that underlie the families' laundry and digital media practices. Bringing in the ethnographic perspective helps develop a much deeper understanding of what is happing in each home. For instance, we know from detailed ethnographic work that digital media play a key role in H43 members' lives. In the case of H43, FA is an artist who works full time from home: in the mornings she paints in her studio in the garden and in the afternoon she uses the computer in the familys office to work on her portfolio and find opportunities to exhibit and sell her work. The electric heater in the studio is programmed to maintain a minimum inside temperature of between 13 and 15 °C, in order to avoid damp. MAs long working day is normally spent in his company office but continues at home in the evening and sometimes at night. It is not uncommon for him to be woken up in the middle of the night by the sound of emails arriving from Chinese partners on his phone. He checks and sometimes replies to them, as the time difference means that, if he were to wait for the morning, he would essentially lose a working day in his dealings with China. This helps explain the spark in energy usage at 3.00am

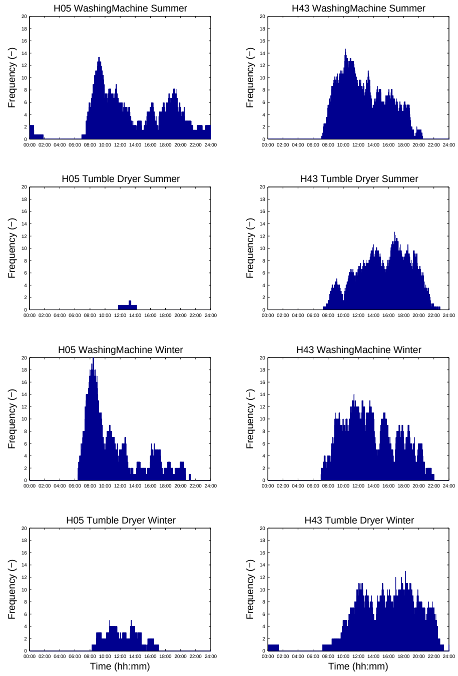

Figure 5: Laundry time-of-use by season.

Because of the nature of his work, H43MA is highly aware of recent developments in digital media and of the importance of being proficient in using new technologies. This is one of the reasons why he makes a point of enabling his children to access and learn using a range of digital devices. The use of digital media in H43 is, thus, a matter of education and very often of work (mainly in the case of FA and MA but also for the children who often do their homework using the computer and the iPad). The parents encourage their children to creatively use and combine various digital media, with the younger daughter for instance producing her own short films. Digital media are important in the H43 family's lives, partly because they consider the ability of using new technologies a skill. Moreover, they form part of how the sensory environment of the home is maintained and experienced; much of MA's engagement with media is multi-sited as he engages with various media sources at the same time while going about other activities in the home. Work and leisure boundaries can also be fluid in the digital media use of H05, specifically since the more recent introduction of an iPad (which, along with the familys mobile phones, is charged in the office overnight and gets engaged for work e-mails and travel but also to keep up with hobbies and TV shows). However, here media use appears more contained, partly due to the smaller number of people and devices (two TVs and one Wii in contrast to H43s numerous screen and consoles), partly through the maintenance of social and material boundaries. In the evenings, the work laptop is physically moved to the back of the desk and a private Apple computer moved forward to engage with hobbies (photography and sports interests) and, in the case of fc2, for gaming, though this tends to happen more on weekends and during holidays. There is an element of routine in the way in which the house comes to life after school, with shared time during cooking and school work-related activities in the kitchen and a coming together of the whole family over TV dinners in the living room.

In terms of laundry processes, wider ethnographic work with additional LEEDR households revealed broad differences between kinds of laundry routines: wash days (often during weekends), daily/nightly washing, and opportunistic washing (which followed less regular patterns and happened when needed). Furthermore, following and interviewing participants as they went about doing their laundry pointed to the importance of the interrelations between washing and drying processes. The monitoring data for the two selected households suggests that weather conditions play a role in how laundry is done, at least with regard to H05 where tumble dryer use, though still minimal, appears more regular during the winter, and the washing machine tends to be used earlier in the day than in summer. However, this only tells part of the story. Both H05 and H43 tend to engage in 'wash day' practices, but their defintion of weekends differs, in that H05MA often works from home on a Friday and thus intersperses work on his laptop with walking the dog and kick-starting some of the familys laundry processes. H05FA then takes over during the weekend. To H05FA, drying laundry outside - in summer and winter - is both a way to connect with her beloved garden and a symbol of staying on top of things, and of being organised. H43FA tends to reserve laundry for a time when the whole family is at home, usually Saturdays and Sundays, as sharing this activity forms part of a particular family game and routine. Reserving washing to the weekend is also a way of preventing household chores from infiltrating her already precious working time in the studio. Accordingly, the laundry 'window' is larger for H05 which partly accounts for their ability to dry laundry on the washing line (or interior airers), starting earlier in the mornings so as allow for longer drying periods when weather conditions are less ideal. For H43, more laundry needs to dry in a shorter amount of time, and so the tumble dryer becomes a convenient aid. From the monitoring and ethnographic examination, laundry appliances' time of use has been found to be highly dependent on: day of the week, time of day, season and occupancy. However, none of these factors can be considered deterministic in a straightfoward way as they are bound up with (often changing) goals, priorities, and household rhythms. In order to accurately predict laundry practices in these two houses, we need to broaden our understanding of temporal and occupancy categorisations, accounting for the different meanings of weekends, work, leisure and chore times. Weather conditions and daylight hours are indiciators only to the extent that they may be exploited by householders in connection with other routines and priorities. With regard to the differences of base line electric usage in H05 and H43, house and family size as well as number of appliances seem to provide some pointers towards energy consumption patterns. Yet again, occupancy, for instance, is not a straightforward factor, as is indicated by the need to maintain a specific temperature for a studio full of artwork. Time of use data usefully illustrates the value of considering patterns of irregularity in people's everyday routines. As our interdisciplinary approach to domestic energy consumption suggests, more needs to be done to consider the complexities of human 'behaviour', that is, the way in which everyday practices are contingent on a number of often interrelated factors.

CONCLUSION

This paper has aimed to develop a deeper understanding of energy use patterns from the basis of how people experience, create and maintain their social and material environment in cross-reference with high-resolution data. From H43 we have learnt that consumption is not just a matter of occupancy, as the question is not merely about the number of people who are at home but about what they are actually doing. Thus, when researching domestic energy consumption, one needs to acknowledge that today's home is no longer a place reserved for leisure, family life and domestic routines, but is increasingly becoming a preferred place for work (Coleman et al., 2012). Indeed, the ways in which energy is actually consumed are part of complex sets of both routine and spontaneous household activities, which have personal and practical meanings. When looking at future energy modeling in the domestic sector it is important to identify inputs which account for the different modalities of human 'behaviour'(Porteous et al., 2012; Malkawi, 2004; Firth et al., 2008; Zimmermann et al., 2012) in more or less routine-driven ways. While building simulation tools require an element of simplification in terms of people-centered inputs, there is an increased need to account for patterns and interrelations that go beyond the consideration of individuals (Herkel et al., 2008; Toftum, 2010) and individual appliance use (Richardson et al., 2008), and instead take into account wider practices and processes. More comprehensive and sophisticated models will prevent the kinds of forgone conclusions that derive from narrowly defined notions of causality. The detail of monitoring data and ethnographic insights in actual practices for sample households allows us to find new and different entry points into the complexities of domestic energy consumption.

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NOMENCLATURE

H05/H43	House code
FA	Female adult
MA	Male adult
fc2	Youngest Female child

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