The significance of difference: Understanding variation in household energy consumption

Janine Morley
School of Computing and Communications
Department of Sociology
Lancaster University
InfoLab 21, South Drive
Lancaster University
Lancaster, LA1 4WA, UK
j.morley@lancaster.ac.uk

Mike Hazas
School of Computing and Communications
Lancaster University
InfoLab 21, South Drive
Lancaster University
Lancaster, LA1 4WA, UK
hazas@comp.lancs.ac.uk

Keywords

socio-technical, energy behaviour, interaction, consumption dynamics, demand patterns, domestic energy, electricity use, households, end-use consumption, practices, practice theory

Abstract

Studies of energy use at the household level show a large degree of variability in consumption that cannot be entirely explained by infrastructural differences. For example, families living in identically-designed homes use strikingly different amounts of energy. These findings were responsible for highlighting the influential role of the occupant in energy demand some thirty years ago. The extent of this variability also implies that there are no "typical" energy-using households within a society. This paper reviews evidence of the variability in domestic energy consumption and presents data from student apartments in a UK university where both the infrastructure and the number of occupants are comparable. As expected, the variability in consumption is less in this homogeneous sample than previously reported in heterogeneous samples of households. Nonetheless, there is variation, particularly in electricity consumption, that can only be explained by reference to some kind of occupant-related feature(s). Further qualitative enquiry explores the idea that this difference arises from the practices of the occupants. It is clear that practices do vary between households. This paper develops hypotheses regarding the resulting differences in energy use. To explore these hypotheses, detailed micro-level consumption data is required. But this is difficult data to gather empirically and is not available here, nor widely reported in the literature. However, a framework based on practices could provide a cross-cutting and meaningful structure to relate details of micro-variations to macro-level understanding of the dynamics of energy demand in a society. In this way, analysis based on a practice theory perspective offers much potential to understand and interpret the variation in domestic energy consumption. In particular, it challenges any view that such difference, as it currently exists, is due to idiosyncrasies of individual behaviour.

Introduction: Turning the spotlight on variation

Decades of research have revealed that energy consumption varies dramatically between the households within a society (see next section). Studies have identified that at least some of this variability is attributable to the occupant, rather than physical differences in built structures (e.g. Sonderegger, 1978). This significant finding helped to introduce the occupant as a point of focus in energy research (Wilhite et al., 2000) but the fact of this variation in itself has remained in the shadows. Yet there is good reason to improve our understanding of variation in its own right.

First, the extreme variation in consumption that is seen across households presents particular problems for those who wish to model and predict demand. As Stern & Aronson (1984) point out: "Tremendous variation… exists in the needs and practices of energy users, so that analyses based on an average situation are likely to be wrong in many or most particular cases" (quoted in Lutzenhiser, 1993, p. 249). Moreover, if we seek to understand the dynamics of demand - how it is constituted and how it changes - then Lutzenhiser and Bender (2008) raise a subtly different issue: "the extreme variability means that these averages do not provide the *detail needed to understand* underlying patterns of demand" (emphasis added, p. 192). Variation is a real and important feature of energy consumption. Accordingly, research needs ways to accommodate and build understanding upon diverse and particular patterns, not averages.

Secondly, without a detailed understanding of the nature of between-household variation in consumption and how it arises, it is difficult to interpret what it means for energy research and policy, especially in the case of occupant-related variation. For example, does this represent an opportunity? Indeed, occupant-related variation has largely been interpreted as being due to individual differences in the occupants themselves. This, in turn, appears to highlight an opportunity to reduce energy demand by creating behavioural change at the individual level. As we shall see below, it is not clear, however, that such occupant-related differences in energy consumption, as they currently exist, are either entirely *behavioural* or *individual*. And although the variation, on the surface, appears to be a feature that occurs between households, this is not necessarily the only "unit" that can help to explain the data.

In particular, several recent analyses of energy use have been inspired by theories of practice (e.g. Gram-Hanssen, 2009, 2010; Røpke et al., 2010). In broad terms, these work with an alternative unit of analysis: *ways of doing*. We will not introduce or summarise practice theory, here, as other authors have already given valuable introductions covering its application to consumption in general, and energy consumption in particular (Shove, 2003; Shove and Pantzar, 2005; Warde, 2005; Røpke, 2009; Strengers, 2010; Gram-Hanssen 2009, 2010). Most pertinently, Gram-Hanssen (2010) analyses variation in heat consumption from a practice theory perspective. The study gives an account of 5 families, living in identically-designed homes supplied by the same district heating system who consume widely different amounts of heat and it illustrates just how idiosyncratic these households can appear: they each have different experiences, different stories to tell and, on the whole, different ways of using and understanding heat within their homes. But by focusing on practices, Gram-Hanssen is able to draw out differences *and similarities* in the elements of what is a collectively shared practice of indoor climate regulation. In this analysis, therefore, there is a cross-cutting structure (or unit), the practice, within which there are multiple configurations of ways of doing and understanding, which can be related to the differences in heat consumption.

Thus, understanding variation in terms of practices appears to offer a subtle shift in focus away from the idiosyncratic characteristics and biographies of households (and associated ways of articulating, grouping, typifying this diversity) towards ways of doing and understanding that cut across individuals and individual households. The aim of this paper is to explore and develop this alternative understanding of occupant-related variation in energy consumption. To do this, the paper presents some new data on the variation in a sample of similarly-built student apartments on a university campus. Through a pilot study, it then asks whether, and how, the practices reported by occupants vary between low- and high-consuming apartments. This analysis focuses specifically on electricity consumption, and illustrates how the use of practices, as a unit of analysis, can help structure a cross-cutting framework within which occupant-related variation can be understood in a systematic and meaningful way.

The next section of this paper briefly reviews the scale of variation in energy consumption reported by previous studies, and considers how the contribution of the occupant to that variation has been investigated. The following section presents variable consumption figures that have been gathered for the current study and explored through qualitative investigation. Finally, the potential of this approach, which centres around practices, is discussed in comparison to accounts of variability that focus on households and individual behaviours.

The scale and nature of variation: A brief review

Lutzenhiser and Bender (2008) refer to the variation in household energy consumption seen within samples from a society as "extreme" (p. 192). This is a particularly apt description for their sample of 1,627 Northern Californian households, where the lowest- and highest-consumers of electricity differed by a factor in excess of 40. Gram-Hanssen et al. (2004) cite electricity consumption figures gathered from over 50,000 Danish homes in the same city, which even when categorised by dwelling-type (detached, semi-detached, apartment), still show "huge standard deviations" (2004, p. 76), with each category having a coefficient of variation[1] (CV) of 48–50 %. The range between the very lowest- and highest-consumers is not given. Similarly, Guerra Santin et al. (2009) report large variations in energy demand for space and water heating in 15,000 Dutch homes with CVs of 40–53 % for each dwelling-type group.

This extensive diversity in energy consumption implies that there is no "typical" home within a society and that statistical averages will offer poor representations of actual consumption patterns. To illustrate, a coefficient of variation of 50 % means that even when excluding households at the extremes of consumption, the lowest- and highest-consumers of the middle majority (68 %) of households differ in their energy use by a factor of 3. In other words, it would be normal for one home to use 2 or 3 times the electricity or heating energy as another home of roughly the same type (e.g. semi-detached). Moreover, the distribution of electricity consumption in the sample of 72 UK homes studied by Firth et al. (2008) shows that only a minority (26 %) fall within a roughly comparable 10 % above or below the average consumption figure. And, in fact, the majority (60 %) fall below average.

There are several potential sources of this diversity, each with potentially differential effects on space heating and cooling, water heating and other electricity consumption: geophysical location/environment, the physical infrastructure of the home (including its size, design, thermal properties, heating systems, energy supply), the socio-economic composition of the household, the appliance stock and how the occupants use those appliances, the home and its heating systems. This paper is specifically concerned with the role of the occupant in generating this evident variation. Previous research has attempted to isolate the contribution of occupants to variability, either by statistical analysis of heterogeneous samples or by studying samples in which infrastructural features are already highly similar. Table 1 summarises the variation found in a selection of heterogeneous and homogeneous samples, the latter of which are drawn from co-located apartment blocks or housing developments built to the same design.

1. The coefficient of variation is the ratio, expressed here as a percentage, of the standard deviation to the mean.

Table 1. Findings of variation in household energy consumption. "Factor" refers to the factor of difference between the highest and lowest consumers and "CV" is the coefficient of variation.

	Sample size	Country	Period	Service (Fuel)	Factor	CV
Heterogeneous Samples						
Sonderegger (1978)	205	US	Winter 6 months	Space heating (gas)	3	22%
Guerra Santin et al. (2009)	15,000	Netherlands	3 years	Space and water heating[$]	-	40-53%*
Gram-Hanssen et al. (2004)	53,804	Denmark	Year	Electricity	-	48-50%*
Lutzenhiser and Bender (2008)	1,627	US	Year	Electricity	40	-
Firth et al. (2008)	72	UK	Year[#]	Electricity	9.5	52%
Homogeneous Samples						
Sonderegger (1978)	45	US	Winter 6 months	Space heaing (gas)	-	16%
Hackett & Lutzenhiser (1991)	476	US	Summer 3 months	Electricity	3	-
Gram-Hanssen (2010)	5	Denmark	Year	Heating (districty system)	3.7	52%

[$] Various fuels
*Grouped by dwelling type
[#] Year 2 data

Occupant-related variation in heterogeneous samples

Statistical regression analyses of heterogeneous samples of homes are the most common method used to explore and comment upon the "impact" of the occupant in "determining" energy consumption. For example, Gram-Hanssen et al. (2004) show that occupancy (the number of people in the home) can account for 22–35 % of the variation in *electricity* consumption when homes are grouped into broad dwelling types. Other features of household composition (income, age, education) accounted for a small degree of the remaining variation. After occupancy, the size of the home accounted for 2–7 % of the variation. But most of the variation was left unexplained by the socio-economic characteristics of households. This reflects the many sources of variation which are not included in broad household characteristics. Guerra Santin et al.'s (2009) analysis suggests that household characteristics and the behaviour of occupants does account for some (4.2 %) of the variation in energy demand for *space and water heating*, once building characteristics have been statistically controlled for (accounting for 42 % of the variation). Other studies show correlations (of varying sizes) between energy consumption and household income (see Kristrom, 2006), age and ethnic group (see Lutzenhiser, 1993).

It is not always clear how to interpret the results of such regression analyses, since the "variables" are inter-related and interacting. For example, occupants have an influence on building characteristics and the effect of these characteristics on energy consumption also depends on the occupants' presence and activities. A clearer idea of the unique influence of occupants upon variation, specifically relating to the way they inhabit a home, can be gained from studying samples of structurally homogeneous homes.

Occupant-related variation in homogeneous samples

As Table 1 illustrates, research suggests that there is a lesser, but still considerable, degree of between-household variation in energy consumption when building characteristics are homogeneous. Thus, the source of this difference cannot entirely lie in differences in the building (and the interactions it enables and influences). There must also be some unique variation due in some way to differences related to the occupants. Early and widely-cited evidence of the variability of energy consumption in comparable homes came from a major study in the 1970s by Socolow and Sonderegger (e.g. Socolow, 1978), known as the Twin Rivers programme. They found considerable variation in energy consumption across identical houses with a factor of difference of at least 2 between the highest- and lowest-consuming homes. This was true both for winter gas consumption and electricity consumption in the summer. In other studies, Hackett and Lutzenhiser (1991) observed consumption differences in electricity of a factor of 3 between nearly identical homes in apartment complexes in California. Gram-Hanssen (2010) analysed a sample of identically-designed Danish homes, with heat energy supplied by the same district heating system, in which the highest- and lowest-consuming households differed by a factor of 3.7.

However, not all similar homes are completely identical: there may be some small, non-obvious infrastructural differences, such as defects. To distinguish between these differences and occupant-related differences, Sonderegger (1978) compares consumption patterns of winter space heating in homes where the occupants change, to those where the occupants remain the same. He found that 71 % of the variation in homes with identical obvious physical characteristics is due to occupant-related consumption patterns. This is consistent with other findings in the Twin Rivers programme, giving Sonderegger the confidence to conclude that "the resident rather than the structure creates most of the observed variation in consumption" (1978, p. 9). It is unfortunate, however, that Sonderegger refers to this occupant-related influence as "occupant behaviour" (1978, p. 4) since this degree of variation is not specific to any particular feature of the occupant. It could, for example, include numbers of occupants, working patterns, income, life-stage and appliance ownership. Fortunately, subsequent studies of homogeneous samples have dug a little deeper into how occupant-related variability might arise through different patterns of activity.

Hackett and Lutzenhiser (1991) found a relationship, in their study, between cultural groups and the variability in consumption. Much of the variation in consumption that emerged in their sample was attributable to the different ways of doing and understanding air conditioning that were shared by households coming from a number of different cultures. They claim, therefore, that it is "erroneous" (p. 451) to conceive of variability in energy consumption as *individual,* i.e. as idiosyncratic properties of households (or the individuals that compose them). Instead, their study highlighted the social patterning of energy consumption. Likewise, Gram-Hanssen (2010) gives an account of the variable heat consumed by different families in terms of plausible differences in the ways of doing and understanding internal comfort that, to some degree, were also shared. (It is worth noting, in passing, that neither of these studies either observed the relevant activities directly or traced their detailed effect in terms energy impacts to be able to demonstrate the link between patterns of activity and consumption.)

Overall, despite an ability to isolate the contribution of the occupant, the literature studying consumption variation in infrastructurally-homogeneous samples is limited. There are few studies and their findings are limited to the energy-intensive uses of space heating or cooling. In reference to electricity, this begs the question of whether, in a situation without large-load heating and cooling appliances, there would remain such a large degree of variability in homogeneously built homes, particularly if the larger, fixed appliances were also the same. Moreover, given the potential influence of household size and other characteristics on energy consumption (as reported in analyses of heterogeneous samples), it is worth noting that all the homogeneous studies reviewed here included households of different sizes and composition.

The current study aims to contribute to the evidence of variability of energy consumption in infrastructurally homogeneous samples, and specifically, to address some of the gaps in previous studies. First, the sample of households will also be homogeneous in size and broad composition. Secondly, it will focus upon electricity that is not used for space heating and cooling, and where the large fixed appliances are equivalent across households. Following the example of previous studies, it will also explore how the variation arises in relation to patterns of activity and ways of doing.

Variation in energy use in a sample of student apartments

This pilot study analyses electricity and gas consumption data from student apartments based on the campus of Lancaster University, UK. This is not a representative sample of UK households. It has been selected precisely because of the minimal variability in certain aspects, which is afforded by this setting. There are 3 blocks of apartments each of which is taken as a homogeneous group. Each apartment within each block has a very similar build and the same number of occupants whose outwardly apparent circumstances and life-cycle stages have much in common. Each apartment in a block is fitted with similar large appliances. And each is maintained and updated along similar schedules as a result of this institutional context. However, there may be some small infrastructural differences, particularly in orientation and non-visible defects.

For the purposes of this study, these blocks of apartments shall be given the names Red, Yellow and Blue. In Red and Yellow blocks there are 12 occupants in each apartment. In Blue, the analysis is slightly complicated by a variation in design on the ground floor which means that 10 apartments have 7 occupants and 40 apartments have 8 occupants. These will be treated as separate groups. Each apartment, regardless of block, has one shared kitchen with an electric cooker and each resident has their own room. There are no fixed appliances that use electricity for space heating/cooling or for hot water. There are no electric showers, no dishwashers, no washing machines and no tumble dryers. This presents a limited scope of electricity use.

Red and Yellow blocks are newer builds and the consumption data is collected by a metering system fitted at the time of construction, which supplies an electronic reading to a central server on a daily basis. This includes natural gas, electricity and water (the water reading is not considered in this study). Each apartment has its own boiler serving space heating and hot water. Blue block is an older construction and the per-apartment metering system has been retrofitted. But likewise, it provides a daily electronic reading to a central server. This is only for electricity. The gas consumption or heating supply is not monitored on a per-apartment basis, and each apartment is supplied with hot water and space heating from shared boilers.

Using the electronic metering systems, daily consumption data was collected over a period of 7 weeks between October and December 2010. In the qualitative part of the study, residents from Blue block were interviewed to explore potential sources of the variation.

Limitations

There are three points to note about the setting of this study that could affect the scale of variation, and its wider relevance. The first is that the occupants of these apartments are not charged for their energy use; it is included in their rent. This might mean that they are not motivated to reduce energy consumption compared to householders who have to pay, resulting in greater distributions especially at the higher end of consumption. Secondly, the apartments in Blue are fitted with real-time energy displays, which could also have some effect on consumption within that block. Thirdly, an incentive to lower energy consumption per apartment was in place in the form of a competition. This was running at the time of data collection and it offered prizes to the three lowest-consuming apartments in each block. It could be argued that this might increase the variation by incentivising those, in particular, at the lower end of consumption to make further reductions. As part of the real context of this observational study, it is not possible to control for these influences nor deny their possible impact. But in response, it is worth noting that much variation remains, particularly in Blue, even if the lowest-consuming 6 or 7 apartments who might have been incentivised by their chance to win a prize, are excluded. Moreover, despite the common lack of energy-billing and the common presence of competition, the difference in the degree of variation that is evident between Red and Yellow, on the one hand, and Blue, on the other, (Figure 1) suggests that the scale of variation is specific to its context. It is hard to argue whether the real-time display, which did differ between the blocks, would itself influence the degree of variability. In other words, whilst these limitations may have an effect, there also appear to be other unknown factors influencing the scale of variation in this study.

Table 2. Average electricity and gas use for each block, calculated per capita, with measures of variability.

Block	No. apts	Electricity				Natural Gas			
		Mean (kWh)	Standard Deviation	Coefficient of Variation	Factor of Difference	Mean (m^3)	Standard Deviation	Coefficient of Variation	Factor of Difference
Red	14	139.48	22.29	16%	1.65	41.15	6.03	14.7%	1.62
Yellow	24	142.53	17.71	12.4%	1.53	38.69	6.21	16%	1.86
Blue (total)	50	168.78	41.06	24.3%	3.41	-	-	-	-
Blue 8-person	*40*	*158.22*	*35.2*	*22.3%*	*2.88*	-	-	-	-
Blue 7-person	*10*	*211.03*	*36.5*	*17.3%*	*1.7*	-	-	-	-

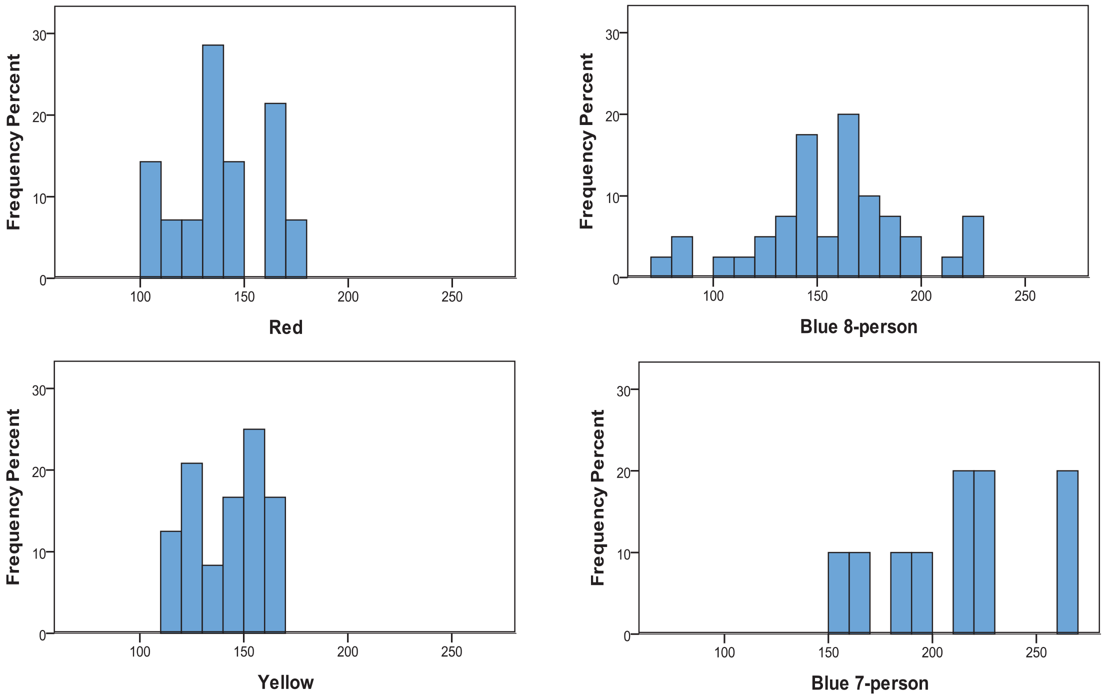

Figure 1. Distribution histograms for each block showing percentage of apartments by increasing electricity consumption intervals (10 kWh). Figures are for total consumption, per capita.

CONSUMPTION DATA

Variation in consumption between apartments

In Red and Yellow blocks, some apartments consume between 1.5 to 2 times the gas or electricity of other apartments. The variance is between 12–16 % of the mean. In Blue, there is more variability in electricity consumption, where some equivalent apartments consume almost three times the electricity of others. There is also a greater coefficient of variation, reflecting greater diversity within the whole range of the distribution (as seen clearly in Figure 1). In order to compare results between the different blocks, per capita figures are used. Table 2 summarises these results.

Day-to-Day variation

The data shows that daily consumption figures also vary within the same apartments over time. This day-to-day variation is best illustrated by consumption profiles for a selection of apartments over the course of the monitoring period (Figure 2). Some of this day-to-day variation is characterised by peaks and troughs. On closer inspection, many of the dips in this pattern are around weekends. In fact, this trend can be seen in the aggregate electricity consumption figures across all the apartments in each block. Sunday, on average, emerges as the least energy-intensive day, followed by Saturday and Monday. The remaining weekdays show higher electricity use with Wednesday being the most intensive day, on average.

INVESTIGATING THE SOURCES OF VARIATION

Despite the similarities within each block of apartments across a number of features that are associated with variability in energy consumption (build, large semi-fixed appliances, number of occupants) this data still shows a considerable degree of variation. It seems likely that this variation predominantly relates to how the occupants live within those apartments. This is especially so for electricity consumption, which should be less affected by slight differences in orientation and build quality. For reasons that are unclear, but would be very interesting to investigate later, the degree of variation is not equivalent between the different blocks studied. Electricity consumption in eight-person apartments in Blue was the most diverse data. This section presents findings from an initial qualitative enquiry into the possible sources of variation within this particular group. This pilots an approach to focus on and locate relevant differences in domestic practices.

Interviews were conducted with one resident from each of four apartments in the Blue block. The apartments were selected based on their overall use of electricity half-way through the

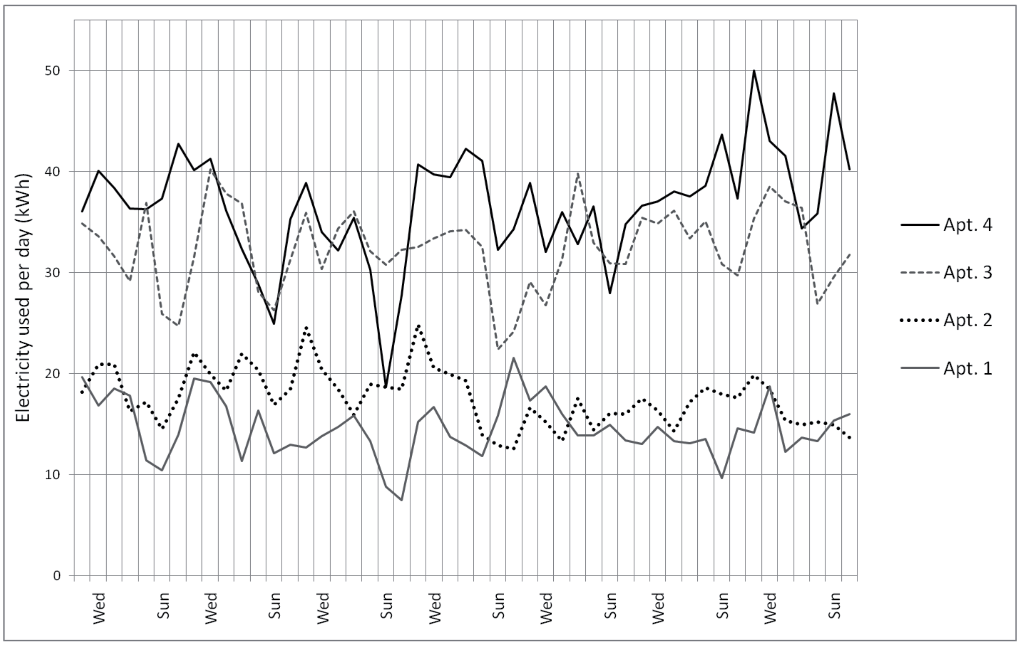

Figure 2. Daily electricity consumption profile for four apartments in Blue block selected for the qualitative study.

monitoring period, consisting of two low-consuming apartments and two high-consuming apartments. None these apartments were in the very extremes of the distribution range. The average daily consumption (and CV) for each apartment was as follows: apt. 1=14.61 kWh (20 %); apt. 2 =17.66 kWh (16 %); apt. 3=32.34 kWh (13 %); apt. 4=36.63 kWh (15 %). Thus, the high-consuming apartments consumed roughly twice the electricity of the low-consuming ones. Despite considerable variation in the daily consumption levels of each apartment, the ranges of the two groups remained, on the whole, separate (Figure 2).

The interviewees were all students from the UK and in their late teens or early 20s. Pseudonyms are used to identify them in place of their real names: Kate (apt. 1), Debbie (apt. 2), Duncan (apt. 3) and Matt (apt. 4). They were each asked questions about domestic, everyday practices that take place in their apartment. The aim is to explore whether there are variations in the practices reported, and how this might relate to, and explain the overall differences in energy consumption. For example, is one practice present in both the high-consuming apartments and neither of the low-consuming apartments? Indeed, how much do everyday practices vary? And do the practices in each consumption group look more alike within than between the groups? Specific examples from the interview data that illustrate the variation in practices are presented.

a) Watching the TV

TV-watching seems to be a practice that was shared by most of the apartments but was done differently in each. In particular, the frequency and time spent watching the television in the two lower-consuming apartments seemed to be hugely different from one of the high-consuming apartments. A TV is provided in each apartment in the shared kitchen area. Debbie explained that the paper eyes and mouth that had been stuck to the TV in low-consuming apt. 2, did mean that it wasn't used. She mentioned one other TV in the apartment which had been inherited from an ex-resident who left early in the term. In her spare time, Debbie did talk about "catching up" with some of the programmes available on the internet using her laptop. She and some of her co-residents also watch some films on a TV but this takes place in another apartment. It sounded like a social occasion: "a girls night in". To Kate, in apt. 1, watching TV is also an activity that seems to take place with other people. The TV in the kitchen does get "a little bit" of use, mainly to watch a particular TV series. Films are generally watched on laptops in co-residents rooms. Matt in high-consuming apartment 4 also explained that the TV in the kitchen wasn't used but this was for a different reason: the digital receiver didn't work. Instead, Matt watches TV in his own room, on a bigger screen connected to his computer. This includes both regular TV programmes and films. Because of this set-up, friends often come to his room to watch TV. He watches TV "a lot", specifically mentioning it as "part of the daily routine". This is mostly later in the evening, but also during the day. And he is not the only one in apt. 4 to have a large TV, he mentions another co-resident who has an even bigger TV. Duncan, by contrast, did not mention TV or film-watching at all as part of his life in apt. 3.

This provides a good example of the types of variation within a practice and in the distribution of that practice. Firstly, TV-watching appears absent as a practice in Duncan's everyday life. Secondly, for those whom it is more regular, TV-watching takes up a variable amount of time and happens at different times of the day. Thirdly, the meaning or the role of TV-watching seems a mostly social event for Debbie and Kate. Fourthly, the material infrastructure of TV-watching varies quite dramatically: from the small cathode ray TV in the kitchen for that one regular programme and the laptops used for films and online TV programmes (apt. 1 and 2) to the computer "server" attached to a separate 32-inch flatscreen TV in Matt's bedroom. Yet despite all these points of variation, most of which will have an impact of the energy that is used, TV-watching is still usefully referred to as a shared practice.

This qualitative data suggests that the socio-technical impact of watching TV is more energy intensive in one of the high-consuming flats. This is a hypothesis that further research into micro-level consumption could test. Studies suggest that TV watching, in general, is not a hugely significant part of aggregate electricity, even when space/water heating is excluded, as is the case in these apartments. Along with video and hi-fi, one study shows TV accounts for 6 % of non-heating electricity use (Denmark, Gram-Hanssen et al., 2004). Another study shows that TVs (in New Zealand) consume an average of 132 kWh/year, compared to, say, 364 kWh/year for a refrigerator (Isaacs et al., 2010).

b) Work, Play and Making Oneself at Home

All of the interviewees possessed laptop computers that they used for working. In addition, the two interviewees in the highest-consuming apartments used desktop computers to help create a more comfortable and homely environment in their rooms. Duncan commented on how much he liked having his computer as well as his laptop, describing how he brought it with him to make his accommodation more comfortable. To him it's like a place: "somewhere I can relax or somewhere I can just listen to music and chill out, check my emails, my webmail, sort of organise my work a bit". Matt has a large range of electronic devices, including games consoles and peripherals plugged into his computer. He commented that: "I like the stuff … It's like an environmental thing. To make me feel more like I'm at home, I've brought more of my stuff". The electronic devices help Matt transform his room into a "fun place". But they also provide the environmental backdrop, if not the very material with which, or through which, Matt spends his day. He starts a typical day by using the computer. Then between breakfast and a shower he browses the internet. Throughout his day, he is always using either the computer or another device in some way. There is no clear division for Matt between when he is working and when he is otherwise using the computer: "I'm kind of on the computer so if I get bored I might do some work, you know, that's how that sort of happens … I don't kind of stick to one thing at all. So I might have a movie on or something or music on in the background while working. Yeah, everything kind of mashes together."

From an energy perspective, this relaxing place (for Duncan) and constant use (for Matt) seemed to require that the computer was left on all the time. Duncan did mention that he had introduced a hibernate setting if the computer wasn't used for an hour. For Kate and Debbie, laptops were used for entertainment such as watching films and listening to music. But this type of use appears to be structured around more discrete events.

The on-tap use of a PC for entertainment is an example of a practice that is present in the high-consuming apartments but not in the low consuming apartments. It is another hypothesis we would like to investigate with micro-level consumption data. Other studies point to the growing impact of information and communication technologies on household electricity consumption (Røpke et al., 2010) but it is not one of the largest uses of non-heating electricity: 3 % according to Gram-Hanssen et al. (2004) for a sample from Denmark, and an average consumption of 196 kWh/year (Isaacs et al., 2010).

Through discussing the different sets of practices, it seemed apparent that there was a general difference between the two groupings of interviewee in the importance of making themselves at home. It emerged that both low-consuming apartments are occupied entirely by first year students, living in their first term at this university, and the high-consuming apartments are occupied by students in later years of their studies. Coming to live in a different context may introduce a certain interpretive indeterminacy (Reckwitz, 2002), where new students don't quite know what to do or how to live. This may mean that some familiar practices such as TV-watching fall out of favour as they're just not quite the same. Indeed, when talking about how little TV she and her co-residents watch, Kate says: "I think people used to watch a lot of TV before but they came to uni and we're just not really bothered about it now … people don't really want to sit down and watch just anything on TV". As the students become more familiar with this context, they may bring more previously familiar practices back into their lives. Duncan for example didn't bring his computer with him in his first year, but did in the subsequent two years. Matt is very clear that he has brought more in the way of electronic devices with him to the apartment each year. It may be that the differential energy consumption observed is related to the more indeterminant, un-fixed situation in which first year students find themselves, followed by a slow process of "settling in" or "inhabiting" in subsequent years.

c) Eating and drinking

Within each apartment and between them there appeared to be both differences and similarities in eating and drinking practices. For example, all of the interviewees talked about eating lunch at their apartments on a regular basis and for all but Kate this usually included some kind of cooked food. Duncan was the only one who more frequently had lunch out of the apartment. In terms of cooking main meals, the impression is that the interviewees in the lower-consuming apartments enjoy it more and engage more in this potentially energy-intensive practice. Kate, for example, "loves" cooking and appears to be the only interviewee who bakes (other than for meals). The day before the interview she had made some shortbread, and she describes bringing a mixer and baking tins with her to the apartment. She also claims to do a lot of cooking of "proper meals". Debbie also likes to cook. In the higher-consuming flats, Duncan typically has a take-away meal in the evenings. Whilst he also talks about cooking, it seems he may do less of it in the evening than the interviewees in the lower-consuming apartments. This might also be true for Matt, who prefers to cook meals in bulk and freeze portions to defrost and reheat later.

Other research shows that cooking is a significant single end-use, accounting for 2–7 % of total energy use in the home (Energy Savings Trust, 2006; Janssen, 2004). When heating is excluded, cooking appears to account for between 12 % (Isaacs, 2010) to about 25 % (Gram-Hanssen et al., 2004) of electricity use.

d) "Minority" practices

Ironing did not seem a very common or frequent practice. Kate, in the lowest-consuming apartment, was the only interviewee to say that she did iron but it was only "now and then". Debbie (in the other low-consuming apartment) pointed out that the co-resident medical students in her apartment do iron more frequently because they needed to wear smart clothes as part of their training. It is an interesting example of an energy-consuming practice that occurs exclusively in both low-consuming apartments but, in accordance with the low aggregate consumption, the energy impact of this practice is likely to be small. A coffee machine, on the other hand, may have a more

Table 3. Hypotheses of relative energy consumption of each practice. Levels of energy use are estimated as high (H), medium (M) or low (L).

Practice	Apartments				Practice Distribution	Energy-use variation of practice		
	1	2	3	4		L	M	H
Watching TV/Film	L	L	-	H	3/4	2	0	1
On-tap entertainment from PC	-	-	H	H	2/4	0	0	2
Main Meals	H	H	M	M	4/4	0	2	2
Baking	M	-	-	-	1/4	0	1	0
Ironing	L	L	-	-	2/4	2	0	0
Using coffee machine	-	-	-	H	1/4	0	0	1
Going away at weekends	L	M	M	L	3/4	2	2	0

significant impact if it is used regularly, as it is in Matt's high-consuming apartment.

e) Patterns of occupancy and habitation

Intuitively, we might imagine that the variability in electricity consumption is a reflection of the degree to which the residents are present in the apartment. Indeed, this may help explain the variation seen within each apartment over time. The dips in consumption around the weekends, evident for at least a couple of weekends in each apartment (Figure 2), may reflect the fact that many of the residents leave the apartment around the weekend to go and visit friends and family. The slightly higher consumption on Wednesdays may reflect that across the University, Wednesday afternoons are free from lectures, and a resident may be more likely to come back to and spend time in the apartment. Being at home certainly would seem to increase the likelihood of electricity use, but a direct or linear translation into electricity consumption cannot be assumed, as what people do when they are at home might make all the difference. This it is another hypothesis worth investigating in further research.

Relating practices to overall energy consumption

This comparative analysis of practices has been conducted through a very limited window because it only involved one resident (out of 8) from each apartment and because interviews, as a method of investigation, have a notorious reputation for (not) relaying precise information about the reality of a practice as it is performed (for example, see Lutzenhiser (1993), p. 261). Nevertheless, it has raised some specific hypotheses about how the variation in overall electricity consumption arises. These are outlined in Table 3 where the hypothetical energy grades of each practice would reflect the variation in overall consumption for all but apartment 3. Further investigation of these hypotheses and the other sources of variation would require micro-level consumption data that is not available in this study. Still, it is possible to imagine replacing the hypotheses with precise figures for each apartment from micro-level data. From this, it would be possible to build an energy profile for each practice including its own degree of variability.

Discussion: Variation from a practice theory perspective

This pilot study shows that a considerable degree of variation can occur in electricity consumption in apartments with comparable built infrastructure and fixed appliances and with the same number of occupants of roughly the same age and working/studying status. Some apartments use almost three times the electricity of other similar apartments. It is likely that much of this difference is related to the occupants, in some way. In particular, we have suggested that it is the practices of the occupants, as articulated in theories of practice, which vary. Our analysis has indicated that this is indeed the case: practices do vary and in ways that seem in keeping with overall consumption differences. And to this extent, a practice theory perspective is appropriate. But what benefits can be gained from analysing occupant-related variation in terms of practices, as opposed to the behaviours of individuals or households? Drawing on examples from the current study, we discuss this in terms of the features of a framework that could potentially be developed by taking practices as the unit of analysis.

Expecting multiple sources of difference

If we understand variation as an individual behavioural difference, and we see that difference arising in energy consumption, we might look solely at the energy-related characteristics and attitudes of the occupants, or for evidence of difference in energy conservation behaviours. In contrast, a practice theory perspective directs us to other, multiple sources of difference. For example, in this study, we can see that low-consuming apartments are not homogeneously low-consuming: for some practices, such as baking and ironing, these low-consuming apartments might use more electricity than high-consuming apartments. Thus, by shifting focus away from energy conservation behaviours and attitudes per se, we can see that an aggregate consumption figure is underwritten and constituted by all sorts of different practices with, potentially, all sorts of different consumption profiles.

Analysing and representing variation

We can make this analysis because practices offer a unit with which to work. In the current study, we can see how there is variation both in the distribution of these units between households and within the units (where they are found). For example, watching TV/films happened in most of the apartments but in distinct ways that seem likely to have different energy profiles. Using a coffee machine, which may be a single considerable contribution to aggregate consumption, was limited in distribution to one apartment.

Framework for quantifying variation

This unit, the practice, with these dimensions of variation (within and between) offers a major advantage over trying to understand variations as if they were properties of an individual or household. In particular, an energy figure, gathered from real-world performance, can be attached directly to a practice. A distribution histogram of the energy consumption of each practice in a sample or across many samples is then possible. By retaining data of variability in each practice we can identify and distinguish between energy-intensive practices of the few and the moderately-intensive practices of the many, where an average value might have concealed this difference. For understanding opportunities for change in energy demand, this could be critical.

Hierarchy of interactions

Yet how easy is it to use practices as a stable and clear unit of analysis? Would multiple studies looking at the same practice include the same things? Can a small action such as turning radiators on and off be a practice? This is potentially a big discussion and we can only offer an initial way forward by suggesting the use of a hierarchy. This might be composed of nested layers of types of interactions, each carrying energy values of their constituent layers (e.g. Sustaining > Eating > Home-cooking > Main Meals > Weekday Dinner > Making Soup). Where an interaction directly involves energy, a "how" layer can be elaborated showing how the energy use figure is composed. To define whether this interaction is a practice in itself that might interest us as a unit (rather than an idiosyncrasy) we suggest three criteria: 1) Does it have an energy impact? 2) Does it occur across space and time, i.e. do other people do it? 3) Is it in someway purposeful or meaningful to the practitioner?

Highlighting similarity, boundaries and commonality

Despite the micro-level detail that we argue is necessary to understand variation in energy consumption (in the sense of how it arises), we would still expect patterns and regularities to emerge. For example, TV watching appears to have broadly-shared meanings and roles despite the different ways it is done. In a larger sample we might identify different "variants" of TV watching as configurations patterned not only in infrastructure, but also duration, timing, and content. These configurations of practices develop within a societal context yet they only take shape as the practice itself is performed again and again. Thus, studying micro-level variability is, in fact, the study of societal or macro-level dynamics as it happens. The unit of a practice enables this integration.

Making the micro meaningful

In summary, our analysis of variation from a practice theory perspective highlights the need to study the detailed energy-consumption profiles of particular practices if we are to understand how, in actuality, variation arises. This approach, drawing on micro-level detail, is quite different from looking for correlations between overall energy consumption and certain demographic or personality characteristics or the presence (or not) of reported behaviours. It implies that it is necessary to understand how variation arises, in detail, in order to understand what this variation represents. This is not necessarily surprising or profound. What may be surprising, then, is the apparent lack of research that follows this logic.

There has been research into end-use consumption (e.g. Wall and Crosbie, 2009) but it is difficult to conduct, and many end-use figures are based on estimates instead. If, as the current study suggests, variation in aggregate consumption reflects many underlying degrees of variation, making sense of all this detail may seem daunting and, moreover, unlikely to have much impact. This combination of difficulty in research and interpretation may help explain the apparently slim literature with empirical end-use consumption data. But a practice theory approach may help make micro-level consumption data more meaningful. In fact, one of the defining differences of such an analysis is interest in the meaning that is encompassed within each energy-using interaction in the home. This calls for qualitative understanding to be combined with the quantitative energy-use data (see Crosbie (2006) for a version of this argument, and Wall and Crosbie (2009) for an example of a study that takes such an approach to lighting as an end-use, but only looks at one particular part of the practice: the efficiency of the fittings).

In addition, a practice theory analysis of micro-level consumption should and can go beyond average figures. This again will make such detailed data so much more compelling and interesting. To say that on average a TV consumes 100 kWh/year doesn't contain within it any notion that this could be different. However, imagine we had the data to show that about a third of TV-watching has a particular shape (e.g. many hours on a large screen) and consumes 220–270 kWh/year; that another third follows another pattern (e.g. infrequent and on a laptop) and consumes 50–70 kWh/year; and that the final third is highly variable and consumes 5–200 kWh/year. This presents an opportunity to understand how a lower-energy practice is already organised and "works".

Conclusion

This paper has taken a very particular interest in the variation that is found in household energy consumption within a society and how the role of the occupant is distinguished in relation to this. In reviewing evidence of variability from previous research, it finds that samples of households living in identically-designed buildings provide the clearest support to the claim that the occupant has a unique influence (of some kind) on variability in consumption. Yet there are few examples of this type of study, particularly of electricity consumption excluding heating and air conditioning. In the studies that do exist, important occupant characteristics, such as the number of occupants, have not been controlled. The current study has attempted to address this and has shown that there is variation in the energy consumption of broadly homogeneous samples of households, where both the characteristics of the buildings, the large fixed appliance stock and certain broad (yet potentially influential) socio-demographic characteristics of the occupants such as numbers and age are similar. This strongly indicates that the way occupants inhabit their apartments is a significant source of variation. However, the degree of variability was not the same in all three sets of buildings investigated (for electricity consumption, a factor of difference of 1.5–2 in two new blocks compared to a factor of nearly 3 in an older block). This raises the question for future research of whether there is something about buildings, or the large appliances fitted within them, that can limit the degree of variability that arises from the way a home is lived in.

We have explored the idea that occupant-related variability in energy consumption relates to practices within the household rather than differences in the characteristics of the household, or the individuals within it, that "determine" their behaviour. Through qualitative investigation, we were, indeed, able to identify practices that varied between households, both within the same practice and in terms of distribution. Some of these differences could help explain the aggregate levels of energy consumption but this cannot be confirmed without micro-level data on the energy profiles of these particular practices. Thus to understand how variation in energy consumption arises, micro-level studies that go beyond averages to represent variations at the many points they occur are needed. And in turn, a practice theory approach should help make this data more meaningful to society-wide patterns of demand. Moreover, a detailed understanding of how variation occurs, which at present is lacking, could transform our understanding of what this variation represents and what it means more widely for the research that takes place and the types of opportunities to reduce demand that are imagined and investigated.

Finally, we have argued that it is important to find ways to represent variations both in practices and in overall energy consumption. Average consumption values fail to represent highly diverse groupings, and they obscure detail from our understanding of energy demand, which for example might help identify particularly intensive varieties of practice. Further, at a time when sustainability motivates energy demand reductions, the variation in energy consumption is *in itself* significant since it reflects the distribution of an increasingly contentious and expensive resource. This calls for consideration of whether variation *in itself* should be a target for change. For example, what does it signify if this kind of variability within a society increases in the future? Trends in variability of energy consumption could be an interesting research area, where a practice-based framework could be useful. At the very least, we suggest that all researchers be more conscious of reporting variability indicators (minimum, maximum and standard deviations) in any consumption data they study.

References

Crosbie, T., 2006. Household energy studies: the gap between theory and method. *Energy & Environment*, 17(5), pp.735-753.

Energy Saving Trust, 2006. The rise of the machines: a review of energy using products in the home from the 1970s to today. Report CO126. Energy Saving Trust, www.est.org.uk

Firth, S., Lomas, K., Wright, A. and Wall, R., 2008. Identifying trends in the use of domestic appliances from household electricity consumption measurements. *Energy and Buildings*, 40, pp.926-936.

Gram-Hanssen, K., Kofod, C. and Noervig Petersen, K., 2004. Different everyday lives: Different patterns of electricity use. In *Proceedings of the 2004 American Council for an Energy Efficient Economy* 7, pp.74-85. Washington, D.C.: American Council for an Energy Efficient Economy.

Gram-Hanssen, K., 2009. Standby Consumption in Households Analyzed With a Practice Theory Approach. *Journal of Industrial Ecology*, 14(1), pp.150-165.

Gram-Hanssen, K., 2010. Residential heat comfort practices: understanding users. *Building Research and Information*, 38(2), pp.175-186

Guerra Santin, O., Itard, L. and Visscher, H., 2009. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy and Buildings*, 41(11), pp.1223-1232.

Hackett, B. and Lutzenhiser, L., 1991. Social structures and economic conduct: Interpreting variations in household energy consumption. *Sociological Forum*, 6(3), pp.449-470.

Isaacs, N. P., Camilleri, M. T., Burrough, L. J., Pollard, A. R., Saville-Smith, K, Fraser, R., Rossouw, P. and Jowett, J., 2010. Energy use in New Zealand Households: Final Report on the Household Energy End-use Project (HEEP). Study Report SR221. Branz, www.branz.co.nz/HEEP

Janssen, R., 2005. Towards Energy Efficient Buildings in Europe: Final report. EuroACE, www.euroace.org

Kristrom, B., 2008. Residential energy demand. In OECD (Ed.), *Household behaviour and the environment: Reviewing the evidence.* Chap. 4, pp.95-115. Paris, France: OECD

Lutzenhiser, L., 1993. Social and behavioral aspects of energy use. *Annual Review of Energy and the Environment*, 18, pp.247-289.

Lutzenhiser, L. and Bender, S., 2008. The "Average American" Unmasked: Social Structure and Differences in Household Energy Use and Carbon Emissions. In *Proceedings of the 2008 American Council for an Energy Efficient Economy* 7, pp.191-204. Washington, D.C.: American Council for an Energy Efficient Economy.

Reckwitz, A. 2002. Toward a Theory of Social Practices: A Development in Culturalist Theorizing. European Journal of Social Theory, 5(2), pp.243-263

Røpke, I., 2009. Theories of practice - New inspiration for ecological economic studies on consumption. *Ecological Economics*, 68(10), pp.2490-2497.

Røpke, I., Christensen, T. H. and Jensen, J. O., 2010. Information and communication technologies – A new round of household electrification. *Energy Policy*, 38, pp.1764-1773

Shove, E., 2003. *Comfort, Cleanliness and Convenience: The Social Organization of Normality*, Oxford, UK: Berg.

Shove, and E., Pantzar, M., 2005. Consumers, producers and practices. Understanding the invention and reinvention of Nordicwalking. *Journal of Consumer Culture* 5, pp.43–64.

Socolow, R.H., 1978. The Twin Rivers Program on Energy Conservation in Housing: Highlights and Conclusions. *Energy and Buildings*, 1(3), pp.207-242.

Sonderegger, R.C., 1978. Movers and stayers: The resident's contribution to variation across houses in energy consumption for space heating. *Energy and Buildings*, 1(3), pp.313-324.

Strengers, Y. 2010. Conceptualising everyday practices: composition, reproduction and change. *Working Paper No. 6. Carbon Neutral Communities*, Centre for Design, RMIT University and University of South Australia.

Stern, P. C. and Aronson, E. (eds), 1984. *Energy use: the human dimension.* New York, US: W. H. Freeman & Co.

Wall, R. and Crosbie, T., 2009. Potential for reducing electricity demand for lighting in households: An exploratory socio-technical study. *Energy Policy*, 37, pp.1021-1031

Warde, A., 2005. Consumption and theories of practice. *Journal of Consumer Culture,* 5(2), pp.131-153

Wilhite, H., Shove, E., Lutzenhiser, L. and Kempton, W., 2000. The Legacy of Twenty Years of Energy Demand Management: we know more about Individual Behaviour but next to Nothing about Demand. *Society, Behaviour, and Climate Change Mitigation*, pp.109-126.