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Understanding the timing of energy demand through time use data: time of the day dependence of social practices

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Understanding the timing of energy demand through time use data: Time of the day dependence of social practices

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ABSTRACT

The time dependence of social practices at specific points of the day shapes the timing of energy demand. This paper aims to assess how dependent energy-related social practices in the household are in relation to the time of the day. It analyses the 2005 UK Office for National Statistics National Time Use Survey making use of statistically-derived time dependence metrics for six social practice: preparing food, washing, cleaning, washing clothes, watching TV and using a computer. The focus is on social practices over temporal scales of different days of the week and months of the year. The main findings show that: washing has the highest value for the time dependence metric; using computers is the least time-dependent practice; Tuesdays, Wednesdays and Thursdays have the highest time dependence for all practices; and certain energy-related practices have higher seasonal dependence than others.

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1. Introduction: time dependence, social practices and the timing of energy demand

Years of research in energy demand have seen the predominance of technical factors (including weather, building characteristics, appliance design, appliance control, interdependencies between energy services, etc.), which have partly explained variations in volumes of energy demand, but have inevitably failed to describe any intra-day variation in patterns (e.g. residential electricity load profiles). Peak energy demand emerges as a phenomenon which epitomises the relevance of practices as a unit of analysis in this context. At the heart of the approach which places social practices at the centre of our understanding of the dynamics of energy demand is the position that the timing of energy demand is determined by the way practices are ordered in time [1]. A simple example which can illustrate how the timing of energy demand and, hence, peaks are a reflection of people's practices derives from the substantial difference between residential electricity load curves for weekdays and weekends. During the same season the weather can be equal at the weekend compared with the weekday. Building type, appliances, fuel substitution, price of energy and appliance control, and the moment of the day in which sunlight is present or absent may be the same between weekday and weekend. The only substantial change between weekday and weekend is in terms of people's activities.

Previous attempts to describe the social phenomenon of peak energy demand have focused on issues of synchronicity of practices [2], sequencing [3] and (lack of) flexibility [4]. Peaks are also triggered by an infrastructure that simultaneously services those multiple 'doings'. Social practices have characteristics which define the way energy demand comes about. They are habitual, synchronised, varied, sequenced and contingent [2].

The issue of time dependence of social practices has been debated for some time at different conceptual levels, but seldom operationalised in empirical research. This relates to the general argument that issues of timing in energy and the social sciences are seldom supported by evidence [5]. The starting point of this work is that the time dependence of social practices at specific points of the day shapes energy demand in households. This is in an effort to operationalise the realisation that a social order underlies regular patterns relating to the fundamental temporal characteristics of social events (e.g. duration and sequence) [6].

This paper aims to assess how dependent energy-related social practices are in relation to the time of the day. It addresses specific questions regarding the variation of time-dependence throughout the working days of the week and the relationship between time dependence and seasonality. The purpose of this paper aligns with how people make decisions about energy [7].

The analysis of the 2005 UK Office for National Statistics National Time Use Survey makes use of time dependence calculations for six

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activity codes: preparing food, washing, cleaning, washing clothes, watching TV and using a computer. Activity codes are used here in order to establish a quantitative link with social practices. The focus is on social practices over temporal scales of different days of the week and months of the year.

Time dependence is defined as high occurrence of the same practice over the same periods of the day. Practices which repeatedly take place at the same time of the day are said to be time dependent. Two simple observations underpin the concept of time dependence of social practices. First, social practices have rhythms [8]. Rhythms introduce the possibility of rigidity of the daily temporal structures [9] and time dependence in social practice ordering. Rhythms and routines co-exist and are interdependent, not rival [10]. This is not to say that time follows exogenous forces or that practices have independent rhythms [11]. Quite the opposite, time can be a quantitative measure of the ordering of practices, notwithstanding the temporal dynamics within and across practices. Second, empirical evidence shows the time dependence of the peak energy demand phenomenon [12]: with different intensities, depending on the season, every morning and evening of any weekday there are the same peaks in electricity demand. Peaks are seemingly time-bound and are a signal of societal synchronisation.

After this introduction, Section 2 briefly reviews the literature on social practices, time and energy demand. Section 3 describes the dataset on which the analysis is based and the statistical methods used for measuring time dependence. Section 4 analyses which practices are more or less time dependent. Section 5 examines how time-dependence varies throughout days of the week. Section 6 explores whether time dependence changes depending on seasons. Section 7 discusses the implications of this paper and concludes.

2. Time, social practices and energy demand

The theoretical foundations of this paper are based on four basic propositions. This section explains the concepts underpinning each of these four propositions and reviews elements of practice theory which are relevant to work on time, social practices and energy demand.

First, the starting conceptual proposition put forward by this paper is that in order to understand the timing of energy demand, the social ordering of practices needs to be analysed. The timing of energy demand is arranged to accomplish social practices, such as watching TV, working, cooking or washing up [13]. By placing the social ordering of people's activities at the centre of the study of social life, social practice theory offers a consistent ground to investigate the dynamics between people, time and energy demand. Social practice theory considers the relation between time and consumption in relation to the fact that human activities are ordered recursively across space and time [14]. From social practice theory, the timing of energy demand can be defined as the result of the socio-temporal organisation of daily practices [15]. Having made this link between time, social practices and energy demand, it is suggested that understanding the timing of energy demand involves studying social practices in terms of their ordering and time dependence.

Second, practices do not occur in isolation, but tend to cluster together over time and space. The temporal and social ordering of practices shapes material arrangements. Material arrangements, as defined by Schatzki [15], are the relatively stable relationships between people and materials and natural objects and infrastructure, which set the frameworks within which practices take place. Arrangements are critical in understanding energy because 'the arrangements amidst which practices are enacted are not only social: arrangements include substances of all kinds, including natural phenomena along with man-made fabrications' [16,p. 23]. Arrangements and social practices are connected as the latter are determinative of and dependent on the former. Social practices happen (for instance at different times of the day), whereas material arrangements 'exist' [15]. Arrangements last longer than any instance or moment enactment. The context in which social practices are enacted depends on the specific practices that are contextualised [16]. Arrangements -including energy- only have meaning within, and in relation to, the practices in which they are enfolded, and through which they are reproduced [17]. Understanding the dynamics of energy demand and the variation which occurs with peak phenomena is a matter of studying the ordering of social practices.

Third, turning to peak energy demand specifically, very few studies of peak demand have used a social practice framework for analysing domestic energy consumption in empirical terms. For instance, Nicholls and Strengers [4] analyse the inflexibility to certain bundles of practices in Australian households with children. Anderson [18] investigates the temporal changes of a single practice (i.e. laundry) over 20 years. More widely, examples of the changing temporal and spatial rhythms of social practices (i.e. 'timespace') abound in the literature: the move from lower frequency and higher duration bathing to higher frequency lower duration showering [19], the change in patterns of consumption in Turkey associated with the import of teabags [20], and the diverse eating timings and durations in different countries [21]. However, the work on the measurement of rhythms in terms of time dependence is not very developed. Both conceptual and methodological challenges explain why time dependence of social practices has seldom been operationalised in empirical research. An exception consists of the qualitative analysis presented by Southerton [22], in which the temporal rhythm of the day is characterised by practices which hold a fixed position in time.

Fourth, a practice approach could make a novel contribution to approaches to managing load shifting. From a research perspective, any household energy demand model seeking to represent and then manipulate electricity demand under different scenarios needs to take account of the timing of energy-related practices. Representations of the time and timing of practices play a vital role in describing the timing of demand and its consequences for time-related scenarios, such as manual Demand Side Response, electric vehicle charging or automated demand control. Understanding where routines are most strongly embedded in everyday lives may provide crucial insights into the predictability of activities and their associated loads.

In addition to the four propositions, two critical clarifications on the definition of time in this paper are that: (i) time is socially constructed, meaning that the distinction, for instance, between weekday and weekend is entirely attributable to the framework of time as designed by the society in which we are living in; and (ii) the resolution of time in this paper is generally intra-day (in tune with the discussion on peak demand, loads profiles and timing of energy demand). For this reason, the concept of time dependence needs to be critically linked to material arrangements. Social practices vary not only from one location to the next, but also in time. The existence of material arrangements and the presence of space dependence (i.e. the fact that practices vary depending on locations, countries, etc.) allows for scope conditions, including time dependence. The existence of scope conditions does not imply that all social processes typically have standard causal configurations from which deviations can be gauged. This work acknowledges the role of time in ordering practices when measuring rhythms and the potential for creating dependence according to the measurements of time, which are processed by the space and time in which practices are performed.

Table 1
Time use activities and associated appliances, including electrical load and proportion of dwellings with appliance.

Time Use Activity	Employed electricity appliances	Average electrical load (kW)	Proportion of dwellings with appliance (%)
Preparing food and washing the dishes	Hob	2.40	46.3
	Oven	2.13	61.6
	Microwave	1.25	85.9
	Kettle	2.00	97.5
	Dish washer	1.13	33.5
Washing	Electric shower	9.00	67
	Central heating pump	0.60	90
Cleaning	Vacuum	2.00	93.7
Washing clothes	Tumble dryer	2.50	41.6
	Washing machine	0.41	78.1
	Washer dryer	0.79	15.3
	Iron	1.00	90
Watching TV and listening to the radio	TV	0.12	97.7
	TV receiver box	0.03	93.4
	Radio	n/a	n/a
Using computer	Personal computer/console	0.14	70.8

Source: Adapted from Powells et al. [39].

3. Data and methodology

The analysis presented in this paper is based on the 2005 Office for National Statistics (ONS) Time Use Survey, which is the most recent, nationally representative time use survey available in the UK. The Time Use Survey contains 10-min intervals information about respondents' activities based on a list of the 30 pre-coded activities. The 10-min activities are recorded by Time Use Survey participants in the form of diary. The data are statistically representative of all households in the UK in the year 2005. A day begins at 4am and ends the following day with the last recording taken at 3.50–4 a.m. Respondents are able to specify a primary activity, a secondary activity and their location at that moment in time. The Time Use survey was conducted over four months: February, June, September and November. The four months were selected by the ONS as to avoid the atypical holiday periods (i.e. non-everyday life) throughout the year and to represent the different seasons of the year [23]. Weekend respondent diaries are not included in this study as the main concern is when system peak demand is at its greatest. After excluding weekend diary days, a final sample of 3554 respondent diary days is available for analysis.

By excluding Saturdays and Sundays from the study, an issue was created, in that the weights for balancing weekdays and weekend days which were originally applied to the dataset by the Office of National Statistics were no longer valid. To overcome this issue, new weights were calculated for the dataset based on the methodology used by Lader et al. [23] in the original survey. The dataset was adjusted so that days of the week and months of the year were equally represented.

The primary activity codes that have been selected from the 2005 UK Time Use Survey are: preparing food and drinks, cooking, washing up; washing, dressing/undressing, etc.; cleaning, tidying house; washing, ironing or mending clothes etc.; watching TV and videos/DVDs, listening to radio or music and; using a computer. The two criteria for selecting activity codes in Table 1 were: (i) typical electrical load; and (ii) proportion of dwellings with appliances from the Energy Using Product Policy (EUPP) Government Standard models. The rationale for this was to target practices with a high probability of causing electricity demand in the household.

Table 1 shows the typical electricity load for each appliance. The electricity loads that may be associated with preparing food or drink show that, if using an electrical appliance, the load is around 2 kW. Not all households own each of the electrical appliances, but notable high ownership of appliances is kettles, vacuums, TV and TV receiver boxes. For consistency, the same terms from activity codes in the Time Use Survey are used throughout the paper. For example, the time use activity code 'washing' involves 'bathing and showering' practices. Existing empirical time use studies recognise (and in some cases attempt to quantify) the different degrees of human involvement associated with the appliances in Table 1. For instance, showering and TV watching require human presence, whereas automation is higher in dishwashers and washing machines. The model by Widén et al. [24] allows to relate volumes of electricity use to human activities thanks to the use of activities schemes. However, that level of modelling accuracy is not needed in this paper as the aim here is to measure time dependence in relation to social practice and not accurately reconstruct load profiles of individual households.

In order to measure quantitatively time of the day dependence, the starting point is that if practices take place in large amounts during the same period (and not at all at other times of the day), this implies high time dependence. On the contrary, practices which take place regardless of the time of the day will have low time dependence.

To examine when time dependence exists throughout the day, the six social practices listed in Table 1 are analysed over two temporal scales. First, individual weekdays are analysed throughout the day for each social practice. Second, individual months are analysed throughout the day for each social practice.

Time dependence is operationalised as follows:

$$\mathrm{T_{DEP}} = \frac{\mathrm{Max}\,[x_i - \mathrm{m}\,(\mathrm{X})]}{m\,(X)}$$

where x_i is the number of minutes associated with the practice x at the time of the day i and $m(X)$ is the mean number of minutes of practice x. The numerator consists of the maximum distance of x_i from $m(X)$. For both x_i and $m(X)$ the unit is the amount of minutes. The volume of minutes dedicated to specific practices will significantly influence $\mathrm{Max}\,[x_i - m\,(X)]$. For example, TV watching is much more dominant in terms of number of minutes throughout the day than washing clothes. By dividing the maximum distance from the mean (numerator) by the mean average (denominator) T_{DEP} controls for the volume of practices.

The standard deviation of xi (σ(X)) is used as a measure of how spread practices are over the day. For practices taking place in large amounts during the same periods and not at all at other times of the

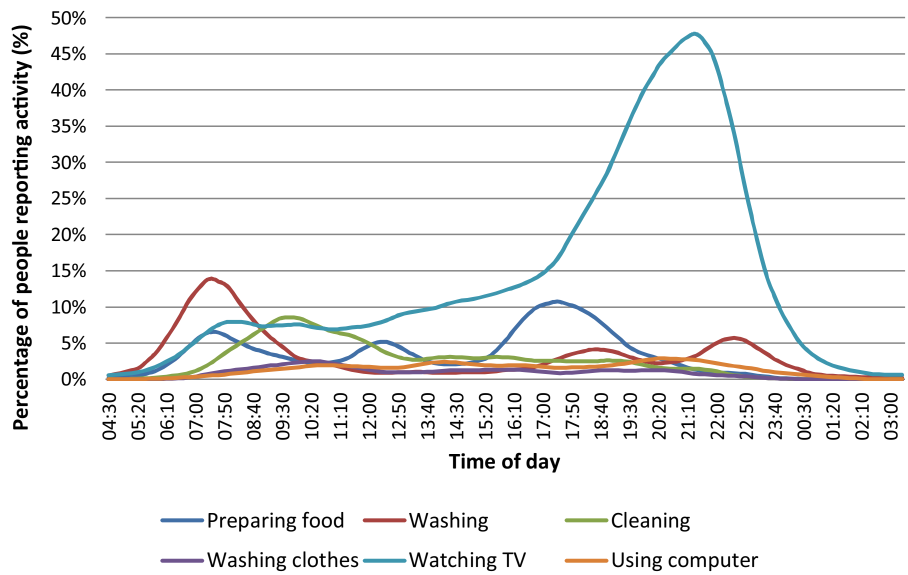

Fig. 1. Distribution of practices throughout the day.

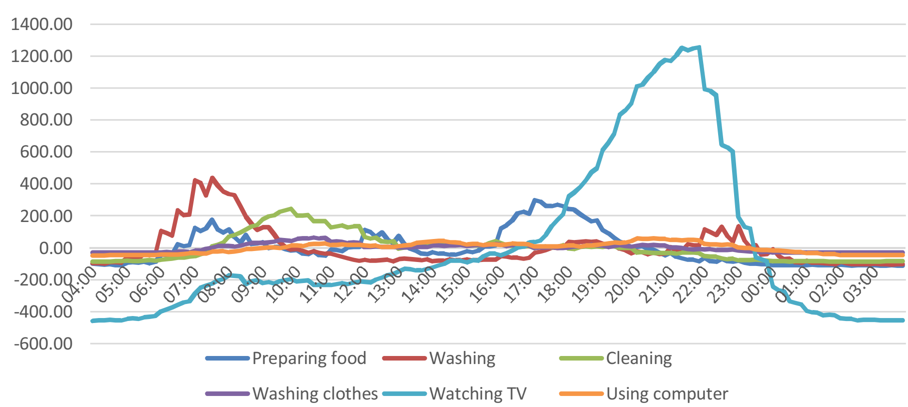

Fig. 2. Distance of practices' values (in minutes) from mean.

day, the standard deviation $\sigma(X)$ will be higher because the practice is not equally spread around the day.

The centred moving average of an hour is derived as a succession of averages of the number of minutes from a 10-min period (xi) to the subsequent 10-min period (xi + 1). This facilitates the analysis of trends in the time use dataset.

In order to capture how time dependence varies across seasons, the standard deviation across seasons and among different days of the week is derived as:

$$\sigma(T_{DEP}) = \sqrt{\frac{\sum_{i=1}^{N}[x_i - m(X)]^2}{N}}$$

where x_i is the amount of minutes associated with practice x at the time i and $m(X)$ is the mean number of minutes dedicated to practice x.

In principle the presence of several 0 values (or unrecorded entries) in time use diaries could have called for the use of the first difference estimator (i.e. an approach used in statistics to address the problem of omitted variables). However, unrecorded entries, which would have been excluded when using the first difference estimator, are of interest to this analysis as a practice with several periods of the day with zero minutes and very few periods with a high number of minutes would be highly time dependent. Hence, unrecorded entries need to be accounted for by estimating distances of each data point from the mean. Shorter duration and lower frequency practices will be associated with a higher T_{DEP}.

4. Time dependence of practices

Fig. 1 shows the distribution of practices in terms of centred average percentage of practices being performed at different times of the day. Watching TV/listening to music is associated with the greatest volume of minutes of all social practices, with a peak of 49% of respondents reporting television in the hour surrounding 21:20. Throughout the majority of the day watching TV is the most reported social practice considered in this study. Our findings do not enter into causal relations as to why TV is such a dominant domestic practice. High availability over the day could be one interpretation along with Bourdieu's concept of habitus which seeks to explain the underlying determinants of the practices that are available to different agents [25].

Likely time dependences in preparing food occur during three periods of the day: the morning, the afternoon and the evening. The concentration periods vary in magnitude and length: the morning peak lasts from 06:00 to 09:00; the afternoon peak is smaller in both magnitude and size, lasting from 12:00 to 13:30; the evening peak is the greatest, starting at 16:00 and ending at 20:00. The analysis shows that there is a convergence of people undertaking this activity during the evening.

Table 2
Standard Deviation, MAX Distance and MAX Distance/average.

Practice	Standard Deviation	MAX Distance	T_{DEP}
Preparing food	108.08	299.90	2.69
Washing	120.08	438.90	3.95
Cleaning	86.04	245.99	2.88
Washing clothes	25.63	66.38	2.13
Watching TV	488.12	1256.16	2.64
Using computer	32.08	58.75	1.22

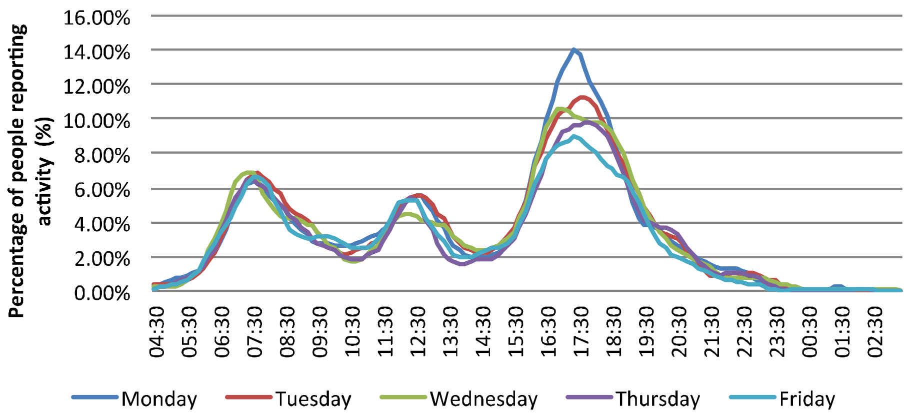

Fig. 3. Centred average percentage of preparing food throughout the day on weekdays.

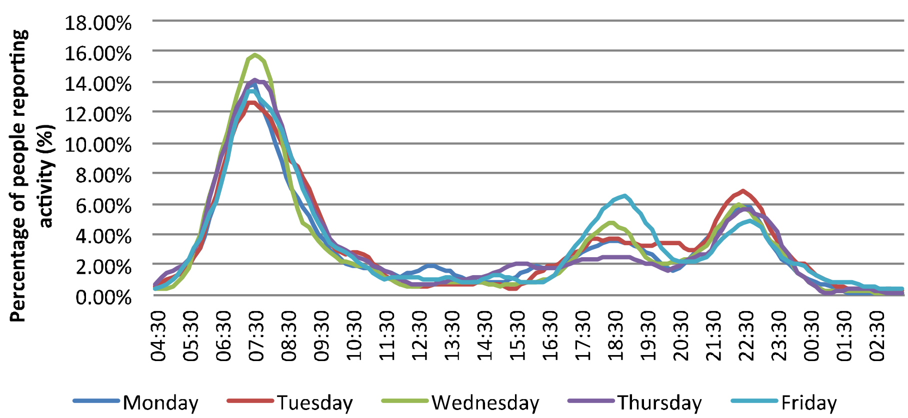

Fig. 4. Centred average percentage of washing throughout the day on weekdays.

Washing and dressing are associated with two concentration periods: a large one during the morning and a small one during the late evening. The morning period is of greater interest as it appears to show a similar rate of increase until around 07:30, when the number of respondents who report this activity falls. The convergence of washing at this time is significant because this practice can lead to the use of an electric shower, which has a very high electricity demand. Cleaning has a high concentration throughout the duration of the morning and into the early afternoon.

Fig. 2 illustrates that washing and watching TV were the activities to show higher distance from the mean throughout the day. Watching TV has negative distance from the mean in the morning and positive distance in the evening. This is explained by a higher occurrence of TV watching in the evening. Significant distances from the mean in preparing food occur during three periods of the day: the morning, the afternoon and the evening. Watching TV has a distinct trend with an asymmetrical shape with gradual increase in the afternoon and abrupt decline in the evening. Other time use work shows that the asymmetry is given by the gradual return to the household (especially in families with children) and the sudden drop in activities followed by sleeping time in the evening [26].

In order to control for the higher volumes of specific practices (e.g. TV watching has the highest number of minutes at evening peak), Table 2 calculates time dependence making use of standard deviation, MAX Distance and MAX Distance/average. Washing has the highest value for the time dependence (T_{DEP}) metric, whereas using computer is the least time-dependent practice. This results in two very different pictures of computer use happening at more or less any time of the day and washing as being extremely bound to time. In time-geography, through the distinction between 'activity' and 'project', using a computer is not considered as an activity in itself, but a means to reach another goal [27,28]. Preparing food is also highly time dependent, though resulting in a moderate T_{DEP} because of the relatively low frequency of meals in a day.

5. Time-dependence variation and work days

Figs. 3–8 show the centred average percentage of activities on the five working days of the week. The y-axis on each of the figures are on varying scales to aid analysis of the data. Preparing food,

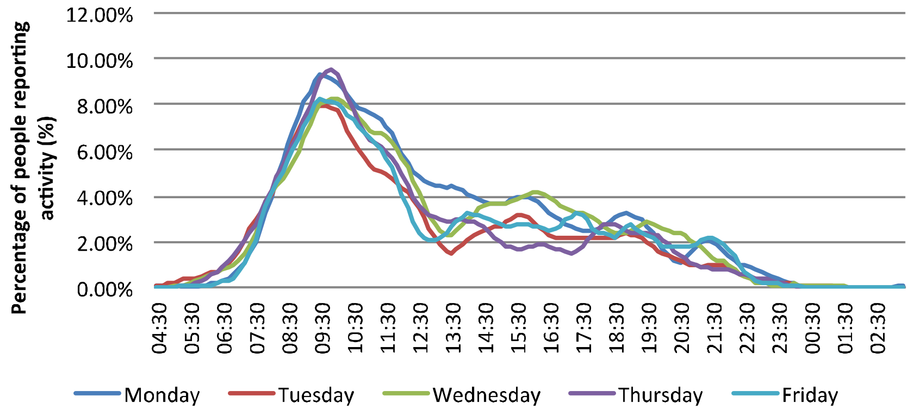

Fig. 5. Centred average percentage of cleaning throughout the day on weekdays.

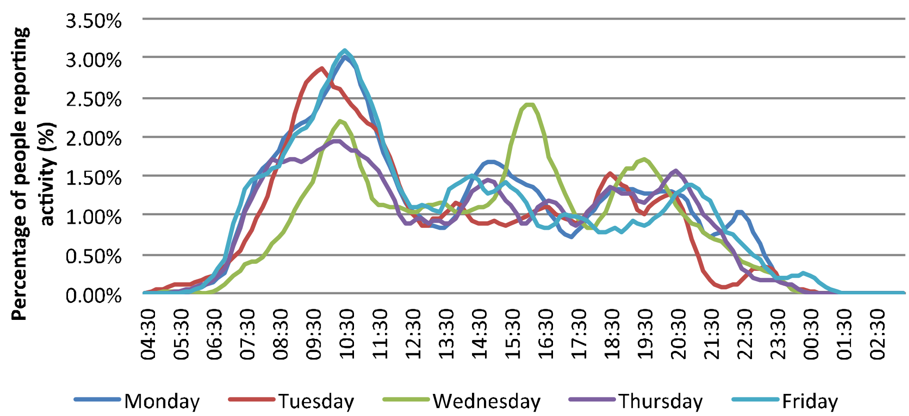

Fig. 6. Centred average percentage of washing clothes throughout the day on weekdays.

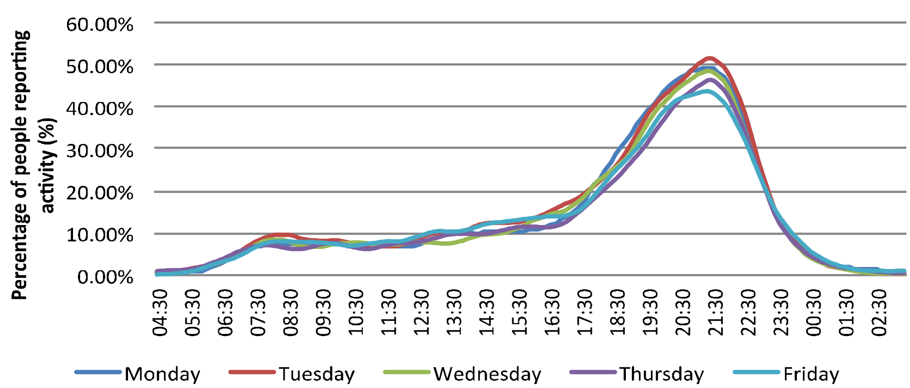

Fig. 7. Centred average percentage of watching TV/listening to radio through the day on weekdays.

washing, cleaning and watching TV show similar time dependences throughout the working day to those obtained in Fig. 1. In contrast, washing clothes and using the computer display more erratic patterns of time dependences throughout the week. The erratic nature of Figs. 5 and 8 is likely to be a result of the smaller scale of the graph, meaning the small changes the patterns of practice appear larger.

The results from Figs. 6–11 show a shift in practices on Friday evenings. Preparing food and watching TV are associated with lower time dependence, whilst the practice of washing is associated with a greater time dependence. On a Friday evening, washing reaches approximately 6%, when it is approximately 2–4% on other days of the week. This finding is likely due to a greater volume of social events, made obvious by the fact washing/dressing in the evening is more diffused than in the rest of the week. The practice of preparing food presents a sharp increase in time dependence on Mondays, when the average percentage is 14%.

Table 3 shows standard deviation, maximum distance and time dependence for different weekdays. Different practices present dissimilar standard deviations, maximum distances and time dependences during the week. For example, watching TV has the highest standard deviation and maximum distance, whereas washing clothes has low standard deviation and maximum distance with respect to different days of the week.

Washing, cleaning and washing clothes have the highest time dependence and this coincides with Tuesday, Wednesday and Thursday. A simple sum of T_{DEP} for all practices shows that overall Tuesday, Wednesday and Thursday are the weekdays with the highest overall time dependence for all six practices. This might

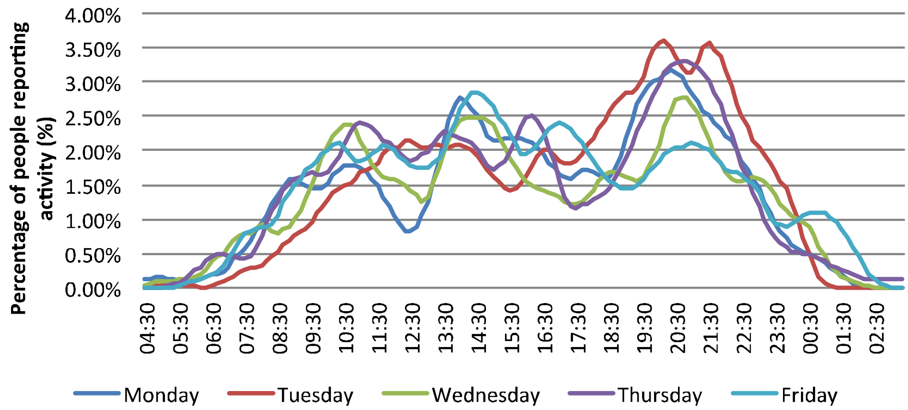

Fig. 8. Centred average percentage of using a computer throughout the day on weekdays.

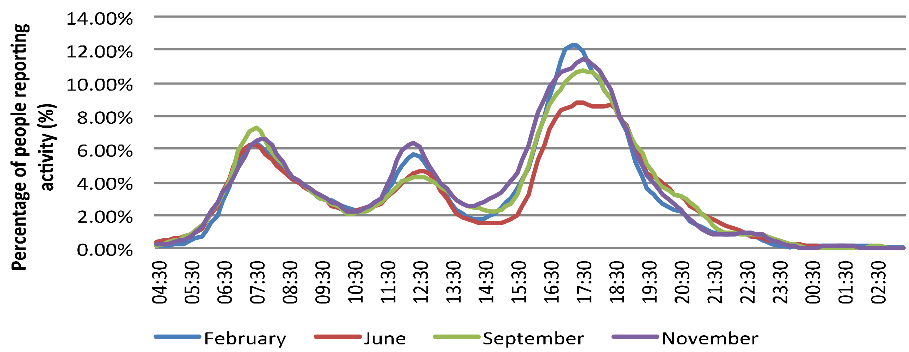

Fig. 9. Centred average percentage of preparing food throughout the day in February, June, September and November. (For interpretation of the references to colour in the text, the reader is referred to the web version of this article.)

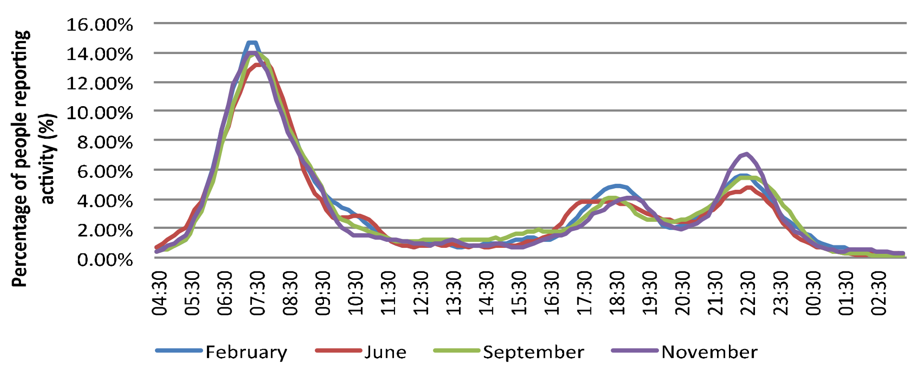

Fig. 10. Centred average percentage of washing throughout the day in February, June, September and November.

be explained by lower occupancy during Tuesdays, Wednesdays and Thursdays compared with Mondays and Fridays, which are associated with a higher level of work from home [29].

Across all practices time dependence varies the most on Thursday, meaning that some practices on this day of the week are extremely time dependent while others are not.

6. Time dependence variation and seasonality

Figs. 9–14 show practices variation across the months of February, June, September and November. The patterns of dependence for preparing food, washing, cleaning and watching TV are similar to those in Fig. 1. There is evidence of seasonal time dependence for washing clothes and using the computer, which are characterised by patterns that are more erratic across the four months.

Time dependence is lowest in June for all practices apart from washing clothes. In June, the peak in evening time dependence is 4% lower than in February. This reduction in peak reaches up to 6% between June and both February and November. June has the lowest peak of washing/dressing.

Overall these results point to high seasonality of social practices. Findings are consistent with the known seasonal patterns in energy demand (i.e. highest in winter and lowest in summer). In this analysis on seasonal time dependence of social practices, there is a clear reduction in the peak of energy-related social practices. For instance, in Fig. 9 the red line indicating the month of June is lower than the lines representing September, November and February during the evening peak (between 4 P.M. and 7 P.M.). The evidence suggests that lower volumes and reduced peakiness of social practices may contribute to the reduction in electricity demand in summer periods.

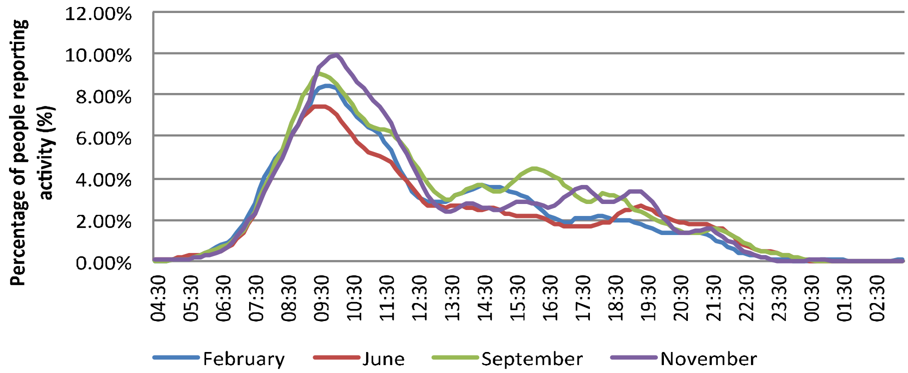

Fig. 11. Centred average percentage of cleaning throughout the day in February, June, September and November.

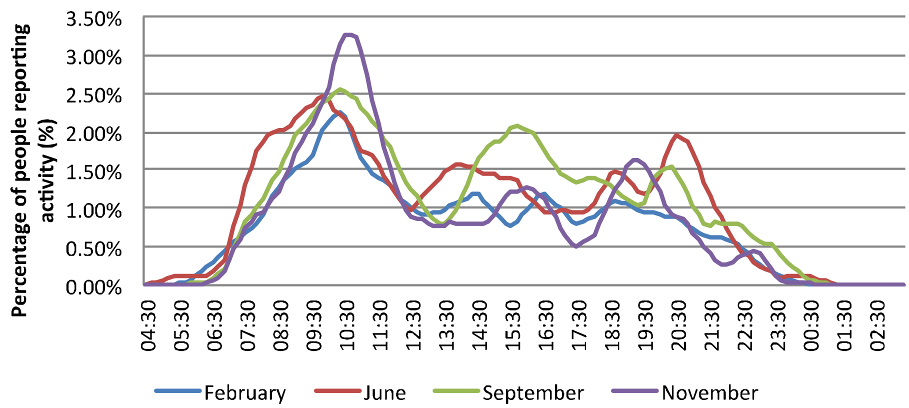

Fig. 12. Centred average percentage of washing clothes throughout the day in February, June, September and November.

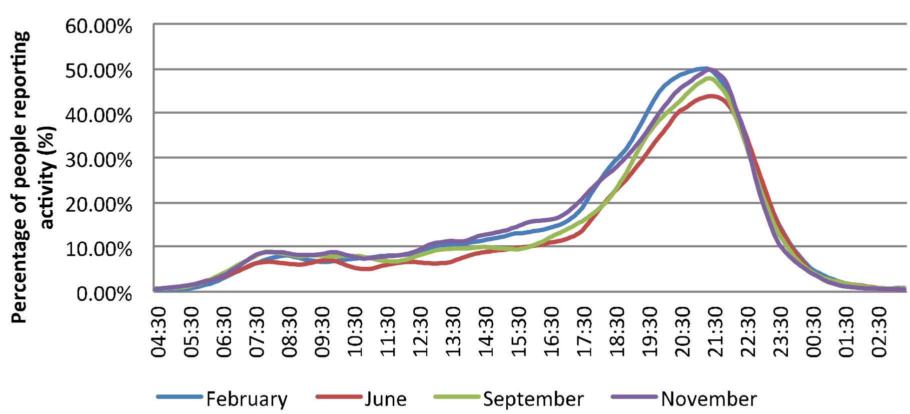

Fig. 13. Centred average percentage of watching TV/listening to radio throughout the day in February, June, September and November.

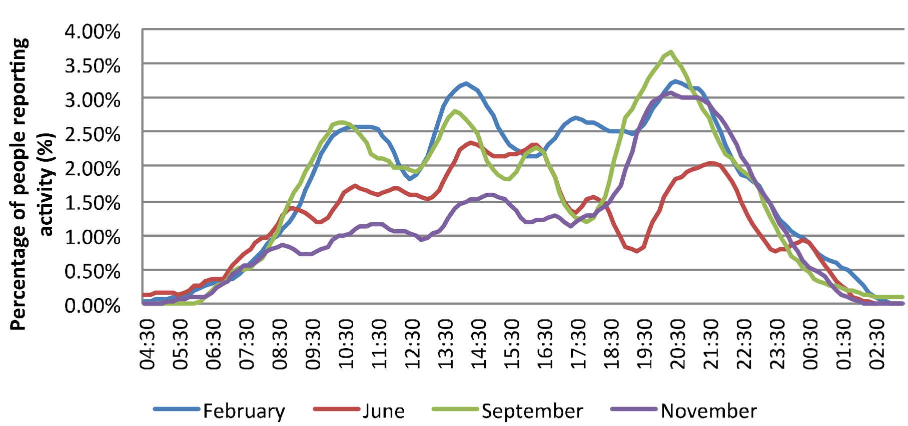

Fig. 14. Centred average percentage of using a computer throughout the day in February, June, September and November.

Table 3
Standard Deviation, MAX Distance and MAX Distance/average for weekdays.

	Preparing food			Washing			Cleaning			Washing clothes			Watching TV			Computer use			
	σ	MAX	T_{DEP}	σ	MAX	T_{DEP}	σ	MAX	T_{DEP}	σ	MAX	T_{DEP}	σ	MAX	T_{DEP}	σ	MAX	T_{DEP}	$\sigma(T_{DEP})$
Monday	25.24	86.67	3.63	22.80	94.89	4.49	19.49	71.84	3.69	5.94	16.33	2.39	104.06	359.11	3.67	6.99	13.95	1.48	108.8
Tuesday	22.84	82.27	3.50	23.48	103.35	4.53	15.79	62.26	4.09	5.90	24.37	4.06	104.57	374.62	3.67	8.24	29.96	2.99	53.8
Wednesday	22.19	81.34	3.58	27.20	129.14	5.94	17.51	60.47	3.33	5.27	22.55	3.93	99.15	352.85	3.71	6.07	21.61	2.42	116.4
Thursday	20.55	72.49	3.46	25.39	119.90	5.37	18.07	72.85	4.47	4.82	16.46	2.80	91.85	342.20	3.80	7.14	24.92	2.51	106.5
Friday	19.25	71.54	3.52	24.05	113.28	4.88	16.84	65.95	4.04	5.90	23.02	3.42	89.77	316.57	3.38	6.11	21.70	2.22	87.4

Table 4
Standard Deviation, MAX Distance, MAX Distance/average for months of February, June, September and November.

	February			June			September			November			
Practice	Standard Deviation	MAX Distance	T_{DEP}	Standard Deviation	MAX Distance	T_{DEP}	Standard Deviation	MAX Distance	T_{DEP}	Standard Deviation	MAX Distance	T_{DEP}	$\sigma(T_{DEP})$
Preparing food	24.08	92.54	3.56	27.37	101.81	3.56	29.22	108.03	3.61	108.05	411.32	3.67	4.9
Washing	29.32	135.64	5.02	29.78	138.94	4.97	31.02	141.57	5.16	120.08	550.14	4.95	9.3
Cleaning	21.30	82.41	4.07	18.54	70.04	3.73	23.03	82.34	3.48	24.51	103.09	4.54	45.9
Washing clothes	5.39	22.91	3.51	6.99	25.51	2.96	7.28	25.56	2.88	7.57	34.98	4.88	92.7
Watching TV	132.19	324.46	2.55	113.63	299.62	2.81	118.33	317.28	2.75	125.89	325.54	2.58	12.7
Using computer	9.91	15.53	1.05	6.75	13.76	1.34	9.91	21.66	1.63	8.06	19.42	2.00	40.3

Table 4 formalises statistically time dependence of practices across seasons by showing the standard deviation, maximum distance and time dependence for the months of February, June, September and November. The highest standard deviation is for watching TV in November, indicating that this practice is particularly spread out across the day in November. Watching TV has consistently high standard deviation throughout the different seasons. The lowest standard deviation by season is for washing clothes in February. This means that at that time of the year washing clothes is more concentrated around the number of minutes dedicated on average to this practice. Computer use has consistently low standard deviation and also the lowest time dependence around February. It has, in general, the lowest time dependence for every season. This indicates that computer use is not dependent on the hour of the day for most seasons. TV watching has the second lowest Time Dependence, despite the fact that it is associated with the highest maximum distance in November, partly due to the high volumes of minutes. This means that there is a significantly high time dependence of TV watching in the afternoon/evening times, low variation across seasons and yet low overall time dependence over the 24 h of the day because of the amount of hours associated with TV watching.

Washing clothes has significantly the highest dispersion of time dependence across seasons. This means that it is the practice whose time dependence varies the most across seasons. Cleaning and computer use also have high levels of seasonal variation. This can be explained by the fact that, for instance, cleaning has a low time dependence in June compared with November. Although preparing food has a relatively high time dependence in terms of the time of the day, it has the lowest seasonal variation.

7. Conclusions and policy implications

This paper studied the relationship between a set of social practices and the time of the day with a view to understanding how time-dependent social practices are and how time dependence varies according to days of the week and seasons. The findings of this paper are discussed here in relation to the four conceptual points highlighted in Section 2.

First, understanding the timing of energy demand depends on understanding ranges of practices and material arrangements and how they are temporally and spatially ordered. The six practices analysed in this paper present different levels of time dependence during the week. It was noted that washing, cleaning and washing clothes feature the highest time dependence. Tuesday, Wednesday and Thursday share in common the highest overall time dependence for all six practices. With regards to seasonal variation, June is the month which is associated with the lowest time dependence. The findings emphasise how seasonal practices are and their intimate relation with material arrangements. For example, cleaning is less time dependent in June than in November, whilst preparing food, which has a high time dependence in terms of the time of the day, has the lowest seasonal variation.

Second, practices tend to cluster together over time and space and have different levels of time dependence. Some practices, like preparing food, repeatedly take place at the same time of the day. Others, like computer use, are less time dependent. Distinctive features of both timing and duration affect time dependence. This was measured also with metrics on distribution of a single practice over the day and distance from the amount of time dedicated to the same practice on average. Practices of short duration (e.g. computer use) can be slotted in between longer duration practices (e.g. TV watching). This has implications on the composition of peak electricity demand and on why this takes place at given times of the day.

Third, this study provides an unprecedented example of application of social practice frameworks for analysing domestic energy consumption in empirical terms. Practices are the independent variable of the analysis. For this reason, this paper avoids any breakdown into socio-economic groups. Indeed, the place of socio-economic categorisations within practices remains debated [30]. Underpinning the conceptual decision to avoid socio-economic categorisations in this paper is that understanding what generates peaks is about analysing portions of time devoted to specific practices and how these are organised across the day. This is for consistency with the conceptual remit of the paper which consists of observing variations in energy-related practices to assess their relationships with time of the day, weekly and seasonal variation. Findings show that arrangements relate to the ordering and intensity of practices. For instance, the seasonality of washing clothes is very high compared with watching TV.

Fourth, findings from this work and, more broadly, practice approaches could make a novel contribution to approaches to manage load shifting. Any intervention which will succeed in moving peaks in residential electricity demand will need to address how time dependent practices are. Two practical examples of applications of this work consist of manual Demand Side Response in the residential sector and automated demand side controllers. Demand Side Response programmes normally require a detailed understanding of the turndown potential of participating loads to accurately forecast when load shifting may take place. However, whilst this is common practice in the non-residential sector, the electricity market has an underdeveloped residential Demand Side Response market as information about load profiles and shiftable loads is missing. The effectiveness of future Demand Side Response penetration in the residential sector depends on accurate information about the timing of electricity demand and an understanding of what causes peaks in load profiles. This is because any price (e.g. dynamic pricing) or technology (e.g. smart appliances with delayers and remote controlling) will have to be developed starting from current practices [12]. Time-dependence of practices can inform about the Demand Side Response potential in the residential sector by informing around what people do in the household and the times of the day in which they can respond to requests to alter consumption.

In the future load shifting may comprise load controllers which will automatically manage electricity consumption from different devices and appliances in the household. The controllers will prioritise loads and appliance use depending on system and users' requirements. The algorithms underpinning automated load controllers will necessitate information about the practices of clusters of end-users. Findings on time dependence of practices could potentially inform automated demand controllers' algorithms.

The findings of this paper feed into a broader discussion on the internal heterogeneity of domestic practices which generate peak electricity demand. The time dependence of social practices, as measured by time use surveys, provides an effective way to re-think peak electricity demand as deriving from synchronous performance of domestic social practices. Causal explanations to this dependence are not provided in this work, but may range from the role of working in determining what happens in the household and at what time [31] to the structuring effect of family commitments and internal synchronisation in the social space [32]. The analysis also draws attention to the time and timing of activities which have implied energy demands. Because the choice of social practices is restricted to their relationship with energy demand in the home environment, the scope of this work has obvious limitations. Practices are not performed in isolation and by treating them individually some of the dynamics of everyday life might be missed. For instance, in real life non-household related practices (e.g. associated with mobility) carry a weight which is at least as significant for understanding both practice complexities and volumes of energy demand as the household practices which were analysed in this work. Energy demand also includes loads, which may be more or less constant and to varying degrees independent from the time of the day, such as air-conditioning, heating and maintaining food frozen. The choice of the dataset also poses limitations as the Office for National Statistics Time Use Survey is statistically representative of the UK in 2005. Time dependence, as measured in this work, is a concept as changeable as time is [33]. Not only practices change over time, but so does their temporal attribution. Hence, representations of practice performance as captured in the time use studies are linked to methodological biases in coding, interpretation and reporting. Changes in rhythms could be internally produced or externally sourced from technological and social agents. On this point, the methodological choice to focus on time use data implies that agency (for instance from technical, organisational and institutional factors) is not considered in this analysis. The paper does not address the issue of reflexive agency among those who carry out various practices. Reflexive agency implies that people might be able to think about their consumption practices and make changes to them in time or content [34]. A recent review of three books on Bourdieu's approach to reflexivity reminds us of the difficulties to reconcile social structures with agents in Bourdieu's work and subsequent empirical work [35].

One of the highest conceptual challenges embedded in the analysis presented in this paper is that it implies dependence, which could be interpreted as some level of causality between time and social practices. This has three implications. First, by adopting a quantitative approach some limitations are also introduced as the emphasis is on trends and broad characteristics of practices and not on motivations, meanings and performances related to practices. Second, time dependence synthesizes related issues of synchronicity (i.e. how co-ordinated a set of people, such as a household, is around a single practice), sequencing (i.e. how different practices are ordered and combined in time) and flexibility (i.e. how some practices can take place at different times of the day compared with other practices). Third, in this work fixed moments of the day -corresponding to peaks in household electricity demand- are used to analyse time dependence and variations in intra-day temporality. This paper focuses only on time dependence and not, for instance, space dependence. By including within the scope of the analysis only household-related practices a conscious decision was made to control for space. As a result, the paper includes only practices which are performed in the household, hence controlling for space variables. The main consequence of this is that no comparison is carried out with other countries, although time use studies from different countries offer a potentially powerful tool in the social practices' realm. The exception is represented by domestic practices taking place in other people's households. The ex ante decision to prioritise time over space in terms of measuring variability was made with a view to enhance the usability of practice theory research in the policy realm. The rationale for this is that, prior to this work, policy intervention in the area of energy demand lacked empirical applications of social practice concepts.

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References

[1] E. Shove, Efficiency and consumption: technology and practice, Energy Environ. 15 (6) (2004) 1053–1065.
[2] G. Walker, The dynamics of energy demand: change: rhythm and synchronicity, Energy Res. Soc. Sci. 1 (2014) 49–55.
[3] G. Mattioli, J. Anable, Gross polluters for food shopping travel: an activity-based typology, Travel Behav. Soc. 6 (2017) 19–31.
[4] L. Nicholls, Y. Strengers, Peak demand and the 'family peak' period in Australia: understanding practice (in) flexibility in households with children, Energy Res. Soc. Sci. 9 (2015) 116–124.
[5] B.K. Sovacool, How long will it take? Conceptualizing the temporal dynamics of energy transitions, Energy Res. Soc. Sci. 13 (2016) 202–215.
[6] E. Zerubavel, Private time and public time: the temporal structure of social accessibility and professional commitments, Soc. Forces 58 (1) (1979) 38–58.
[7] B.K. Sovacool, What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda, Energy Res. Soc. Sci. 1 (2014) 1–29.
[8] M. Jalas, A time use perspective on the materials intensity of consumption, Ecol. Econ. 41 (1) (2002) 109–123.
[9] D. Southerton, 'Squeezing time': allocating practices, coordinating networks and scheduling society, Time Soc. 12 (1) (2003) 5–25.
[10] E. Shove, F. Trentmann, R. Wilk, Time, Consumption and Everyday Life: Practice, Materiality and Culture, Berg, 2009.
[11] H. Lefebvre, Rhythmanalysis: Space, Time and Everyday Life, A&C Black, 2004.
[12] R. Wardle, C. Barteczko-Hibbert, D. Miller, E. Sidebotham, Initial Load Profiles from CLNR Intervention Trials, Customer-Led Network Revolution, 2013.
[13] A. Warde, Consumption and theories of practice, J. Consum. Cult. 5 (2) (2005) 131–153.
[14] A. Giddens, The Constitution of Society, Polity, Cambridge, 1984.
[15] T. Schatzki, Materiality and social life, Nat. Cult. 5 (2) (2010) 123–149.
[16] T. Schatzki, The Site of the Social: A Philosophical Account of the Constitution of Social Life and Change, University Park, PA, 2002.
[17] E. Shove, G. Walker, What is energy for? Social practice and energy demand, Theory Cult. Soc. 31 (5) (2014) 41–58.
[18] B. Anderson, Laundry, energy and time: insights from 20 years of time-use diary data in the United Kingdom, Energy Res. Soc. Sci. 22 (2016) 125–136.
[19] M. Hand, E. Shove, D. Southerton, Explaining showering: a discussion of the material, conventional, and temporal dimensions of practice, Sociol. Res. Online 10 (2) (2005).
[20] G. Ger, O. Kravets, Special and ordinary times: tea in motion in time, in: E. Shove, F. Trentmann, R. Wilk (Eds.), Consumption and Everyday Life: Practice, Materiality and Culture, Berg, Oxford, UK, 2009, pp. 189–202.
[21] A. Warde, S.L. Cheng, W. Olsen, D. Southerton, Changes in the practice of eating a comparative analysis of time-use, Acta Sociol. 50 (4) (2007) 363–385.
[22] D. Southerton, Analysing the temporal organization of daily life: social constraints, practices and their allocation, Sociology 40 (3) (2006) 435–454.
[23] D. Lader, S. Short, J. Gershuny, The Time Use Survey, 2005, Office for National Statistics, 2006.
[24] J. Widén, M. Lundh, I. Vassileva, E. Dahlquist, K. Ellegård, E. Wäckelgård, Constructing load profiles for household electricity and hot water from time-use data—modelling approach and validation, Energy Build. 41 (2009) 753–768.
[25] P. Bourdieu, Outline of a Theory of Practice, Cambridge University Press, Cambridge, 1977.
[26] J. Torriti, R. Hanna, B. Anderson, G. Yeboah, A. Druckman, Peak residential electricity demand and social practices: deriving flexibility and greenhouse gas intensities from time use and locational data, Indoor Built Environ. 24 (7) (2015) 891–912.
[27] T. Hägerstrand, Focus on the corporeality of man, society and environment, in: The Science and Praxis of Complexity, The United Nations University, 1985.
[28] C. Isaksson, K. Ellegård, Dividing or sharing? A time-geographical examination of eating, labour, and energy consumption in Sweden, Energy Res. Soc. Sci. 10 (2015) 180–191.
[29] J. Torriti, Demand side management for the European supergrid: occupancy variances of European single-person households, Energy Policy 44 (2012) 199–206.
[30] R. Galvin, M. Sunikka-Blank, Schatzkian practice theory and energy consumption research: time for some philosophical spring cleaning? Energy Res. Soc. Sci. 22 (2016) 63–68.
[31] A.R. Hochschild, The Time Bind: When Home Becomes Work and Work Becomes Home, Henry Holt, CA, 1997.
[32] Y. Strengers, Peak electricity demand and social practice theories: reframing the role of change agents in the energy sector, Energy Policy 44 (2012) 226–234.
[33] K. Breedveld, The double myth of flexibilization: trends in scattered work hours, and differences in time sovereignty, Time Soc. 7 (1) (1998) 129–143.
[34] T. Schatzki, Practices and actions: a Wittgensteinian critique of Bourdieu and Giddens, Philos. Soc. Sci. 27 (3) (1997) 293–308.
[35] K. Telling, Bourdieu and the problem of reflexivity: recent answers to some old questions, Eur. J. Soc. Theory 19 (1) (2016) 146–156.
[39] G. Powells, H. Bulkeley, S. Bell, E. Judson, Peak electricity demand and the flexibility of everyday life, Geoforum 55 (2014) 43–52.