Household activities through various lenses: crossing surveys, diaries and electricity consumption

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ABSTRACT

The analysis of household energy consumption usually involves the description of technical systems and of people behaviors. This work focuses on the relationship between people activities, appliances use, and electric consumption. It relies on the application of a wide range of measurement tools on a unique sample of 60 households in France. Overall, questionnaires, diaries, and measured consumption provided a consistent description of the intensity and time of use of the three appliances studied. However, variations were found, depending on the indicator and appliance studied. The levels of activity derived from the diaries and consumption show large differences. However, they can be explained based on reasonable assumptions on the differences in the nature of the activities. Most importantly the variations in the intensity of use across households are consistent among the three measurement tools. This result allowed a partial description of the role of the frequency and duration of use, appliances features and energy saving gestures in the final energy consumption. In terms of methodology, this study shows that, questionnaires can provide consistent information on the relative level of energy consumption by household, while diaries provide reliable information about when this energy is consumed, supporting the use of the large scale and wide spread "Time Use Surveys" to model the diversity of power demand in Europe and America.

Introduction

Household energy consumption models first relied on the technical performance of buildings and space heating or cooling systems (knowing they account for the largest share of household energy use). Such is still the case for the reference models on which energy policies in several Western Europe countries currently rely (see Cayre et al. 2011 for an evaluation of the model used for the Energy Performance Certificate in France, and Huebner et al. in press, for an evaluation of the model on which the Standard Assessment Procedure is based in the UK). Progressively, more information about people behaviors have been introduced into these thermal models as described by Cayla (Cayla et al. 2010), where usage intensity and management are added to the socio-demographics and technical variables. In parallel, a quest for energy saving behaviors, as the natural human complement of the technical energy efficiency, lead many studies to focus on dedicated conservation gestures, underlying environmental attitudes, and behavior change levers (see Huebner, et al. 2013, for an overview of the human characteristics in existing energy models, in relation with comfort, and Gadenne et al. 2011, Hori et al. 2013, Sweeney et al. 2013, for recent examples). In many of these studies, energy saving behaviors tend to hide the role of behaviors using energy, or simply people activities. Some of them occasionally interpret human related consumption variability as potential savings. This bias toward an energetic interpretation of the meaning of people behavior asks for a broadening of the scope of the analysis.

The development of the practices theory answers this redefinition need in a radical way, linking domestic consumption to routines and habits, and exploring how they are maintained or changed in conjunction with the infrastructure evolutions (Shove, 2003). This deeper approach has proved difficult

to implement in quantitative studies so far. However, much more modest approaches have been effective involving the quantitative study of usage frequencies for a number of electrical appliances in the modeling of household annual electric consumption (Sanquist et al. 2012, Vassileva et al. 2011).

Going further in that direction, recent researches tried to model when energy is consumed, which is crucial to electric demand peak management. In these researches, electricity load curves are modeled from the reported activities time patterns collected in Time Use Surveys, using activity diaries (Widén et al. 2009, Lopez-Rodriguez et al. 2013.). While the synchronization between occupancy patterns and the global electric load curve could be observed, more detailed analysis of the impact of different activities and related appliances are needed.

This work aims at improving our understanding of the link between activities, appliances usage, and the associated electric consumption. The first question addressed was the evaluation of the consistency between three different ways to measure people activities at home: quantitative questionnaire, activity diaries, and measured electric consumption of the related appliances. In particular, do diaries allow the extraction of useful information regarding the time of electric consumption? How often do they agree? When they don't, what can we learn from the discrepancies? The second question was to identify which of the reported variables describing activities and energy related gestures are more relevant to explain the diversity of specific electricity consumption among households. Who consumes more electricity for a given activity and how does it happen?

Data

The data on which this analysis is based, were collected in the ENERGIHAB project[1], aiming at the investigation of energy usage in the residential sector. There are four levels of data collection: quantitative questionnaire, qualitative interviews, activity diaries, and real time energy consumption with sensor measurements.

Sample

Two nested samples were involved. The main sample included 1,949 households in the Ile-de-France region (the area around Paris, France), who answered a comprehensive questionnaire over the phone. This sample represented the diversity of the region in terms of household structure, income, type of dwelling, and urban location.

The sub-sample was made of 60 self-selected households from the main sample, who accepted to take part into a much deeper study involving in-depth interview, one week of diary completion, and home monitoring. This sub-sample had two seasonal sub-groups: 34 households were studied between October and January, while the 26 other households were studied between May and July. This split allows the entire sub-sample data to capture some of the seasonal variability, while it makes the comparison of the results between households more difficult halving the number of households studied in the same conditions.

Quantitative questionnaire

The quantitative questionnaire was intended for the main sample, and covered the fields of

[1] The ENERGIHAB project was founded by the French Research National Agency (ANR), it was lead by the National Centre for Scientific Research (CNRS) and associated the Scientific and Technical Centre for Buildings (CSTB) and Electricité de France (EDF) (http://www.agence-nationale-recherche.fr/en/anr-funded-project/?tx_lwmsuivibilan_pi2%5BCODE%5D=ANR-08-VILL-0006)

people socio-demographics, building, heating system, transportation, appliances, frequency of use, energy use, energy saving gestures, and environmental attitudes, through more than a thousand questions. This paper focuses on two series of questions describing the intensity or frequency of use of three appliances, the associated energy savings gestures, and some technical features for the TV sets (Table 1).

Questionnaire variables	TV Set	Computeur	Washing Machine
Number of days of use by week (every day, several days, once a week, less)	yes	yes	yes
Hours of use by day (more than 5, between 5 and 3, between 3 and 1, less)	yes	yes	No
Standby when not used (leave on standby, switch it off completely)	yes	yes	no
Time of use (off-peak hours, on-peak hours, either)	no	no	yes
Size of the main TV set diagonal (cm)	yes	no	no
Number of TV sets	yes	no	no

Table 1. Questionnaire variables describing the use of the three appliances studied

In depth-interviews

The in-depth interviews of the sub-sample households aimed at a detailed understanding of everyday consumption practices, and their underlying motivations and energy representations. The analysis of this material is out of the scope of this paper. The detailed results of this analysis were the object of a previous communication (Roudil et al., 2012).

Activity diaries

The diaries aimed to collect the activities undertaken by the households members of the sub-sample, at home and outside, during one week. At home activities were collected using several paper diaries, each dedicated to one room. We asked occupants to fill in what they had just done in this room, on a regular basis, giving the following details: participants, activity, equipment used, start time, and end time. An extra diary was used to collect outside activities described with: participants, goal, distance, transportation mode, time of departure, and time of arrival. After this "open-ended" collection, raw activities and equipment were re-coded into a limited number of items. We then created categories to help the manipulation of fields of activities.

This protocol differs slightly from the diaries operated in most of the national Time Use Surveys, which apply to thousands of households with the ambition to be representative of large populations.[2] In these national surveys, the diaries are more structured, prompting respondents to fill in predefined time slots (10 to 15 minutes), they more often cover one or two days rather than one week for each household, they spread all along the year in order to fully account for seasonality.

Real-time electricity consumption and sensors

Sensors and metering devices were installed in the sub-sample homes, during the same week when the diaries were filled in by the participants. In this paper, the analysis focuses on the measured electricity consumption for three appliances: TV set, Computer (desktop), and Washing machine. We measured electricity consumption for those appliances, at the plug, with a time step of 1 minute, and a consumption step of 1Wh. That is to say, each time an additional Wh of energy is consumed, the total

[2]Europe : https://www.h2.scb.se/tus/tus/doc/Metadata.pdf, France:
« http://www.insee.fr/fr/methodes/default.asp?page=sources/ope-enq-emploi-du-temps-edt-2009.htm »

consumed energy is written into a file, where it's stamped with the current time in minutes.

Some other appliances with higher power demand (i.e: oven) were measured with a precision of 1kWh, which means no value is written to the file until one kWh is consumed, which even for those appliances is not small enough to know accurately when the energy was consumed. Not every appliance was measured in every home: respectively 48, 47 and 38 households had their TV, desktop computer and washing machines monitored. The analysis of the sensors data, which measured temperatures, movements, or lights operations, is out of the scope of this paper.

Methods

The comparison of the measurement tools used for the description of people activities and energy consumption relies on the definition of the dimensions that can be compared, and their proper translation into each data source. For each of the three appliances, the investigated dimensions were: intensity of use, time of use, energy savings, and appliance size where available.

Beyond the obvious differences, we recognized that the measurement tools do not measure the same objects. Most importantly, the questionnaire provides information on the general intensity of use at any time during the year, requesting some generalization task from the respondent, while the diaries and the electric consumption measure the use during one specific week. From there, the comparison between the questionnaire level and the sub-sample detailed measures, will tell us about the relationship between annual average intensity and the usage on a random week, as much as about the differences between general perception of the activity, real-time reporting, and measured consumption.

We also encountered some difficulties in the interpretation of the measured electric consumption. Some equipment can demand different levels of power depending on their state or solicitation, while, like any signal, the measured consumption can include a varying amount of noise. If in some cases, the pattern of power demand is repetitive and unchanged, in some others it can vary significantly in shape and level, questioning when the appliance is actually used and in what way.

On the diary side, the relationship between the people activity and the actual work of the equipment can vary. The TV set has to be on for people to watch TV, but the contrary is not true. When people report they are using the washing machine, they can fill it with clothes, have it running, or program it for a later launch. Hence, the comparison of these different levels of description should be seen as an analysis of the global consistency and specificities of these tools, rather than as a quality evaluation of the subjective stated behaviors against the hard reality of electric measures.

Data preparation: diaries and energy consumption

The information about the three appliances studied that were extracted from the diaries for comparison with the other data sources were the declared use of the appliance for each hour of the monitored week, and the average duration of use of the appliance per day. For the first indicator, any equipment used for at least 5 minutes in a one-hour slot, is coded as used during this hour.

A number of treatments were necessary to use the measured electric consumption. The measured cumulative consumptions were transformed into "instant consumptions," that is the energy consumed during the last one minute step. Extreme and inconsistent values such as negative consumption was regarded as inconsistent, and for each appliance type, a threshold above which consumption values were regarded as extreme was set. We discarded homes with too many inconsistent values, while for the others only extreme values were discarded.

Time stamps were also corrected according to summer time when relevant so as to fit the official time. From there, we computed power at each measurement time, dividing the energy

consumed by the time spent. We defined one appliance usage occurrence as a continuous sequence of power above zero. For washing machines, only sequences during which at least 1,000 Wh were consumed were kept. We computed the frequency and duration of these occurrences for the entire monitored week and averaged them by day for each household.

In the households where several desktop computers or TV sets are in use, the frequencies, durations, and consumptions of all the appliances in the house are summed up. In the case of the TV set, for many households the real-time consumption shows two levels above zero. The lower level, or base consumption, defined as under 20 W, or below 50% of the higher level, was removed for the calculation of the use frequency, use duration, and consumption without base. Our assumption is that the consumption without base is related to the actual use of the TV; it amounts to 75% of the total consumption. We developed a set of variables with different time granularity for use in comparison with the other data sources and used a 15 minutes step average power variable for graphic representations. We also developed variables describing if an appliance has been used at all for each hour of the week, using the identification of the states of the appliances (on/off/base).

Finally, we aggregated diaries and electric consumption data into household level indicators to allow the comparison with the questionnaire data.

Usage intensity across the different levels: questionnaire, diaries, measured electric consumption

For each of the equipment studied the first question addressed was the evaluation of the relationship between the three levels of measurement regarding intensity of use. The measures to be compared were:

- Categories of general frequency and/or duration per day from the questionnaire
- Number of occurrences and durations per day declared on a specific week from the diary
- Number of occurrences, durations per day, and total electric consumption from the sub-meters

First, for each of the three appliances studied independently, usage frequency, and durations reported in diaries were compared to those extracted from the consumption data through correlation analyses. In those analysis one statistic observation is defined as one household, for which an average rate or duration of use by day of experiment was computed.

Secondly, analyses of variance (ANOVA), and Duncan means comparisons, were computed to evaluate the differences between the mean frequencies of declared or measured usage of the appliances in the diaries and consumption signals, depending on the answered category in the general questionnaire. ANOVA was also used to evaluate the differences between average durations by day, in the diaries and consumptions, depending on the duration categories answered in the questionnaire.

Then, ANOVA was computed again to compare the mean electricity consumption of the appliance, depending on declared frequency and duration categories declared in the questionnaire. For all those ANOVA, we defined an observation as one household. In the case of TV sets, we analyzed both the total consumption and the consumption without base.

Time of use across the different levels

After studying how much each appliance was used, the second question was to know when they were operated. The answers came from the comparison of the following variables:

- Use of the washing machine during the off-peak hours as stated in the questionnaire
- Hourly time distributions of the appliances use as reported in the diaries
- Hourly time distributions of the appliances use in the energy consumption data

First, for each appliance, a confusion matrix was obtained from the direct match of the

occurrences of use by hour, day, and household, for diaries and electricity consumption. This matrix shows the percentage of hours when diaries and measured consumption agree or disagree on the use of the appliance. Here an observation is an hour of possible use of an appliance by one household.

Secondly, the time distributions of reported and measured washing machine occurrences were compared depending on the use of off-peak hours for this appliance as declared in the general questionnaire.

Energy saving gestures and appliances performance

We computed an ANOVA to measure the impact of the number, size, and type of TV set used by the household on the total electricity consumption and average power consumed by these appliances. Another ANOVA was computed to measure the impact of the declared state of the TV and Computer when not used on the total electricity consumption consumed by these appliances. We compared the distributions of the time of use of the washing machine depending on the household reporting the use of this appliance during the off-peak hours or not.

Results

Usage intensity across the different levels: questionnaire, diaries, measured electric consumption

Table 2 summarizes the comparison of the measured and reported (diaries) data describing the frequencies and duration of use for the three appliances studied.

	n obs.	Mean (meter)	Mean (diary)	Mean difference[1]	Pearson correlation
Number of uses / Day					
Washing Machine	19	0.53	0.37	0.16	0.69**
Computer	38	2.09	2.33	0.29***	0.43**
TV Set	38	1.46	3.12	1.66**	0.47***
Total duration / day (minutes)					
Washing Machine	18	49	22	27**	0.68**
Computer	38	566	208	358	0.68***
TV Set	38	361	292	132**	0.79***

[1]mean(meter)-mean(diary)
Significance of the difference to 0: *** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05

Table 2. Comparison of the diaries reported usage and the measured usage on the same week

The mean values give descriptive information about the time spent using each appliance. On an average day of the monitored weeks, people reported watching TV three times for a total of 5 hours, while using the computer more than twice for a total of 3 hours and 30 minutes. They also reported running the washing machine once in three days, while according to the measured electricity consumption it was used once in two days.

The duration mean differences between the two collection methods show a systematic bias: durations reported in diaries are smaller than those derived from the measured electricity consumption of the appliances. This is particularly the case for the number of uses of the computer and the duration

of the washing machine. On, the contrary, for TV and computers, the reported frequencies of use are higher than the measured ones. This could result from the diaries describing activities first, and the equipment used for the activity after. Several activities or episodes of watching TV could happen while the TV stays continuously on.

In spite of these biases, the correlations between the measurements of the two methods are all statistically significant: the diversity in the intensity of use among households, as revealed by the diaries, is consistent with that derived from the measured data. For TV and computer, durations are more consistent than frequencies. The quality of these relationships checked directly when we plotted diaries durations against measured durations.

The following results address the question of the link between this specific week of collection and the general activities described in the questionnaire. For each appliance and variable, Table 3 displays the results of the analyses of variance comparing the measured usage indicators means for category answered to the relevant usage question in the questionnaire.

		TV Set				**Computer**			**Washing Machine**		
	Measured average daily usage by appliance	Number	Duration	Electricity consumed	Electricity consumed	Number	Duration	Electricity consumed	Number	Duration	Electricity consumed
Questionnaire reported usage		of use	(minutes)	/WB[1] (Wh)	(Wh)	of use	(minutes)	(Wh)	of use	(minutes)	(Wh)
Number of Days of use	Several days a week	1.56	448	885	1019	2.2	642	1253	0.78	61	605
	Once a week or less	0.99	202	257	420	1.7	238	284	0.18	30	327
		n.s.	*	*	n.s.	n.s.	*	n.s.	**	n.s.	n.s.
Duration on a day of use	More than 5 hours	2.00	642	1338	1507	3.7	875	2011	.	.	.
	Between 3 and 5 hours	1.51	420	870	1003	1.7	462	811	.	.	.
	Less than three hours	1.30	344	581	715	1.5	416	560	.	.	.
		n.s.	*	*	n.s.	n.s.	*	*	.	.	.
Leave on standby	Leave it on standby	.	448	843	894	.	714	1695	.	.	.
	Switch it off completely	.	392	772	974	.	492	736	.	.	.
		.	n.s.	n.s.	n.s.	.	n.s.	*	.	.	.
	n obs.	37	37	37	38	41	41	41	24	20	20
ANOVA models	Factors		-Days used -Duration	-Days used -Duration			-Days used -Duration	-Duration -Stand by	-Days used		
	R2		**0.23***	**0.20***			**0.21***	**0.25***	**0.36****		
	Additional factors			+ TV Size	+TV Size +Number of TV Sets						
	R2			**0.44*****	**0.35****						

[1]WB = Energie consumption after removing the base consumption (less than 10 W or 50% of power of the TV set).
Significance of the difference between the means of the categories from the unbalanced ANOVA
*** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05, n.s. not significant

Table 3. Comparison of the questionnaire reported general usage and the measured usage on a week

The number of times the washing machines ran during the monitored week is consistent with the general frequency reported in the questionnaire (p-value < 0.001). People declaring an everyday use of this appliance used it 8 times in 10 days (0.78), while people reporting a weekly use ran it twice in 10 days (0.18). The R^2 of the associated linear model shows that the reported frequency explains 36% of the variance of the measured frequency. However, this frequency of use is not enough to explain the total duration and the energy consumed along the monitored week.

On the contrary, in the case of TV and computer, the questionnaire is significantly correlated

with measured durations and energy consumption, while frequencies of use are not. For TVs, the duration and consumption (without base) are partially explained by the number of days of use per week and duration per day. For computers, the reported days of use and duration by day explain the measured average duration (R^2 =21%); and the duration by day and leaving the appliance on when not used explain the electric consumption (R^2=25%).

In a sense, these results could support the idea that it's easier for people to talk about the time they spend using their computer or watching TV, and count the number of washing machines they run, rather than the contrary.

Time of use across diaries and measured consumption

What do the three collection levels reveal about when the energy is consumed? First, the diaries and measured data were associated hour by hour to produce a confusion matrix showing how many times they agree or not on the occurrence of an appliance being used during an hour (Table 4). Each observation is a specific hour in the monitored week of one household.

Metered use by hour	TV Set			Computer			Washing Machine		
Diaries reported use by hour	Not used	Used	*Total*	Not used	Used	*Total*	Not used	Used	*Total*
Frequency									
Not used	5397	1945	*7342*	4887	2983	*7870*	2533	236	*2769*
Used	218	960	*1178*	169	769	*938*	26	61	*87*
Total	*5615*	*2905*	*8520*	*5056*	*3752*	*8808*	*2559*	*297*	*2856*
Percentage of the reported cases									
Not used	**74%**	26%	*86%*	**62%**	38%	*89%*	**91%**	9%	*97%*
Used	19%	**81%**	*14%*	18%	**82%**	*11%*	30%	**70%**	*3%*
Percentage of the metered cases	66%	34%		57%	43%		90%	10%	

Table 4. Comparison of the measured and reported working state for each hours of the week

The bold percentage values express the proportion of the reported situations that are consistent with the measured state of the appliance. When people say they are watching TV on a specific hour, in 81% of the cases the consumption signal tells us the TV was in use. When no TV watching is reported, the electric measures agree in 74% of the cases. Overall, diaries and energy meters agree on the time of use of the three appliances. As mentioned earlier the total reported durations are systematically lower than the measured ones. The level of measured but not reported usage is higher for computers (38%), which could mean this appliance is on while not actively used more often. In contrast, households are more likely to report using the washing machine when not consuming energy, which could result from the loading or from the programming of the machine.

Energy saving gestures, load shifting, and TV size

After describing how much and when people use the three appliances, we also investigated the way they use them.

We looked at the impact of switching off the TV or the computer, rather than leaving those appliances on standby as part of the intensity of use analysis, comparing questionnaires and measured data (table 5). There is no significant effect of this energy saving gesture on the TV consumption (either with or without base consumption). On the contrary, the computer energy consumption is significantly lower for people reporting they switch it off when not used.

For the washing machines, the measured usage time distribution is clearly different, depending on people reporting whether they use it or not during the off-peak hours (Figure 2). Off-peak users are much more likely to run their washing machine during the early morning off-peak hours, between 4 and 7 AM.

To complete our understanding of how much the questionnaire brings information about the measured consumption, we entered the reported number and size of the TV sets in the consumption models (table 4). The size of the main TV set has a significant impact on the consumption, whether including base consumption or not. Together, this effect and the reported days of use explain 44% of the consumption without base. The number of TV sets plays a significant but smaller role in the total TV consumption. Further, the size of the TV set varies significantly depending on the reported use frequency and duration, which shows the consistency between people purchase behavior and everyday usage.

There was no information in the questionnaire about other energy saving practices or performance in relation with the three appliances studied.

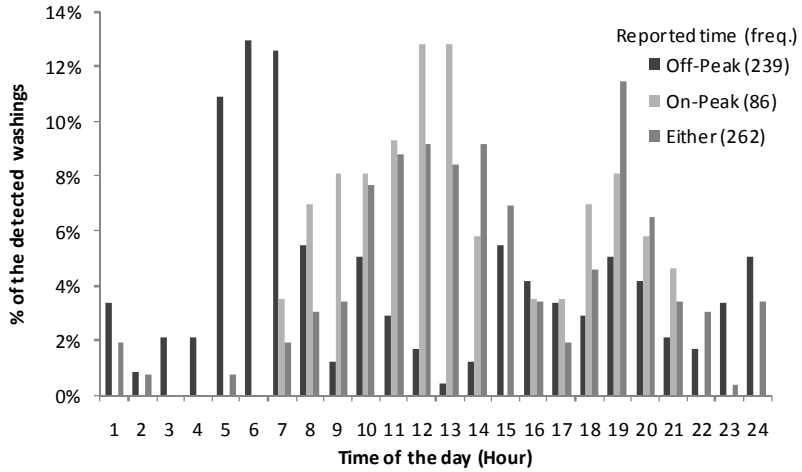

Figure 2. Time distribution of the Washing Machine measured usage depending on the reported off-peak hours usage

Discussion

The results show an overall consistency of the three tools regarding the measurement of the intensity and time of use of the three appliances studied. However, variations exist, depending on the indicator and appliance studied.

First, the absolute level of the intensity of use collected from diaries and measured consumption are very different. Reported computer and TV usage is much more frequent in the diaries, while their duration is much longer according to the energy consumption. These gaps could well translate to a real difference between the active dedicated use of the appliance described in the diary and the on/off state of the appliance which can be derived from the consumption. Several distinct tasks can be chained while the TV set remains continuously on, and computers are not switched on and off each time they're needed, they're more likely to stay on and available for an entire occupancy sequence. The situation is a little different for the washing machine, which usage rate does not differ significantly from one method to the other. Its usage duration is still longer according to the consumption values, which could result from the fact people do not "attend" the washing.

Secondly, the relative intensity of use is much more consistent across the three methods: they agree on who consumes more. Here again, appliances have specific traits. For washing machines, diaries and measured consumption show the same variations in the frequency of use between households. Moreover, those variations are well explained by the general frequency of use reported in the questionnaire. These correlations between diaries and measured frequencies are lower for TV sets and computers, and cannot be explained with the information collected in the questionnaire. However, for these two appliances, the relative usage durations by household are similar across all collection methods.

Thirdly, the time of use reported in the diaries are well synchronized with the time of the measured consumption. There are more errors on that indicator when this computer is not reported to be used and when the washing machine is reported to be used. This could result from the previously described differences in the use of those appliances. On a much more detailed scale, this result brings more evidence of the diaries relevance to understand electricity time of use, which is observed in the significant similarities between the Spanish reported occupancy time profiles and the national domestic electricity load curve (Lopez-Rodriguez, 2013).

Then the global understanding that was built based on the comparison of those measurement tools also provides insights on the respective role of the activities, level of service and energy saving gestures in the final energy consumption. For TV, duration of use and size of the TV set, which can be interpreted as part of the level of service, are the main drivers of electric consumption, while switching off the TV set rather than leaving it on standby doesn't make any difference. This last factor does play a role in the computer consumption, which also depends on the total duration of use. The technical features of this type of appliance were not reported.

Contrary to the TV and computer, the washing machine usage frequency, which revealed to be consistently measured across all levels of collection, and the total duration of use, do not explain the variations in the energy consumption of this appliance. Other measurements of the intensity of use, capacity of the machine, amount of clothes, or washing temperature, and energy saving gestures are possible explanatory factors that were missing in this study. These results support the idea that reported usage intensity of a number appliances can contribute to model the diversity of electric consumptions on real time data, while it was demonstrated for annual consumption in Sanquist (2012).

Still, there are many limits to these analyses. First, the interpretation of the diaries and measured consumption requires a number of choices and simplifications that could heavily alter the results. More qualitative and technical investigation of these two measurement tools would be needed to improve this interpretation.

Secondly, the size of the sample is small enough to limit the conclusions on two aspects. The assessment of the links between the questionnaire and the real-time monitoring is weakened by the small number of observations that are households. The external validity of the results, that is their extrapolation to the Ile-de-France region, is mainly qualitative.

Thirdly, in addition to the small size of the sample, a seasonal effect interferes with the study of the differences between household, because of the sample design. This point should be further investigated in order to consolidate our results.

It's also to be noticed, a fourth investigation method was applied to the same sample: in depth qualitative interviews focused on energy related practices and their underlying motivations. It described people everyday behaviors in terms of practical arrangements ("bricolages") between their need for consumption and comfort, and the emerging necessity to conserve energy. Three types of arrangements were found to be associated with different households and types of activities: opportunistic arrangements, rational arrangements, and radical arrangements. This description differs from the one reported in this paper in many ways. First, they focus on the motivations and on how activities are carried out rather than on their occurrence. Secondly, they describe complex patterns of gestures and choices rather than isolated activities. Thirdly, the different types of arrangements were

not clearly attached to identified objects (i.e: household, time period, activity). For these reasons, the comparison of these interviews results with the three datasets studied in this article, cannot be done in a direct and simple way, and would need more work to be undertaken.

However, the overall interpretation of the three measurement methods studied here, including their discrepancies, reveals converging insights on the relationship between different types of activities and how they are pictured by different collection tools.

This work could be extended in several directions. First, complementary analyses could be undertaken on the same sample, investigating the relationship between socio-demographics and activities, or extending the study of the link between activities intensity and reported energy saving practices in the entire quantitative sample.

Secondly, the relationships identified between activities, the various ways they can be described and energy consumption could be refined, corrected, or confirmed on a larger sample, with a better seasonal sampling, or in other populations.

Thirdly, more activities, energy services, or appliances could be compared. Heating, cooling, and lighting, which still account for a large part of households' energy consumption, relate to people activities in a much more complex and indirect way than the services studied here. Those usages are already intensively investigated, but the coordination of multiple measurement tools mixing reported activities and measured consumption remains rare, while it should help to build a better understanding of the variability in comfort related energy consumption, beyond the usual factors covering the technical performance, the energy saving gestures and environmental attitudes.

Most importantly, these results should help to design relevant energy consumption distributions and dynamics analyses based on the Time Use Surveys conducted in many countries. Those analyses could indeed associate relative changes in consumption between households, according to their frequency, duration and time of use, taking into account these changes differ from one appliance to another.

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