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Profiling Occupant Behaviour in Danish Dwellings using Time Use Survey Data - Part I: Data Description and Activity Profiling

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SUMMARY

Occupant behaviour has been shown to be one of the key driving factors of uncertainty in prediction of energy consumption in buildings. Building occupants affect building energy use directly and indirectly by interacting with building energy systems such as adjusting temperature set-points, switching lights on/off, using electrical devices and opening/closing windows. Furthermore, building inhabitants' daily activity profiles clearly shape the timing of energy demand in households. Modelling energy-related human activities throughout the day, therefore, is crucial to defining more realistic occupant profiles for prediction of energy use to reduce the gap between predicted and real building energy consumptions.

To generate accurate occupant profiles for the residential sector in Denmark, the Danish time use surveys are considered an essential data source. The latest Danish diary-based time use survey was conducted in 2008/09 among 17,707 individuals from 4,679 households. Individuals' daily activities were logged in 10-minute time increments throughout 24 h, starting and ending at 4am, during both weekdays and weekends. The dataset was clustered in 10 activities that were considered suitable for modelling occupancy profiles and behavioural patterns related to energy use. The latter were analysed for different categories such as variation during different days of the week and seasons of the year.

INTRODUCTION

In most developed countries, such as Denmark, the residential building sector is a major consumer of energy and has therefore become a focus for energy consumption efforts. To optimize building energy use, dynamic simulation models are increasingly used to gain a more precise understanding of the underlying processes of energy flows. However, simulation results are still prone to errors since many of the fundamental phenomena are still not sufficiently understood. In particular, the stochastic nature of the human interaction with the building is a key driving factor of uncertainty in the prediction of residential buildings' energy demand (Janda 2011, Peng et al. 2012). Indeed, many studies have shown that there is an urgent need for comprehensive and validated stochastic models predicting residential occupancy and activities, as well as the variations between individuals and households (Andersen et al. 2007, Mahdavi 2011, Masoso and Grobler 2013).

In this context, occupants' activities evidently shape the timing of building energy use throughout the day. Diary-based surveys on how occupants spend their time during the day can therefore help to shape occupancy profiles and energy-related activities.

Time use surveys (TUS) have been carried out at national level since the early 1970s, firstly in Europe and other developed countries. They were designed to understand and assess progress in lifestyles, focusing mainly on time spent for leisure, transport, and work. In the late 1990s, the first time use surveys were implemented in developing and transitional countries, with the main objective being to measure the gender gap in paid and unpaid work. In 2015, nearly a hundred surveys for 65 countries were available for in-depth analyses (Charmes, 2015).

Indeed, the potential value of time use data has long been recognised and TUS based on a comparable survey design have been conducted in the past in most European countries. To foster comparability, the guidelines on harmonised European time use surveys were issued in 2000 (Eurostat, 2008). The latter have been the cornerstone of the European time use harmonisation process. As a major example stands the development of a web-tool for flexible and easy database tabulation for fifteen European countries. Eurostat (2008) further developed the definition of a harmonised framework for the conduction of TUS providing a solid methodological basis for countries intending to carry out time use surveys, to ensure that the results are comparable between countries and hence to greatly increase the value of the data.

Although TUS have predominantly been used for answering research questions related to social aspects, work, and economics, they are becoming an essential data source for energy-related occupant behaviour modelling as well. Wilke (2013), for instance, developed stochastic models based on the French TUS to predict time-dependent residential occupancy and activities, relating the use of electrical appliances to the activities performed. Yu et al. (2013) used data collected in a household TUS in Beijing to develop a household time-use and energy-consumption model, which incorporates multiple behavioural interactions. Torriti (2016) used the British TUS in order to assess how dependent energy-related social practices in the household are in relation to the time of the day.

The aim of this paper is to introduce and analyse the latest diary-based Danish TUS in order to (i) investigate its representativeness of the wider Danish population and (ii) shape energy-related daily activity profiles in the Danish residential sector during different seasons and weekdays/weekends. In particular, different energy- and occupancy- related activities were clustered and analysed.

6	Practical Work	Other work, do-it-yourself work, garden work
7	Family care/Free time	Child care, reading with children, family care, reading, hobby, social gathering, phone conversations
8	Relaxing/TV/IT	TV/radio/music, IT, relaxing
9	Not at home	Work, lunch break, transportation as part of work, transport to and from work education, education, transport to and from education, shopping, errands, visiting public offices, pick up/bring children, association activities, voluntary work and similar, exercise/sport, entertainment/culture, restaurant/café
10	Others	Others

METHODOLOGY

Survey Framework

This study was based on the Danish TUS 2008/2009 which consisted of responses from 17,707 individuals from 4,679 households drawn randomly from a part of the Danish population aged 18-74 years (Bonke, 2016). The questionnaire included 50 questions about general information on the respondents such as family background, incomes, and labour market connection. Respondents were asked to complete two forms for daily time use – one for a specific weekday and one for a specific weekend day. If respondents in the 18-74 age group had a spouse or cohabiting partner and/or children aged 12-17, the latter were also asked to complete the forms for time use. The main respondent of the family completed surveys for children under 12. Finally, a booklet with information about the previous month's spending on goods and services and about regular costs and durable goods bought within the previous year was filled out for all household members.

Thus, the survey included three different instruments:

Q_{hm}; $D_{hi\,jm}$; E_{hm}, where Q is the questionnaire, D the diary, E the Booklet – expenditures for the household. Subscript h represents the household, i the individuals/household members, j the diary day – weekday or weekend day – and m the method used – telephone or web.

A pre-coding system for different types of activities was used in the diary for enabling the respondents to easily compile the TUS and to facilitate data analysis. The day was divided into 10-minute intervals (in total 144 intervals). The time spent on a given activity in the course of a day therefore becomes the sum of 10-minute sequences, where these activities occur. This was intended to ensure more consistent processing of the responses. Interviews were conducted at regular intervals over twelve months, covering the period of March 2008 to March 2009. A detailed description of the survey can be found in Bonke (2002) and Bonke and Fallesen (2010) where the response rates and other information are specified.

Energy-related activity clustering

More than 35 primary activities were pre-coded and included in the Danish TUS 2008/09. These activates were selected by the respondents for describing in 10-minute intervals how they spent their day. The present study aimed at reducing, or rather clustering these activities into a set of 10 activities that were considered energy- and occupancy-related and therefore valuable for occupant behaviour analysis in the residential sector. The set of 10 activities was shown in Table 1. The focus of the study was occupant behaviour in dwellings so activities taking place outside the home were placed in the same category-not at home.

Table 1. Activity clustering

No.	New clusters	Activities included in the TUS2008/09
1	Sleeping	Sleeping
2	Toilette	Toilette
3	Eating	Eating
4	Cooking/Washing dishes	Cooking/Washing dishes
5	Cleaning/Washing clothes	Cleaning/Washing clothes

RESULTS

Representativeness of the DTUS

This section (i) provides a more detailed description of the main characteristics of the respondents and (ii) assesses the representativeness of the respondents with respect to the Danish population. This step was performed by comparing information on the respondents (DTUS 2008/09) to the same type of statistical data available for research at the national level (Statistics Denmark) in 2008 (DK-2008) and 2015 (DK-2015). These two years were chosen for the comparison in order to provide a reference during the year in which the survey was compiled (2008) and to understand if the trend significantly changed in recent times (2015). Figure 1 depicts the age and highlights that the trend of the distribution roughly matches the Danish population in 2008 and 2015. The most populated age range is between 41 and 60 years.
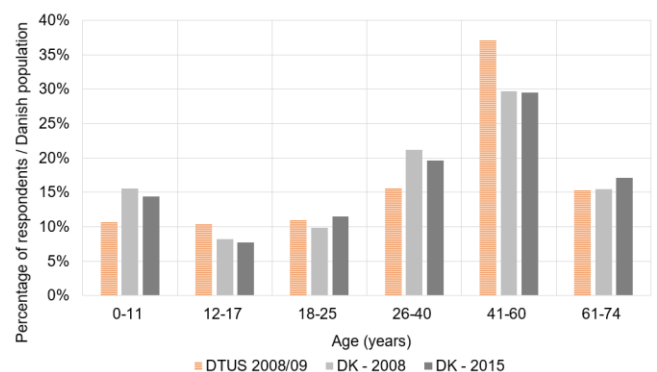

Figure 1. Age of survey respondents and comparison the Danish Population in 2008 and 2015

As regards the number of household members (Figure 2), the analysis yielded that in all samples one- and two- member households were the most frequent, while a smaller fraction lived in households of three to six people. There was a

balanced gender ratio of 51% male to 49% female among the surveyed occupants.

The trend in the surveyed yearly household net income (DKK) was slightly smoother than the trend of DK-2008, which clearly peaks at incomes lower than 200.000 DKK (Figure 3). Nevertheless, the trends are comparable and the DTUS can

be considered representative for the wider Danish population. Finally, Figure 4 depicts the work statuses of the survey respondents and highlights that the highest percentage of them were employees (27%) and students (16%). Both retired survey respondents and skilled workers represent 10% of the total respondents; all the other categories represent a lower percentage with respect to the total sample size.
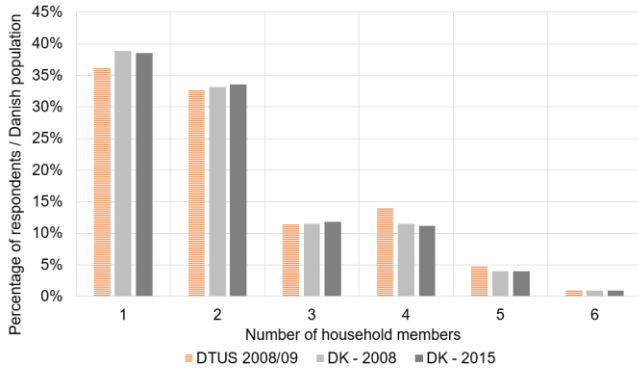

Figure 2. Size of the surveyed households compared to the composition of all Danish households in 2008 and 2015
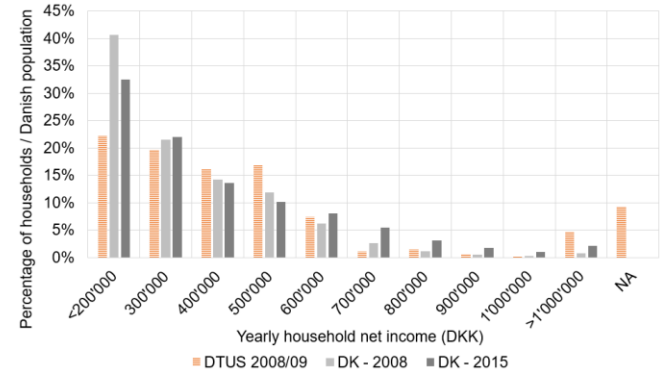

Figure 3. Yearly household net income and comparison to statistical data on Danish Population (2008 and 2015)
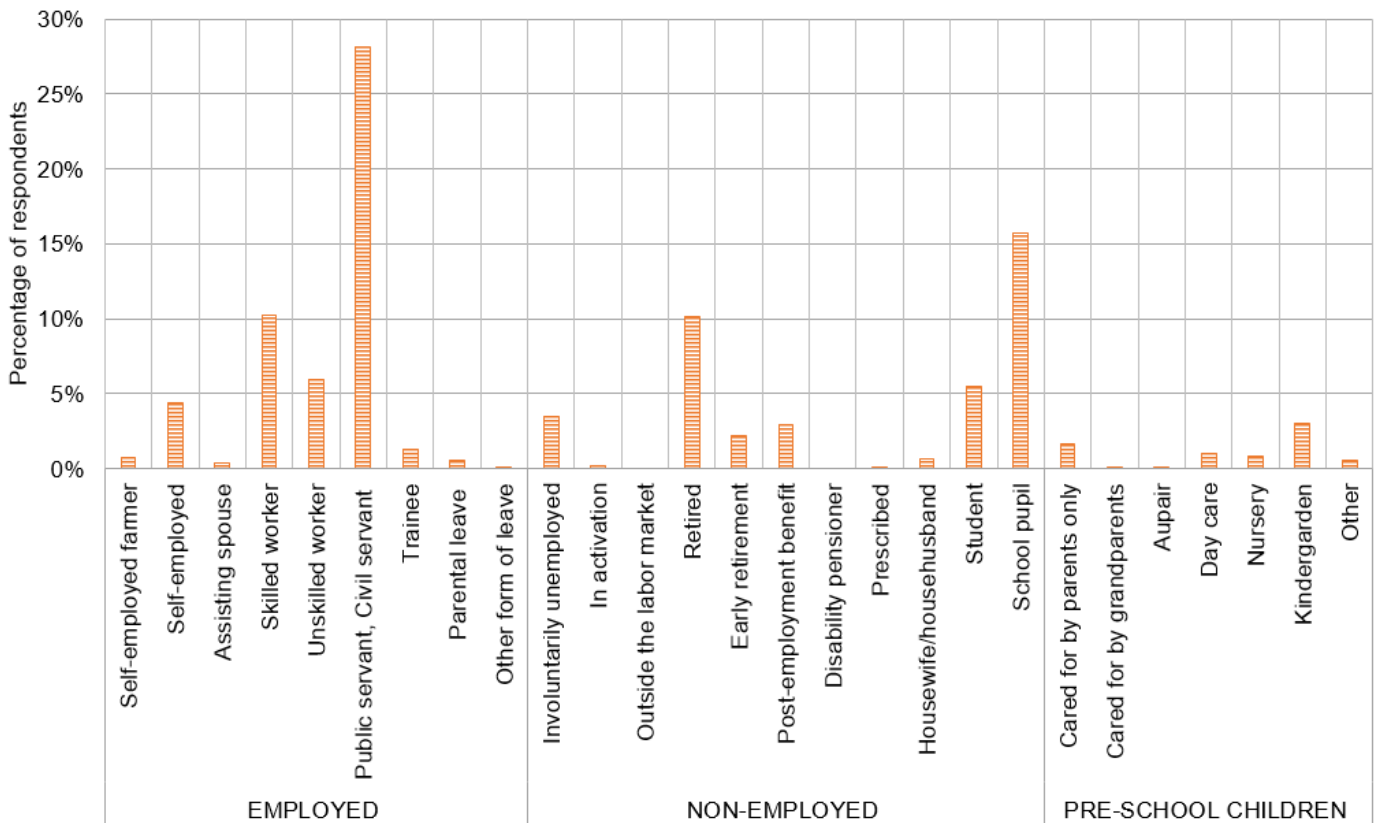

Figure 4. Work status of the survey respondents

Investigation on daily activity profiles

The preliminary outcomes of this study shape the daily activity profiles of the survey respondents based on the DTUS 2008/09. Figure 5 represents the percentage of respondents carrying out each of the ten identified activities throughout the day. Sleeping clearly is the dominant activity with 90% of the survey respondents were asleep between 0.40am and 6am. Two evident peak events in "eating" can be observed, corresponding to lunchtime (ca.12.30pm) and, even more pronounced, during dinnertime (ca. 6.30pm). Two other large portions of the graph represent the activities "Not at home" and "Relaxing/TV/IT". The largest percentage of survey respondents were out of home around 11.20am and returned during the afternoon hours. A large percentage of respondents were at home during the whole or a large extent of the day. However, it is worth mentioning that the graph accounts for the same number of weekdays and weekend days. As regards the activity related to relaxing and the use of TV and IT devices, a peak can be observed between 7pm (after dinnertime) and 23pm. In particular, the identified patterns related to (a) cooking/washing dishes, (b) occupancy (at home/not at home) and (c) use of TV and IT devices provided valuable energy-related information with respect to occupant behaviour and its impact on building energy use.
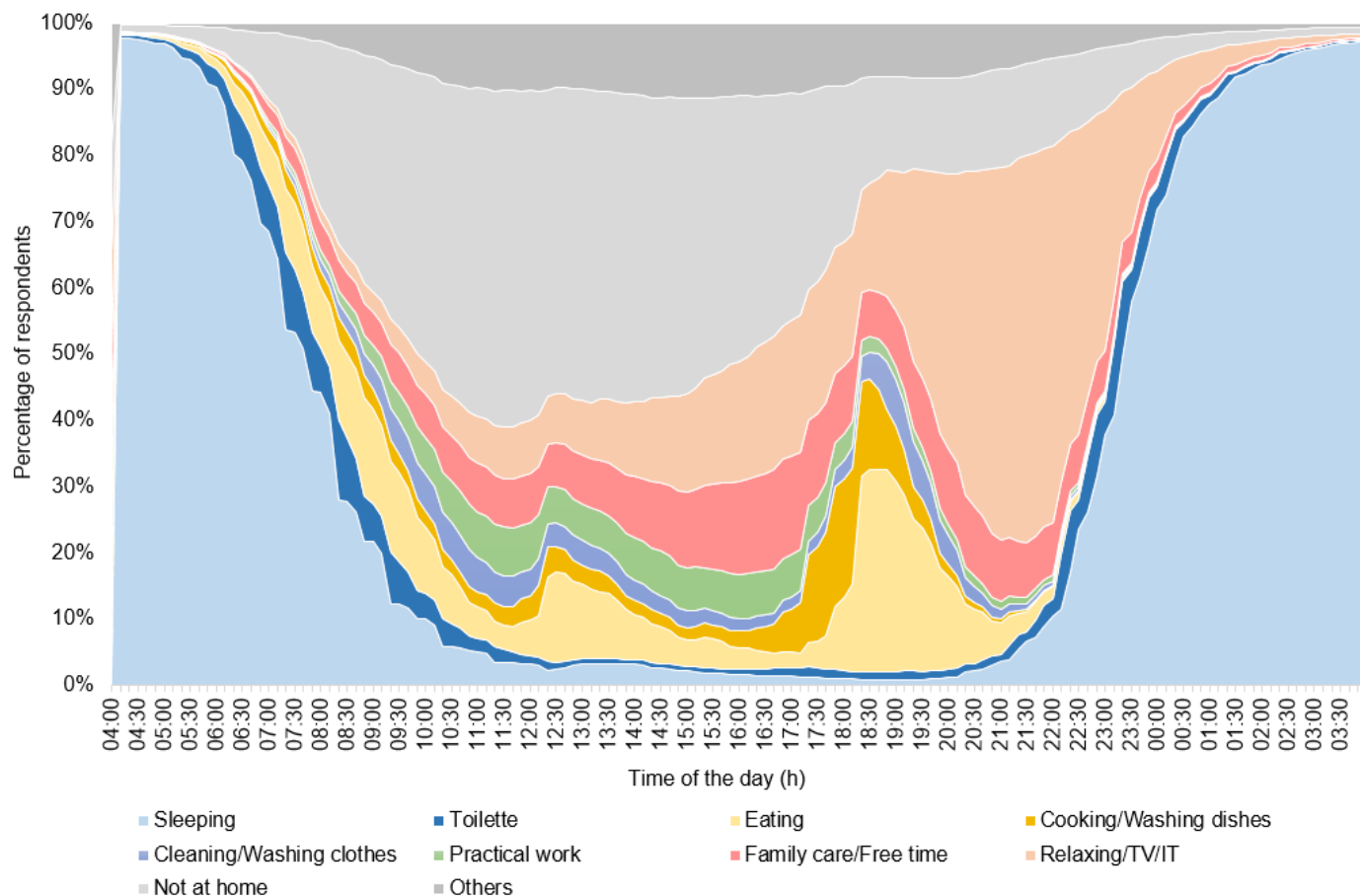

Figure 5. Daily activity profiles based on DTUS 2008/2009

It is important to highlight that Figure 5 combines all of the collected survey responses in one graph, hence, without distinguishing activities with respect to different seasons of the year or different days of the week. For this reason, an additional analysis (Figure 6) investigated differences in the daily activity profiles during different seasons and on weekdays (WD) and weekends (WE). Since no noticeable differences were found respectively between the spring/autumn and the summer/winter period, only outcomes related to summer (June, July and August) and wintertime (November, December and January) were reported.

The key results of this analysis were:

- longer sleeping times during weekends (8h39m – 9h1m) with respect to weekdays (8h-8h17m);

- longer sleeping times in winter than in summer on both weekdays (8h17 and 8h, respectively) and weekends (9h1m and 8h39m, respectively);

- more time spent on practical and garden work in summer (43m-1h) than in winter (19-22m);

- more time spent out of home during weekdays (6h30m-6h41m) than on weekends (3h51m-4h9m);

- longer relaxing times on weekends (3h59m-4h14m) than on weekdays (3h6m-3h32m);

- no significant difference in time spent for personal care (ca.40m) and cooking/ washing (ca.40m) for different seasons and/or day types.

This analysis took into account the total time spent on the several activities in 24h, further analysis to define starting times of the single activities throughout the day is described in part II (Barthelmes et al. 2017).
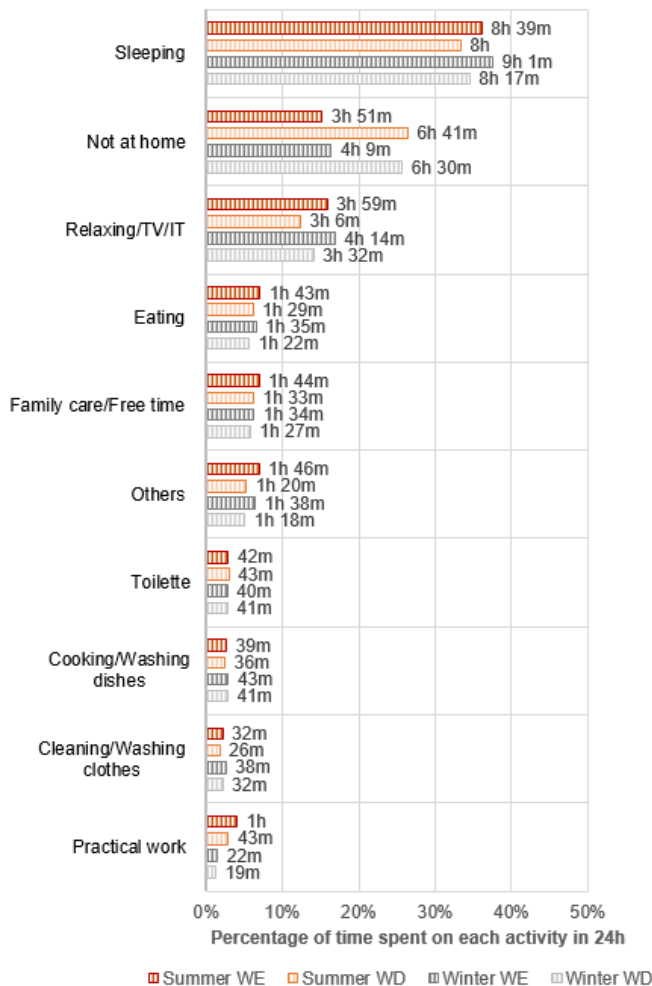

Figure 6. Daily time spent on the activities during summer and winter weekdays/weekends

DISCUSSION

As demonstrated in the previous section, survey respondents (e.g. household composition, age range, yearly net income) who completeed the DTUS 2008/2009 can be considered representative of the wider Danish population. A further step towards understanding the significance of the survey responses for profiling energy-related occupant behaviour is to determine whether the clustered activities can be related to existing studies on building energy use, and in particular to electricity use trends in the residential sector. In line with this, the following supplementary analysis compares two significant energy-related activities: eating (Fig.8) and related cooking/washing dishes activities (Fig.7), to typical hourly mean load profiles in Danish households during weekdays and weekends. The latter refers to the study of Marszal-Pomianowska et al. (2016) who developed a high-resolution model of household electricity use based upon a combination of measured and statistical data. Their study shows that typically there are two peaks during weekdays: a morning peak, which is caused by activities such as preparation of breakfast, morning toilette e.g. hair drying, and an evening peak, which reflects dinner preparation/cooking and evening entertainment, e.g. use of TV and/or PC. Furthermore, during

weekends, the morning peak often moves to later morning hours due to longer sleep, and it is more flat. As depicted in Figures 7 and 8, similar trends can be found from the analysis of the DTUS 2008/2009. These outcomes therefore confirm that these activities can be strictly related to the electricity loads in the households with an evident peak during dinnertime.
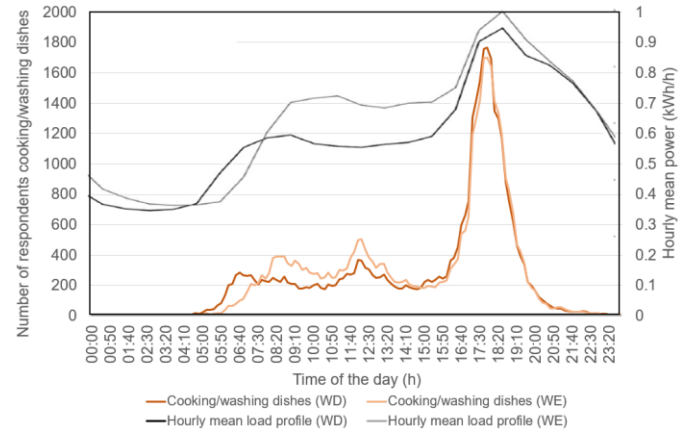

Figure 7. Number of survey respondents cooking/washing dishes during the day compared to hourly mean load profiles
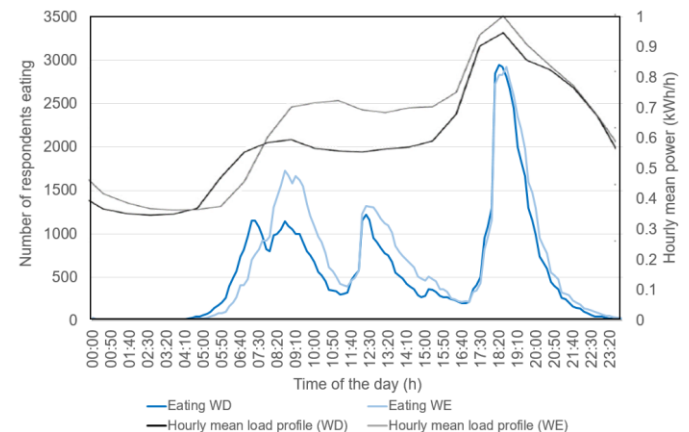

Figure 8. Number of survey respondents eating during the day compared to hourly mean load profiles

CONCLUSIONS

The goal of the present paper was to investigate daily activity profiles of the Danish population based on the Danish TUS 2008/09. In particular, the survey framework was introduced and a comparison with national statistical data (dated 2008 and 2015) confirmed its representativeness of the wider population in Denmark. The daily activities were clustered into ten energy- and occupancy-related activities that might have an impact on building energy uses in the residential sector. The study highlighted that some differences in the daily activities profiles can be found when comparing different seasons of the day and different days of the week (weekdays and weekends).

Furthermore, the outcomes have been compared and shown to be in line with typical trends of hourly electricity profiles in Danish households. Indeed, similar peak values of hourly electric load profiles and some energy-related activities can be observed during the same hours of the day. In detail, these

peaks refer to the early morning hours, lunch time and dinner time, and can therefore be strictly correlated to cooking and eating activities. This paper highlights that the Danish TUS is an important source for developing more accurate energy-related occupant behaviour profiles in Danish households. Further research steps will include detailed analysis on time-related factors, such as the duration of single activities during the day and related starting times. More detailed analysis will also include the definition of typical occupancy patterns based on the Danish TUS in order to create stochastic models which might be implemented in dynamic energy simulation programs towards bridging the gap between predicted and real energy consumptions.

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