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Activities related with electricity consumption in the Spanish residential sector: Variations between days of the week, Autonomous Communities and size of towns

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ABSTRACT

Nowadays the electricity consumption in the residential sector attracts policy and research efforts, in order to propose saving strategies and to attain a better balance between production and consumption, by integrating renewable energy production and proposing suitable demand side management methods. To achieve these objectives it is essential to have real information about household electricity demand profiles in dwellings, highly correlated, among other aspects, with the active occupancy of the homes and to the personal activities carried out in homes by their occupants. Due to the limited information related to these aspects, in this paper, behavioral factors of the Spanish household residents, related to the electricity consumption, have been determined and analyzed, based on data from the Spanish Time Use Surveys, differentiating among the Autonomous Communities and the size of municipalities, or the type of days, weekdays or weekends. Activities involving a larger number of houses are those related to *Personal Care*, *Food Preparation* and *Washing Dishes*. The activity of greater realization at homes is *Watching TV*, which together with *Using PC*, results in a high energy demand in an aggregate level. Results obtained enable identify prospective targets for load control and for efficiency energy reduction recommendations to residential consumers.

1. Introduction

Within its 2020 energy strategy the European Union has proposed a 20% reduction in primary energy consumption and CO_2 emissions, as well as 20% of total final energy consumption coming from renewable sources [1]. The energy consumption in the residential sector, which represents 30% of global consumption and it is rising due to the growing number of residential housing units and the increasing quality of life [2,3], attracts a lot of attention from researchers and local authorities [4]. In this sector, policy and research efforts to date have focused primarily on overall energy savings and sustainable electricity use, by optimizing energy production and distribution, attaining a greater integration of renewable energy and balancing consumption with production. The attempt to reach the last goal, a point of interest to this research, is through the development of strategies for demand response (DR) solutions. Such solutions would lead to the displacement of consumption from peaks, or hours of greatest demand, to off-peak hours (load shifting) [1,4,5].

Electricity consumption in households depends on a great number of conditions, such as environmental or socioeconomic factors; the type, size and location of the housing, the appliances therein, the number of occupants, etc. The use of appliances such as refrigerators, freezers or security alarms, does not depend on the number of occupants who are in the house. The use, however, of most appliances and therefore the household electricity demand profile, is highly correlated to the active occupancy of the households [6–10]. The profiles are, therefore, directly and almost exclusively related to the occupants' activities while at home [11–13]. Some authors consider that the primary driver of energy demand is the frequency and duration of various personal activities [5,14]. In fact, these cyclical activities and individual behaviors are related to patterns of consumption demands on the relevant energy services. Changes to the timing of energy demand can only be undertaken through an in-depth understanding of these non-discretionary factors, such as levels of household occupancy and the activities of the occupants [15].

Moreover, the fact that all of this information must be fed back to the consumers also leads to a reduction in power

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consumption because it enables them to detect electricity misuses, to restructure their consumption and to control individual customer loads by using electricity at times of the day when the electricity could be cheaper, or during periods when the electricity consumed could be produced in situ through the use of installations based on distributed renewable energy sources [16–20]. Shove et al. [21] indicated that energy conservation rests fundamentally on the notion that routines and social practices are the principal driver of reducing consumption.

In countries like Spain, measured data from electricity consumption of individual households via advanced metering technologies is unlikely to be available for some time because their installation and use are still very limited [6]. Moreover, in order to break down the different components of electricity end-use, accurate measurement of its use in households is required. For example, each appliance would require a monitoring device, thus making the measurements both complex and costly [12]. A cost-effective alternative approach consists of making use of the information available on energy-demand related activities taking place in households.

In recent years some researchers have begun to use data on national Time of Use Surveys (TUS) to establish a more reliable causal relationship between activities in the household and residential energy use. This approach has been seen either as a complement, or even an alternative, to metered energy use [7,11–13,22–25]. In Spain the most recent TUS was conducted by the Spanish National Statistical Institute for an annual period following the EUROSTAT guidelines for harmonizing time use data in 2009–2010 [26]. It captured the activities of 19,295 people over the age of 10, living in a total of 9541 homes. The survey includes information about their daily activities, recorded at 10-min intervals, of the participants over the full 24 h of one random day.

The objective of this study is to determine and analyze how people's activities affect trends in the Spanish residential sector's electricity demand, based on the information collected by the TUSs. Time-use data is one of the most significant factors for energy demand models [27]. However, to our knowledge, there is no work in literature linking time use data to location, despite the fact that it has been empirically proven, at least in the UK, that average electricity demand varies depending on municipality size and the household's geographical location [28]. In this paper resident activities and active occupancy profiles of households in Spain as a whole and in a number of its Autonomous Communities (regions) were obtained, differentiating between weekdays and weekends. The aim was to examine the differences and similarities among these profiles in the communities, and to analyze them, taking into account the size of the municipalities in which TUS respondents live.

The structure of this paper is as follows: Section 2 introduces the methodology for extracting active occupancy and household activity patterns of Spanish household from TUS data and for stochastically modeling active occupancy. Section 3 presents findings on active occupancy profiles, discussing the implementation and validation of the occupancy models as well as linking household activities with a set of loads. Section 4 discusses the findings, implications and limits of this work.

2. Methodology

2.1. Determination and analysis of daily active occupancy profiles of households

The active occupancy of a household has been defined as a situation in which at least one of its residents is at home and awake [13]. Real data on the active occupancy of Spanish households can be extracted from the information provided by the diaries filled in by each of the 19,295 TUS participants. The interviewees noted in their diaries, with a frequency of 10 min, data concerning the activities they performed during the 24 h of one random day, the place where the activities took place and whether someone accompanied them. Because each person completed the diary for one day only, the results were statistically significant in aggregate mode but not for individual consumers, in the same way that electricity demand only becomes significant at high levels of aggregation. The information corresponding to the occupancy of each of the 9541 households analyzed in the TUS was obtained by feeding the microdata corresponding to TUS into a database and making use of a series of filters or queries. Once the individual profiles are obtained, it became possible, through their appropriate aggregation, to obtain active occupancy profiles of households both in the whole of Spain and in its main Autonomous Communities. Autonomous Communities were sampled, based on the highest number of available surveys and geographical spread. Occupancy profiles were also grouped according to the type of municipality, (i.e. rural vs. urban). In all cases, the profiles were grouped as a function of the type of day (i.e. weekdays vs. weekends).

After obtaining the active occupancy profiles, peaks of 1-h duration were identified, establishing the time intervals (six 10-min. registers) in which the maximum active occupancy values occurred throughout the day and whose occupancy percentages values were averaged. This analysis was conducted for the national profiles of the whole of Spain, those of the sample of Autonomous Communities analyzed in this work, and those of the different types of municipalities, distinguishing between weekdays and weekends.

Variations in the previously-determined active occupancy profiles were analyzed in order to extract information on potential residential Demand-Side Management (DSM) programs. DSM measures aim to modify daily consumption profiles, and have been classified according to the type of impact they have upon the demand curve, either reducing overall loads throughout the entire day, or by shifting demand at critical hours [29].

Torriti [6] assumed that active occupancy levels reflected the reality of electricity demand loads and these changes in active occupancy obviously lead to changes in power consumption in households. He introduced the concept of occupancy variance, which can be interpreted as the probability of occupancy changes, under flat tariffs, during the time interval under consideration. This parameter was determined using the expression:

$$V(t, t+1) = \frac{(\omega_{t+1} - \omega_t)}{\omega_{t+1}} \quad (1)$$

where ω_t is the level of occupancy at the time interval t, and ω_{t+1} is the level of occupancy at the next 10-min. interval, $t+1$, reflecting the changes in active occupancy of households from a 10-min interval to the next. This parameter was first analyzed throughout the day, and secondly in the time intervals previously determined in which occupancy peaks take place. To determine variation at occupancy peak periods, named $V_p(t,t+1)$, the magnitude of expression (1) was calculated and averaged only during the time intervals in which maximum occupancy takes place. High variance during peak periods means that the changes in occupancy are more likely at peak time, and therefore changes in electricity consumption are also more likely to occur. Variation throughout the rest of the day, given by the off-peak time variation $V_{off\text{-}p}(t,t+1)$, was also determined by means of expression (1), but in this case averaging over all of the time intervals in the day except those already considered to determine peak occupancy variation. A high value of this magnitude, representing a baseline occupancy variance during the day, is associated with a high variability in loads throughout the day [6].