SIMULATION OF HOME ACTIVITIES TO ANALYZE HOUSEHOLD ELECTRICITY COSUMPTION

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ABSTRACT
The aim of this paper is to propose a simulation model to study residential energy consumption. The model includes the inhabitant´s activities linked to their behavior and their habits.
Real data obtained from smart-meters placed in several households have been used to model the electrical consumption of the equipment.
The model is able to assess the influence in residential energy consumption electricity of behavior changes and to quantify the cost of good/bad good consumption habits and its environmental consequences.
We combine methods coming from statistical techniques and the engineering analysis.

Keywords: simulation, residential energy consumption electricity

1. INTRODUCTION

Nationally, energy consumption of the residential sector accounts for 16-50% of the amount consumed by all sectors and averages approximately 30% worldwide (Swan and Ugursal (2009)). Due to this importance many scientific research articles are devoted to model the energy consumption of the residential sector. A complete review can be found in Swan and Ugursal (2009), while specific models are described in Paatero and Lund (2006), Shimoda et al. (2004), Larsen and Nesbakken (2004), and Muratori et al (2013). The inhabitant behavior strongly influences energy consumption patterns and is an important factor that accounts for a big share of the observed variability in the household consumption (see, for example, Chiou (2009), Kashif et al. (2011) and Keirstead and Sivakumar (2012)).
The aim of this paper is to model the residential sector energy consumption by estimating the energy consumption of representative set of individual houses. We combine methods coming from statistical techniques and the engineering analysis.
Our interest is to understand the characteristics of the individual house consumption which present high variability, still not completely defined, mainly due to a great variety of households (individual houses/apartments, different sizes, building materials, sun orientation,…), differences in the occupant behavior and habits and differences in the amount and quality of the equipment.
In our model we consider all the consumptions coming from appliances and lighting. These consumptions are strongly dependent of the attitudes of the home inhabitants, while other consumptions, for example those related with the thermal control, are also highly influenced by other factors as the region climate, the building material characteristics and size, etc.
The construction of simulation model heavily relies on the input data available. We have detailed consumption data at minute frequency level obtained from metering devices placed in several households. These data allows us to determine the amount of energy consumed in each individual use of the appliance but also the consumption profile as a function of time. Lifestyle description combined with appliance consumption profile data is used to develop the simulation model.
The flexibility of the model allows discerning the effect of the occupants' behavior, by assessing the effect of changing their attitudes and habits, but also the effect of introducing new technologies.
This simulation model can be used as a bottom-top model to estimate the total energy consumption of a residential community if a set of representative dwellings (known as archetypes) is considered.

2. MODELING OF INHABITANT ACTIVITIES

Activities have been categorized into one of the following eight groups: Sleep, Breakfast, Eat, Dinner, Cook, Leisure, work and study staff at home, away from home.
The list of appliances and equipment included in the model are: Refrigerator, Freezer, Combo refrigerator, Oven, Kitchen glass-ceramic, Microwave, Dishwasher, Washing machine, Dryer, TV 32 " and 40 ", Computer, Lighting and Other equipment (radio, video game console…).
In addition, the house has been divided into four zones: kitchen, living room, bedroom and study and leisure room. The assignation of activities to each of these areas is as follows (see Table 1). When an individual is doing an activity, certain appliances are used according to his/her habits (see Table 2). Washing machine, dishwasher and dryer are not included in any activity because their way of use is limited to plug it in and let it

run by itself. However, the consumption of these appliances is also an important part of the model.

Table 1: Single Line Table Caption

	ACTIVITIES
Kitchen/dining room	Breakfast
	Eat
	Dinner
	Cook
Bedrooms	Sleep
Lounge	Leisure
Study and leisure room	Leisure
	Work and study staff
Outside of the House	Away from home

Table 2: Activities and appliances

ACTIVITY	RESOURCE
Sleep	None
Breakfast	Microwave
	TV 32 "
	Radio
	Lighting
Lunch	Microwave
	Lighting
	Radio
	TV 32 "
	Oven
	Ceramic hob
Dinner	Microwave
	Lighting
	Radio
	TV 32 "
	Ceramic hob
Cook	Lighting
	Radio
	Television
	Oven
	Ceramic hob
Leisure	Lighting
	TV 40 "
	Game console
	Computer
Work and study	Lighting
	Computer
Away from home	None

3. MODELING OF THE ELECTRICAL CONSUMPTION OF THE EQUIPMENT

To simulate the energy consumption of an appliance it is necessary to learn how is the consumption profile of energy against the time. For example, although the full cycle of a dishwasher washing can last 140 minutes, this does not mean that during that time interval the consumption of electricity is at the maximum power. The manufacturers of household appliances do not include in the user or technical specifications manual this type of consumption data. Usually, only the total energy consumed per cycle for those appliances that operate in a cyclic way, such as washing machines, dryers and dishwashers are provided. Or energy consumed per unit of time (hour, day, or year) in the case of refrigerators and freezers, which doesn't help much in determining these profiles (see Table 3).

There are two different ways for characterizing these profiles. On the one hand, there is the engineering way in which the consumption is inferred from the deep knowledge of the mechanical and electrical performance of each appliance. For example, in the case of a washing machine, times where it is heating water or centrifuging must be known as well as the instant consumption of energy at these time periods. Usually this information is not accessible.

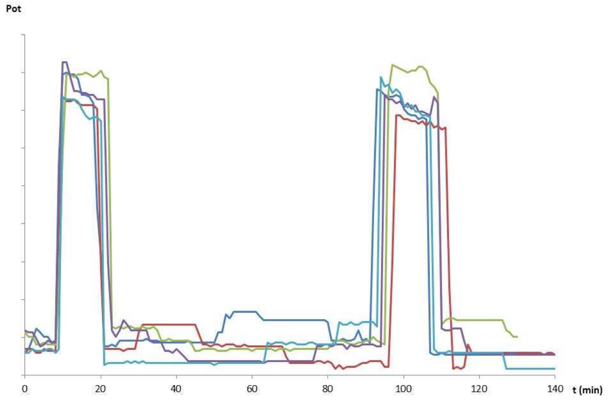
On the other hand, the data can be obtained by using metered devices. We carried out the monitoring of several appliances consumption. Figure 1 shows the resulting measurements for several operating cycles of a washing machine. A drawback is the large variety of models and marks for each type of equipment, and could be differences in the consumption pattern. Nevertheless, we assume a same shape and rescale according with the energy efficiency category of the unit. Following this methodology we have modeled the washer machine, dryer, dishwasher, refrigerator, freezer, oven, glass ceramic, etc. While the lighting is present in all the activities, the power of the above table refers to all the power installed in the housing.

Table 3: Power of certain appliances, energy consumed per cycle and cycle duration

	Energy consumed per cycle [kWh]			
	To^{+++} and^{++}	To^{+} and A	B, C and D	Life cycle
Washing machine	0.77	1.15	1.53	120 min
Dryer	1.4	2.1	2.8	120 min
Dishwasher	0.93	1.40	1.86	140 min
	Energy consumed in a year [kWh]			
	To^{+++} and^{++}	To^{+} and A	B, C and D	
Refrigerator	252,4	504,9	757,3	
Freezer	189,4	378,6	568,0	
Combi refrigerator	311,2	622,4	933,6	
	Energy per hour of use [kWh]			
	TO^{+}	TO		
Oven	0.8	1.12		
Ceramic hob	0.773			
	Power [W]		Stand-by [W]	

Microwave	1,500		4	
Computer	185		5	
Game console	200		4	
Radio	20			
	TO^{+}	TO		
TV 32 "	43	86	3	
TV 40 "	65	130	3	
Oven			4	
	Low	Conv		
Lighting	250	1,000		

Figure 1: Consumption of energy associated to several uses of a washing machine

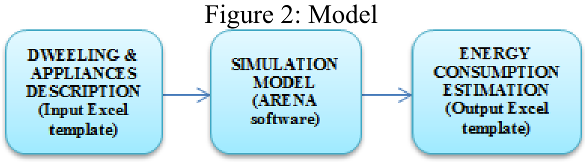


4. SIMULATION MODEL

4.1. Model construction

A discrete-event simulation model has been built to analyze household electricity consumption. The model is schematized in Figure 2.

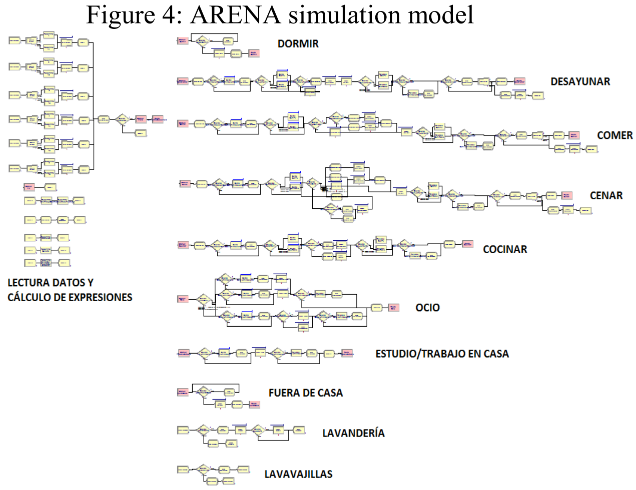
Figure 2: Model



A user-friendly Excel template has been built to facilitate the data input related with the schedule, the activities and the appliances used by each individual at home (see Figure 3). The simulation model was implemented in ARENA software. A screen capture of the model is shown in Figure 4. A 3D-animation of the model was included.

Figure 3: Excel template screen capture

Figure 4: ARENA simulation model



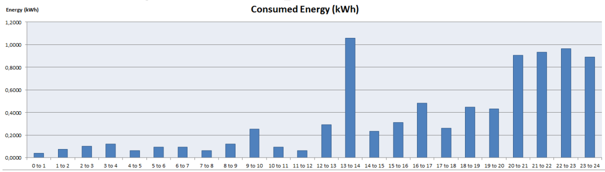
4.2. Experimental results

After verifying the model, a simulation with endpoint event was run. The number of replications was determined by sequential sampling to achieve prefixed half-width confidence intervals. A few seconds were needed to run each scenario. Generally one-minute time steps are used, but when some appliances (microwave, hob or oven) are working, the time step is reduced to one second, due to their consumption profiles.

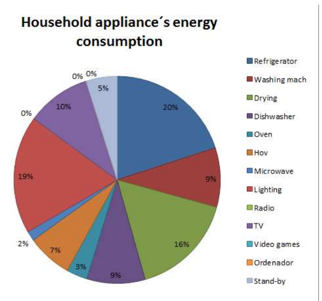
The energy consumed in each clock step interval (t, t +At) is calculated as the instantaneous power in t+At multiplied by At. The simulation results are captured in an Excel Template where a graphical and statistical analysis is provided. Performance measures are calculated in relation with energy consumption, household appliances consumptions, CO2 emissions equivalent and costs for different tariffs. As an example,

Figure 5 shows some of these results for one scenario of a family of two adults.

Figure 5: Example of simulation results



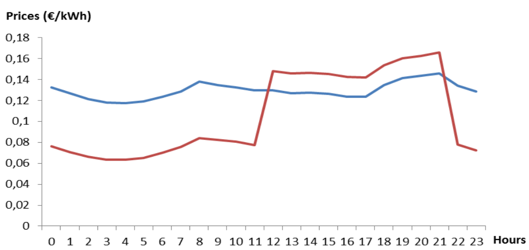
Expected energy (kWh)		
Refrigerator	1,6835	20,01%
Washing	0,7770	9,24%
Drying	1,3772	16,37%
Dishwasher	0,7675	9,13%
Oven	0,2756	3,28%
Hov	0,5966	7,09%
Microwave	0,1271	1,51%
Lighting	1,5500	18,43%
Radio	0,0000	0,00%
TV	0,8462	10,06%
Video games	0,0000	0,00%
Computer	0,0000	0,00%
Stand-by	0,4105	4,88%
TOTAL	8,4112	100,00%



Expected monthly consumption of energy	252,34 kWh
CO2 emissions equivalent	139,87 kg
Costs for general tariff	49,40 €
Costs for tariff with time restrictions	47,44 €

The simulation model allows to analyze and to compare different energy consumption profiles considering, among others, different types of families, specific consumptions patterns, the effect of good consumption habits, the effect of different levels of energy efficiency for domestic appliances and lighting equipment, the different seasons of the year, and different electricity price tariffs with (see for example red line in Figure 6) or with no time restrictions (see for example blue line in Figure 6).

Figure 6: Different electricity tariffs



5. CONCLUSSIONS

In this work we propose a simulation model to study residential energy consumption. The model includes the inhabitant´s activities linked to their behavior and their habits.

Real data obtained from smart-meters placed in several households have been used to model the electrical consumption of the equipment.

The model is able to assess the influence in residential energy consumption electricity of behavior changes and to quantify the cost of good/bad good consumption habits and its environmental consequences.

This assessment analysis can be used to smooth the residential energy consumption curve. Then, the simulation model can be extended to include renewable energy systems and used it to solve storage sizing problems (batteries or other energy storage devices) and the backup with other energy sources in island energy systems. This topic is one of our current work in progress.

The integration of this simulation model in an energy-oriented educational software constitutes another current author's research topics.

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