The uncertainty of the energy demand in existing Mediterranean urban blocks.

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Short Summary

The objective of the paper is to describe a stochastic model that has been developed to obtain load profiles for household electricity. For the study, several profiles have been generated in order to simulate the electrical demand of a residential building block or neighbourhood and evaluate the uncertainty of its energy use. The paper is divided in three different parts: development of the model, validation and determination of the uncertainty demand. In the first parts the basis of the model and how it works is explained. The second one represents the validation of the model, the input data and its results. The last step is focused on a statistical analysis of the electricity demand of a block of dwellings to evaluate minimum number of dwellings needed to estimate the average demand representative of the Mediterranean dwelling with different levels of accuracy.

Keywords: stochastic model; electric load; residential building; Mediterranean regions; cluster of buildings

1. Introduction

In the last years, the increased interest on energy efficiency and on the use of renewable energy technologies in residential buildings has produced the need to improve the knowledge of all the factors that take part in the energy balance. In addition to the technological improvements, an important progress has been the increased availability and use of energy simulation tools. The simulations tools allow realizing building model to test and optimize the energy efficiency measures and energy renewable systems in the design stage. Therefore, detailed load profiles for domestic energy use are important as input to simulations of energy systems such as distributed generation or Net Zero Energy Buildings (NZEB). The heating and cooling load can be calculated by physics models, because these loads are mainly forced by external phenomena. However, the DWH and electric loads of appliances depend on the user behaviour and must be pre-determined, with assumptions, profiles and statistical studies. On the other hand, if the objective is to analyse a cluster of buildings having information of each individual building, it is not realistic to use the same electric load profile for all dwellings. For these reasons are needed to have tools that reproduce real and random electric load.

The objective of the study is to develop a stochastic model to obtain high resolution load profiles for household electricity in Mediterranean climate. Several profiles have been generated in order to simulate the electrical demand of a building block or neighbourhood and evaluate when the uncertainty demand is low enough. Moreover, this paper wants to share information to the Energy Services COmpanies (ESCOs) about the uncertainty in the energy demand in the residential sector. The rate of energy efficiency refurbishment of the buildings is low, especially in the Mediterranean regions [1]. High investments are needed to carry out the renovations, and the ESCOs are the entities that could afford this investment. However, there are aspects that restrain the ESCOs to carry out this kind of projects, as the uncertainty of the energy demand in residential dwellings.

In the last decade, occupancy and behaviour models have been developed with different motivations, but all of them with the need to obtain realistic profiles of the energy use of buildings. Widen [2] has worked in an occupancy model based on Markov-chain transition probabilities and Time Use Data (TUD) of Sweden. TUD gives the information about the occupancy and their activity, which should be translated to end-uses. Widen uses the Markov-chain method to produce realistic patterns and to produce realistic load profiles for household electricity. The model has been adapted to generate different load profiles: electricity, hot water and lighting. Richardson [3] has developed a model of domestic electricity use based on a combination of patterns of active occupancy and daily activity profiles, using Markov-Chain Monte Carlo techniques. The statistical information used is from the United Kingdom. Dar [4] has used the Richardson's model in the field of the NZEB design for a case study in Norway. All of these aspects are related to the Demand Side Management (DSM), where Paatero [5] has been working on. Paatero has built a model for generating electricity load profiles for a dwelling using representative data sample and statistical averages from Finland. The randomness has been included using stochastic processes and probability distribution functions (starting probability function based on the seasonal, hourly and social factors). Another key element is the high influence of the occupancy activity with the heating and cooling loads and in consequence with the size of the systems. Baetens [6] has simulated in Modelica the user behaviour and the use of lighting and appliances. The use of appliances has been implemented by a semi-Markov-process based on the presence of an occupant and the activity profiles. In the paper the results of the model have been compared with deterministic approach proposed by the ISO 13790 [7], obtaining important differences in the demand peaks.

The models described above are based on statistical data of equipment stock of dwellings and user activities or habits in Northern European countries and UK. Recently, "Instituto para la Diversificación y Ahorro de la Energía" (IDAE) has been carried out the SECH-SPAHOUSEC project [8], where a detailed characterization of the energy use of the residential sector in Spain. This study has been used as basis information for the model presented in this paper.

2. Method

All the study has been carried out using mainly the detailed data from the SECH-SPAHOUSEC project. This project characterizes the energy consumption of the residential sector in Spain. The dwelling description includes detailed information about the equipments stock and different energy uses. The information is divided by regions (Atlantic, Continental and Mediterranean) and building type (detached houses and block of apartments). In this paper, the results are related to Mediterranean region and for block of apartments.

The model is divided in two sub-models: electrical appliances (refrigerator, freezer, washing machine, dish washing, television, tumble dryer, microwave, PC, lighting and others which includes a group of small appliances) and kitchen devices (gas and electrical stove and oven).

The model has been developed as a component of TRNSYS 17.1 and gives the possibility to simulate more than one dwelling at the same time. The time resolution is one hour. Each equipment has to be characterized with the parameters described in the Table 1. In addition, general parameters are needed to carry out the simulation: number of simulated dwellings and seeds for the random number generators.

Table 1 Description of the parameters and inputs of the stochastic model of electrical load profiles of dwellings

Data type	Parameter	Units	Description
Stock characterization	Penetration rate (Pr)	%	Fraction of dwellings with at least one equipment. The input of the model is its complementary (1-Pr).
	Multi-equipment probabilities (Mp)	%	These values represent the probability to have 1, 2, 3 or 4 equipments in a dwelling. The multiequipment is defined with 4 probabilities (probability to have 1 equipment, to have 2...). At the same way of the penetration rate, the input of the model is its complementary (1-Mp).
	Fraction of electric devices (FE)	%	In the case of the kitchen devices, it is necessary to include the fraction of electric devices. The gas devices are calculated as the difference of the electrical ones.
Technical data	Power (P)	kW	This power has reference to the nominal power. This information is available in the technical sheet of the equipment. This power could be different to the used power when the equipment is working.
	Power Fraction (PF)	%	PF is the hourly mean power when the equipment is ON divided by the power (P) of the equipment. This parameter is constant over time.
	Cycle Length Fraction (CF)	%	CF is the relation between the cycle length and the integer hours. For example, the duration of the cycle of a washing machine is 1.5 hours, then the integer hours is 2, and CF is 1.5/2. This parameter represents the fraction of the hour when the equipment is spending energy. This parameter is constant over time.
	Power of Stand-by (Pstb)	kW	Pstb is the power of the stand-by mode. If the equipment does not have stand-by, the value should be 0.
Statistics of use	Hourly profile of probabilities of use (prob(t))	%	The probabilities of use represent the probability to use one equipment at each hour. There are hourly profiles for each season (summer, winter and mid season) and type of day (weekday and weekend). It means that there are six hourly profiles of probabilities of use.

The simulation is divided in two steps: dwelling characterization and simulation process. The dwelling characterization is done only at the beginning and consists in the selection of which equipments are in each dwelling. The selection is done by a random number that is compared with (1-Pr). After that, how many equipment there are has to be defined. To do that, the same random number is compared with the multi-equipment parameters. In the equation (1) is represented the conditions to choose the equipments of each dwelling.

$$\left.\begin{array}{ll} RNE_e^d < (1-\mathrm{Pr}_e) & \rightarrow \text{There is no equipment } e \text{ in dwelling } d \\ RNE_e^d \geq (1-\mathrm{Pr}_e)\begin{cases} (1-Mp_{e1}) > RNE_e^d & \rightarrow \text{There is 1 equipment } e \text{ in dwelling } d \\ (1-Mp_{e1}) \leq RNE_e^d < (1-Mp_{e2}) & \rightarrow \text{There is 2 equipments } e \text{ in dwelling } d \\ (1-Mp_{e2}) \leq RNE_e^d < (1-Mp_{e3}) & \rightarrow \text{There is 3 equipments } e \text{ in dwelling } d \\ (1-Mp_{e3}) \leq RNE_e^d < (1-Mp_{e4}) & \rightarrow \text{There is 4 equipments } e \text{ in dwelling } d \end{cases} \end{array}\right\} \quad (1)$$

Where RNE_e is the random number for each type of equipment e and dwelling d. Pr_e is the penetration rate for each type of equipment. Mp_{e1}, Mp_{e2}, Mp_{e3} and Mp_{e4} are multi-equipment probabilities for each type of equipment.

The selection of the equipments in the sub-model of the kitchen devices is different. First, it is necessary to define the presence of the kitchen devices in each dwelling. After that, it has to be chosen if the device uses electricity or gas. It can be represented in the following equation:

$$\left.\begin{array}{lll} RNE_e^d < (1-\mathrm{Pr}_e) & & \rightarrow \text{There is no equipment } e \text{ in dwelling } d \\ RNE_e^d \geq (1-\mathrm{Pr}_e) & \begin{cases} FE_e < RNE_e^d \\ FE_e \geq RNE_e^d \end{cases} & \begin{array}{l} \rightarrow \text{There is an electrical equipment } e \text{ in dwelling } d \\ \rightarrow \text{There is a gas equipment } e \text{ in dwelling } d \end{array} \end{array}\right\} \quad (2)$$

The second step starts after setting the equipments of each dwelling: the simulation process. In each time step of the simulation period, in our case an hour, the model has to define which equipments are ON or OFF (or Stand-by) to be able to calculate the energy consumption for each dwelling. Then, in each time step another set of random number has been generated ($RNP(t)_e$) in order to be compared with the probabilities of use of each equipment type. In the following equation the comparison done at each time step is shown:

$$\left.\begin{array}{ll} RNP(t)_e^d \geq prob(t)_e \rightarrow E(t)_e^d = Pstb_e \cdot \Delta t & \rightarrow \text{The equipment is OFF or in Stand-by} \\ RNP(t)_e^d < prob(t)_e \rightarrow E(t)_e^d = P_e \cdot PF_e \cdot CF_e \cdot \Delta t & \rightarrow \text{The equipment is ON} \end{array}\right\} \quad (3)$$

Where $RNP(t)_e$ is the random number generated for the equipment *e* of the dwelling *d* at time *t*. $prob(t)_e$ is the probability of use at the time *t* of the equipment *e* (*t* refers to the season, type of day and hour of day). $Pstb_e$, P_e, PF_e and CF_e are the parameters of the equipment e described in the Table 1. Δt is the time step (1 hour). Finally, the $E(t)_e$ is the energy consumption for the equipment *e* of the dwelling *d* at time *t* (in kWh). The probabilities of use have been obtained after post-processing work using the database of the project SECH-SPAHOUSEC.

As can be seen in the model description, there are two sources of stochasticity: the random selection of the type and the number of equipment in each dwelling and the random selection of which equipment are ON or OFF (or stand-by) in each time step.

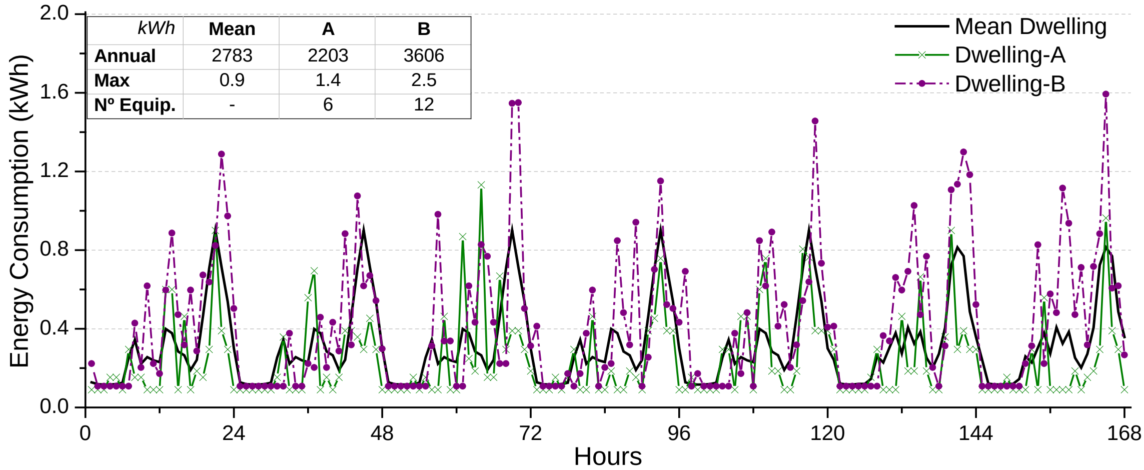


Fig. 1 Hourly electric consumption for a winter week. Example output of the model, two random dwellings and the mean dwelling (reference data).

In the Fig. 1 an example of the output of the model is shown, plotting the hourly electric consumption of two random dwellings during one winter week. In addition, the hourly consumption of a mean dwelling has been included in the graph, in order to view that the simulated dwellings have random profiles. One of the most important advantages of the outputs is to catch the peak values of the load profiles, which are different between days and dwellings.

3. Model validation

The validation of the model is done in two levels: energy consumption of individual equipment and energy consumption of a dwelling. To validate the model, 1000 dwellings of Mediterranean region have been simulated (multi-dwelling building). In the Table 2, the used technical parameters of the equipment in the simulation are shown. The parameters have been obtained from the database of the project SECH-SPAHOUSEC, where there are measurement data of equipments of 200 dwellings over Mediterranean regions of Spain. These parameters has been compared and adjusted with reference studies. However, the following assumption has been done in the case of gas kitchen and gas oven due to the absence of data: the efficiency of the gas kitchen and gas oven is lower than the electrical ones (60% for gas and 75% for electrical ones).

Table 2 Technical data of the equipments used in the simulation

Equipment	P W	PF %	Cycle Length Min	E_{ON} Wh	E_{STB} Wh
Refrigerator	180	96	27	77	-
Freezer	130	96	24	50	-
Washing machine	2200	23	91	380	6
Dish. Washing	2200	94	82	350	-
Television	125	99	48	100	5
Tumble dryer	2000	30	90	450	-
Microwave	1100	50	6	55	3
PC	200	99	36	120	5
Others	3000	22	6	65	1.4
Lighting	200	100	60	200	-
Kitchen (electric)	5000	28	22	510	-
Kitchen (gas)	6176	28	22	630	-
Oven (electric)	2500	27	31	340	-
Oven (gas)	3162	27	31	430	-

Table 3 Annual Energy Consumption for each equipment. Comparison of the results of 1000 dwelling simulation with reference data.

	Annual energy consumption for (single) equipment (kWh/yr)					
	Simulation		SECH-SP [8]	Smart-App[9]	Remodece[10]	Richardson[11]
Geographic area	Med area ON	STB	Spain	EU-15	EU-12	UK
Refrigerator	674	-	550-700	403	344-575	426
Freezer	438	-	400-750	414	256-634	271
WashMach	247	53	250-450	150	92-377	191
DishWash	246	-	250-350	241	132-330	273
Television	196	34	100-250	-	61-456	242
Dryer	249	-	250-400	251	211-393	314
MWave	36	24	50-100	-	16-54	77
PC	311	31	200-300	-	31-368	349
Others	75	11	50-150	-	-	-
Lighting	479	-	300-500	-	68-1013	715
Kitchen (ele)	435	-	450-550	300	138-287	276
Kitchen (gas)	545	-	-	-	-	-
Oven (ele)	163	-	150-350	225	138-287	236
Oven (gas)	202	-	-	-	-	-

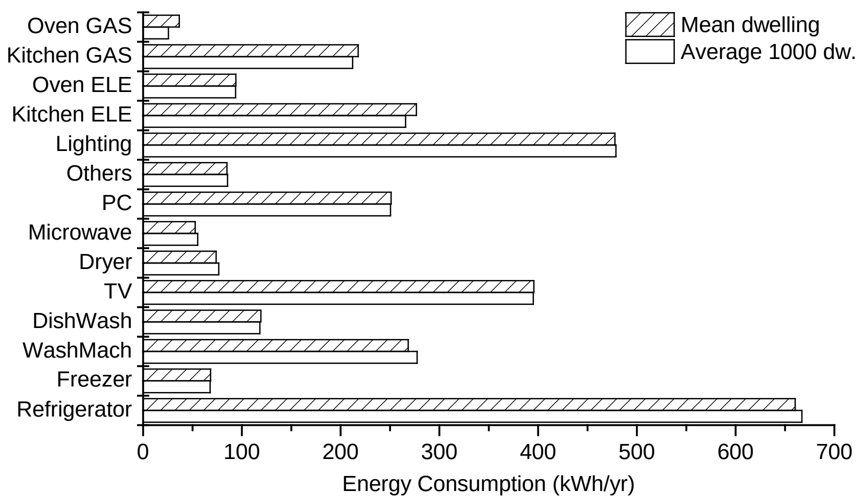
In the Table 3 the average annual energy consumption for equipment is shown. In addition, reference data are included in order to be compared with the model results. Comparing the results, in general terms the model fits to the reference data. There are differences in some equipment although they are coherent with the SECH-SPAHOUSEC. The input data of the model are based on the equipment stock of Spain, where approximately 40% of the equipments has an energy labelling equal or higher than A-label [8]. Reference data in Table 3 (Smart Appliances [9], Remodece [10] and Richardson [11]) are from other European countries with cultural and climate differences which affect to the energy use. Both aspects could be the cause of differences between the simulation results and the reference data.

Once the equipment parameters have been checked, a validation of the energy consumption of dwellings is presented. In the Fig. 2 the annual energy consumption for a mean dwelling are represented, broken down by energy uses. The bar diagram compares the average of 1000 simulated dwellings with the mean dwelling. The graph shows a good performance of the model, having differences lower than 5%.

Moreover, in the Fig. 2 the normalized root mean square error (NRMSE) has been included (equation 4) in order to evaluate goodness of fit of the model. The great part of the elements has an acceptable value of residual variance, lower than 20%. Particularly, there are four elements, washing machine, dishwasher, electric oven and electric kitchen that are lower than 10% of residual variance, which means that the 90% of the variance observed in the these elements are reproduced by the model. However, there are two equipments, refrigerator and freezer, which NRMSE is considerable high, comparing with the other equipments. The reason is that, despite the nearly constant profile over the year, in the reference data there are small variation between seasons, and the model uses a constant value. This variation does that difference between the maximum and minimum value is very small, and then the normalization is done with a low number (denominator). Comparing the diagram with the NRMSE, it is possible to see that a good annual performance not involve a good hourly behaviour. In the section 5, the sources of error that could influence in the results are discussed.

$$NRMSE = \frac{1}{\left(E_{mean}^{\max} - E_{mean}^{\min}\right)} \cdot \sqrt{\sum_{t}^{n} \frac{\left(E_{sim}(t) - E_{mean}(t)\right)^2}{n}} \qquad (4)$$

Where the $E_{sim}(t)$ and $E_{mean}(t)$ is the hourly energy consumption simulated and the reference data, t is the time and n are the 8760 hour of the year. E^{max} and E^{min} are the maximum and the minimum value of the reference data over the year.

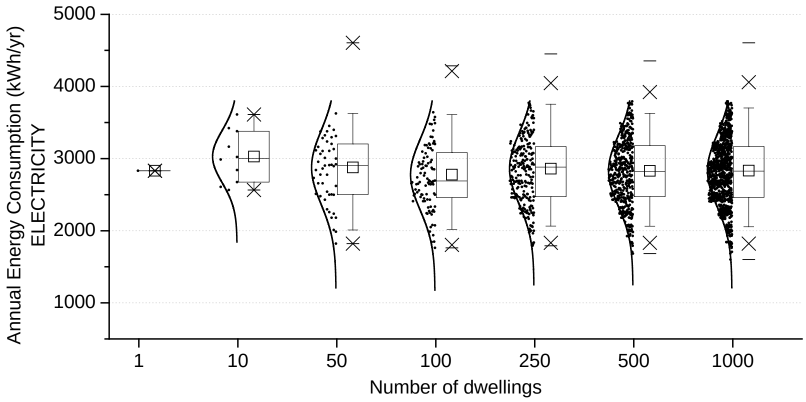


	NRMSE
Oven (ele)	8%
Kitchen (ele)	9%
Lighting	10%
Others	15%
PC	17%
Microwave	13%
Dryer	14%
TV	19%
DishWash	9%
WashMach	7%
Freezer	56%
Refrigerator	31%

Fig. 2 Annual energy consumption for equipment type. Comparison of the average consumption of 1000 simulated dwellings with the mean dwelling (reference data).Right: Normalized root mean square error (NRMSE) of hourly energy consumption for each equipment for the year.

4. Sample size analysis

The objective of this section is to analyse the sample size needed to characterize the buildings during the design process of energy efficiency measures. For this scope, the empirical distribution of the annual energy consumption is analysed. The Fig. 3 represents the distribution of the annual energy consumption simulated for different sample sizes. It can be seen that over 100 dwellings, the two main parameters of the distribution converge; the mean is around 2850kWh/yr and the standard deviation around 500kWh/yr. The distribution of the annual energy consumption is slightly left-skewed but it performs quite similar to a Normal distribution.



nº DW	STATISTICS (kWh/yr)			
	Mean	SD	MIN	MAX
10	3028	364	2565	3611
50	2877	513	1822	4606
100	2777	492	1763	4287
250	2861	495	1791	4452
500	2829	484	1683	4354
1000	2834	499	1600	4606

Fig. 3 Distribution of the annual energy consumption for dwelling, increasing the number of dwellings. Description of the box plot parameters: mean by square; median by horizontal line; 25% and 75% percentile by box; 5% and 95% by whiskers; 1% and 99% percentile by cross; minimum and maximum by dash. In the right table, the statistical values of each sample (mean, standard deviation (SD), minimum and maximum).

Based on the data from the SECH-SPAHOUSEC project and the simulations performed the sample size for two different scenarios are calculated. As previously, the decision variable in this analysis is the total annual energy consumption of a dwelling. The first scenario is designed with the objective to characterize of a population; it wants to determinate the number of dwellings that are required to estimate the mean annual energy consumption of the total population, with different levels of accuracy. The following equations define the sample size for this scenario:

$$n = \frac{N \cdot \sigma^2 \cdot Z_{\alpha/2}^2}{(N-1) \cdot e^2 + \sigma^2 \cdot Z_{\alpha/2}^2} \qquad (5)$$

$$n = \frac{N \cdot \sigma^2 \cdot Z_{\alpha/2}^2}{e^2} \qquad (6)$$

Where (5) is the equation used for a known target population size and (6) for an unknown one. $Z^2_{\alpha/2}$ is the normal distribution value for a confidence level α, σ^2 is the variance of the variable, e^2 represents the error corresponding to the defined level of accuracy, and *N* is the target population size.

Table 4 shows the value for different levels of accuracy. It can be seen that with a sample size of 48 and 12 the mean annual energy consumption can be estimated for any set of Mediterranean dwellings with an accuracy of 5% and 10% respectively. For lowers values of accuracy, the sample size depends on the target population size.

Table 4 Sample size to estimate the mean annual energy consumption for different targets of population size (α =0.05).

Target population size	Accuracy		
	1%	5%	10%
20	20	14	8
100	92	33	11
500	354	44	12
1000	548	46	12
3000	862	48	12
10000	1079	48	12
Unknown	4839	194	48

Table 5 Sample size to reflect the annual energy saving in the electric consumption after to apply energy efficiency measures (paired test, α = 0.05, β = 0.9).

Energy saving	Sample size
5%	265
10%	66
15%	29

The second scenario wants to define the sample size for an energy efficiency measures in a set of dwellings. Given an expected energy saving, the sample size needed for observing differences between the annual yearly consumption before and after the action is calculated.

$$n = \frac{2 \cdot \sigma^2 \cdot \left(Z_{\alpha/2} + Z_{\beta}\right)^2}{\Delta^2} \tag{7}$$

Where Δ^2 represents the expected energy saving after the energy efficiency improvement. The Table 5 shows the value for different levels of energy saving, applying different energy efficiency measures. It can be seen that for greater values of improvement, smaller sample sizes are required. This is because, when comparing two values (mean energy consumption before and after the measure), the greatest is the difference, the easiest is to find it statically significant.

5. Discussion

Regarding the validation process, the model is able to generate random profiles of electric consumption for a dwelling or several dwellings, with preservation of important qualitative features. The load profiles are realistic and their annual consumption is consistent in comparison to Spanish data and from other European countries. However, analysing the results in detail there are slight differences between the simulation and the reference data. The reasons could be due to the limitation of the model, where the following approximations have been done. 1) The technical parameters of FP and CF for each equipment are constants over time. For a refrigerator and for a freezer, it may be a good approximation because their variations during the year can be lower. However, in the case of the other equipments, such assumption could not be justifiable, as for example that the power of lighting is the same during the whole day or the programme of the washing machine or dryer is always the same. 2) Although the input data (hourly consumption of each equipment) takes into account the length of the cycle, in the model there is no relation with the previous hour and the duration of the cycle is not simulated.

In the section 4 a statistical analysis of the annual energy consumption distribution for the simulation results of Mediterranean dwelling is done. The objective has been to evaluate how to reduce the uncertainty in the energy consumption choosing the adequate sample of dwellings. For the first test, it is observed that in the measure that the target of dwellings increase, the size sample needed is proportionally smaller. The second test shows that the energy efficiency measures with high impact are not necessary to be applied in a high number of dwellings to obtain the expected energy savings.

6. Conclusion

The model developed in this study is able to reproduce the hourly and annual patterns of the electric consumption for a residential building or a block of buildings of the Mediterranean region. A general validation has been done in this paper. However, there are aspects that should be tested and improved. A sensitive analysis has to be done to analyze the influence of the variation of technical parameters of equipments, now constants during the simulation. The validation of the model results is done at annual level. It would be interesting to validate the model at hourly level, in order to verify the hourly peaks. At the moment, the model is not related with the occupancy level neither with the user behaviour. These parameters could be included in the model to increase the range of possibilities to adapt the model to each situation and necessity. The use of this type of models is a good tool that could help to reduce the uncertainty of the energy consumption of the residential sector, improving making decision process in the early stage of refurbishment projects.

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8. References

[1] CUBÍ E, ORTIZ J, SALOM J. *"Potential impact evaluation: an ex ante evaluation of the Mediterranean buildings energy efficiency strategy"*, International Journal of Sustainable Energy, DOI: 10.1080/14786451.2013.796945; 2013, Volum 1-17.

[2] WIDÉN J, MOLIN A, ELLEGÅRD K. *"Models of domestic occupancy, activities and energy use based on time-use data: deterministic and stochastic approaches with application to various building-related simulations"*, Journal of Building Performance Simulation, DOI: 10.1080/19401493.2010.532569; 2011, Volum 5, pp. 27-44.

[3] RICHARDSON I, THOMSON M, INFIELD D, CLIFFORD C. *"Domestic electricity use: A high-resolution energy demand model"*, Energy and Buildings, DOI: http://dx.doi.org/10.1016/j.enbuild.2010.05.023; 2010, Volum 42, pp. 1878-1887.

[4] DAR UI, SARTORI I, GEORGES L, NOVAKOVIC V, *"Evaluation of load matching and grid interaction index of a Norwegian all-electrical Net-ZEB under stochastic user loads"*, Proceedings Eurosun 2012, Rijeka, 2012.

[5] PAATERO JV, LUND PD. *"A model for generating household electricity load profiles"*, International Journal of Energy Research, DOI: 10.1002/er.1136; 2006, Volum 30, pp. 273-290.

[6] BAETENS R, SAELENS D. *"Integrating occupant behaviour in the simulation of coupled electric and thermal systems in buildings"*, 8th Int. Modelica Conf., March, 2011, Volum 20-22.

[7] AENOR. *Energy performance of buildings - Calculation of energy use for space heating and cooling*. ISO 13790. 2008.

[8] IDAE, *"PROYECTO SECH-SPAHOUSEC: Análisis del consumo energético en el sector residencial en España",* Instituto para la Diversificacion y Ahorro de la Energía, 2011, http://www.idae.es/index.php/mod.documentos/mem.descarga?file=/documentos_Informe_SPAHOUSEC_ACC_f68291a3.pdf

[9] STAMMINGER R, *"Synergy Potential of Smart Appliances",* Smart Domestic Appliances in Sustainable Energy Systems (Smart-A), IEE Project, 2008,

[10] GRINDEN B, FEILBERG N, *"Analysis of Monitoring Campaign in Europe. REMODECE",* Intelligent Energy – Europe (IEE), 2010, http://remodece.isr.uc.pt/

[11] RICHARDSON I, THOMSON M. *"Domestic Electricity Demand Model - simulation example",* Centre for Renewable Energy Systems Technology (CREST), Loughborough University, 2010, https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/5786