Stochastic Model of Demand Curve Supported in Consumption Habits of Electric Energy for Residential Sector

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Abstract

This paper shows the methodological aspects to design and develop a stochastic model, which determines the demand curve from variation in energy consumption habits, using a survey that was applied to a group of 114 residential users located at Bogotá-Colombia in South America, in the same socio-economic sector, which is called four stratum. It was chosen because it does not receive any government subsidy; nevertheless, the proposed methodology can be replicated in any residential environment for its random nature. The users were chosen at different places of the city, taking into account aspects related to: knowledge of energy resource, habitual consumption behaviors and behavior regarding electrical energy management. The developed stochastic model shows consumption variations in eight groups of devices that are commonly used in a household. It should be noted that each time that another simulation is performed with same parameters; likewise, it is possible to determine how changes in the consumption habits influence energy's demand projection for a residential sector. The changing of the energy consumption habits directly impacts on demand curve, but such changes should be based on aspects related to incorporation of dynamic knowledge of energy resource and everything that surrounds it.

Keywords: Consumer habits, Demand Curve, Knowledge Resource, Stochastic Model.

Introduction

The electrical system needs correct mechanisms to maintain the balance between generation program and reality, if this does not happen, the system operator which is in charge of balancing the demand curve may have costs and penalties (Kieny, Berseneff, Hadjsaid, Besanger, & Maire, 2009). The active participation by electrical energy users is used to increase the system efficiency with its proper use and makes possible a flattening for demand curve (Cerezo Moreno, 2010). It requires users contribution to adapt their consumption habits to situations in system and complementary services that market offers (Vallés Rodríguez, Frías Marín, Reneses Guillén, & González Sotres, 2013). Flattening for demand curve could decrease needs for investment in networks offering contracts to consumers adjusted to their consumption habits, including greater choice and savings in electricity bill (Spees & Lave, 2007). In foregoing view, energy consumption habits become a fundamental element to know the consumption patterns and its behavior in different signals.

This paper proposes a stochastic model to see changes in demand curve according to consumption habits and knowledge management. In section two conceptual elements are displayed related to stochastic models about demand curve analysis linked to consumption habits and probabilistic empirical models posed by some authors, where its main features are extracted as input data, output data and processing used to obtain demand curve. Section three explains design about stochastic model proposed, taking as support the design a survey based on consumption habits with three specific aspects: knowledge of electrical energy resource, common habitual consumption and behavior for its use. Section four shows model development, starting with some data obtained by applying the survey which are basis for model development by devices group. In section 5 results of proposed model are presented, and the paper ends with conclusions.

I. Models of Demand Curve

Changes in energetic behavior by user can lead to saving energy, so regulators know that to vary the energy pattern consumption, there is a potential through a people behavior change, which is influenced by various factors such as price, security in provider, comfort, environment, commitment to change, personal actions and sometimes emotions (Zaeri, Sharda, & Zahedi, 2014).

The importance about knowing disposition in families to adopt different behaviors for energy savings, have different degrees of success (Yue, Long, & Chen, 2013). However, diversity of activities related to electrical energy can be difficult to capture, and there are many questions in relation to the users and their behavior patterns associated with energy use (Hiller, 2015).

The analysis related to energetic behavior by users are based on a theoretical framework, which covers: economic reasons, psychological ones and use of electrical appliances in a household for energy consumption decision making, which opens other factors that influence the activity in houses as well as social interaction and this way the interaction with service provider (Ek & Soderholm, 2008).

A. Stochastic models

Demand for power due to its random nature and its severe fluctuation is more complicated to predict than the demand for energy. Analysis models for electrical residential load curve have been divided into two categories: up and down (Deterministic models), and bottom-up approaches (Random statistical models, Probabilistic empirical models, etc) (Grandjean, Adnot, & Binet, 2012), see below an explanation of some about them:

- Random statistical model: applies a randomized procedure making use of statistical data to generate variations in a given scenario.

- Probabilistic empirical model: defines a probability from data collected on consumption habits, to generate a variety of results.

- Statistical engineering model: dwelling characteristics, meteorological data and input rates are included. Furthermore, statistical coefficients that adjust original results are added, which are calculated with load curves measures and socio-economic data.

- Upward hybrid models: is estimated electricity demand for few houses. These results are extrapolated to obtain unit electricity consumption for the studied area.

B. Probabilistic empirical models for demand curve based on consumption habits

Probabilistic empirical models by its nature allows to know time intervals in periods where it requires the analysis of demand curve behavior, there are some proposed models showing: input data, processing and output data:

- Yao et al Model (Yao & Steemers, 2005), proposes the demand curve generation through cluster analysis, both at macro (national) as well as micro (individual houses) level, by means of load profile for each device, with a statistical analysis using random numbers techniques for the amount of household appliances and presence in housing by occupants. With the data processing model gets: specific daily profile by appliance, load curve with presence the people in housing, load curve for single housing which is replicated at regional or national level.

- Stokes model (Stokes, 2005) calculates load factor for every appliance over time allowing to take into account the reactive power demand. The author for input data processing performs random numbers generation with Laplace-Gauss density function and employs a Boolean factor of appliances utilization, applying the likelihood that an event of demand occurs. With these elements gets: load curves adjustable to profiles of a situation both current and future, individual average profile and total households number every 30 minutes in load curve.

- The model proposed by Richardson et al (Richardson, Thomson, Infield, & Clifford, 2010), takes into account patterns of housing occupation that is limited to 5 people. When people are in house and awake, it selects electrical appliances used (week or weekend, month at the year), besides, it correlates with time amount taking into account basic appliances data (maximum 33). It uses a random process from appliances selection with random number. Similarly assigns a calibration scale that determines use percentage. Model was validated with load profiles for 22 houses in different days per week.

II. Design of Stochastic Model Proposed for Demand Curve

To design the proposed model, methodology presented in Figure. 1 was developed, which has two fundamental elements such as backgrounds found in other authors and analysis unit. From probabilistic empirical models analyzed in section two, the main characteristics for each one of them were extracted, and analysis unit is used for survey development, which was a tendency about behavior related to electrical energy consumption habits for residential users.

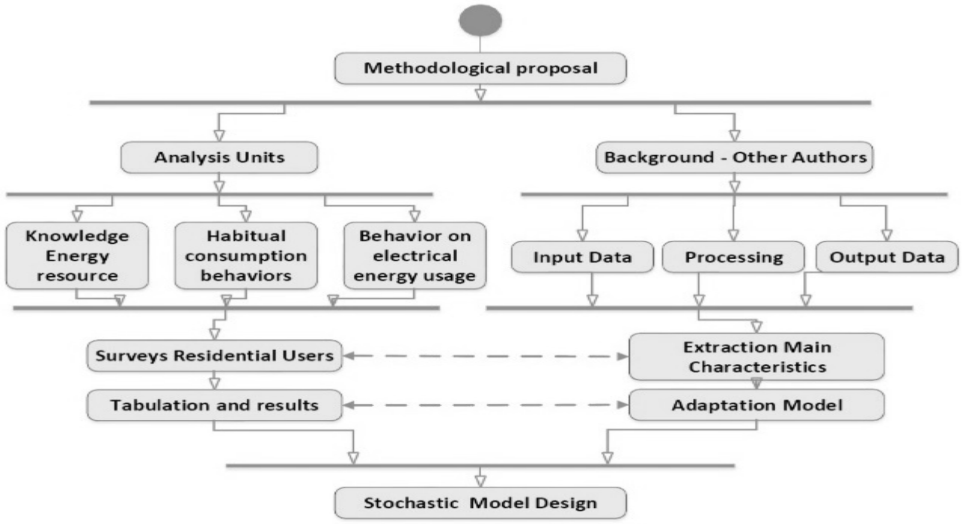

Figure 1. Development methodology for proposed model

A. Analysis Unit "Consumption Habits”: With this analysis unit data related to the consumption habits and knowledge management are obtained to categorize them according to the information that is needed when establishing the demand curve. With analysis unit called "Consumption Habits and knowledge management” the way in which a user makes use electric service in his residence is seen, in such a way that was divided into three aspects: knowledge of electrical energy, behavior habits of electric energy consumption and behavior on electric energy use.

1) Knowledge of energy resource: Variables related with the understanding that target population has about basic aspects of electrical energy, according to this, the following variables are analyzed:

- Knowledge on appropriate electrical energy use,
- Energy efficiency concepts,
- Knowledge about peak time and flat time related to electric power,
- Agent "aggregator" concept,
- Smart grid concept.

2) *Habitual consumption behaviors of electric energy:* With this aspect, data related to main devices and/or residential appliances are collected to meet consumption without diminishing users comfort in a given day (Consorcio CORPOEMA - CUSA, 2012), which were established according to employment percentage of them at different times per day and devices use or intelligent technology for energy management in residences (Jiménez, 2013). The variables are: intelligent devices for energy management, one day in a week where it consumes more power, number of devices and/or appliances, hours of use, percentage use of devices and/or appliances.

3) *Behavior on electrical energy usage:* In this aspect it is discussed how user behaves in certain aspects related to use electrical energy in residence, such as: Alteration of consumption habits by dynamic pricing, Use domestic appliances (remain on or off), Own initiatives for energy saving, Community initiatives on energy savings, Renewable sources use, another motivation.

B. *Elements of proposed model*

The proposed stochastic model design is composed by input data, processing and output data as shown in Figure. 2. The foregoing was processed with elements obtained in survey implementation and its respective tabulation. Below each model block is detailed:

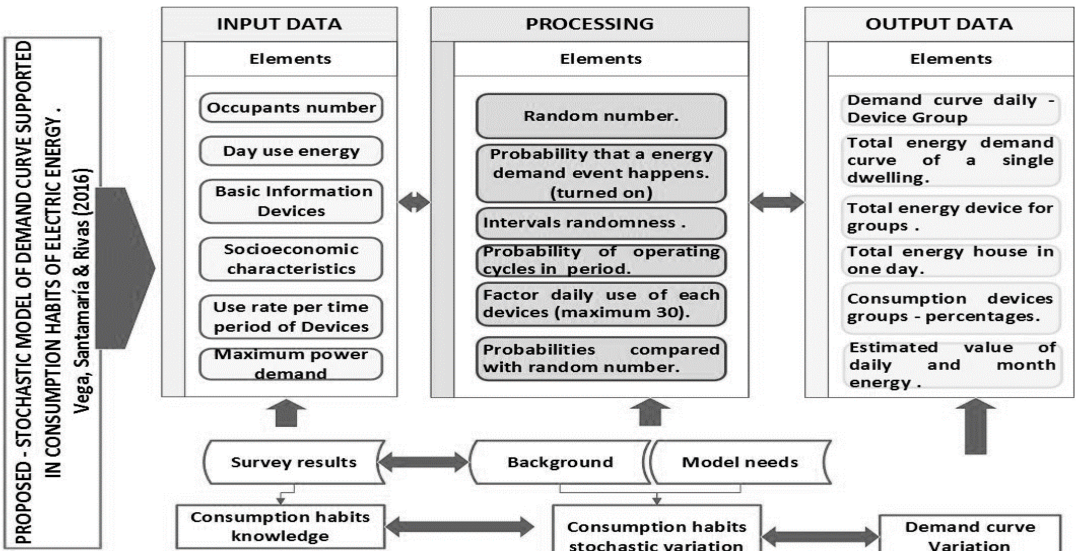

Figure 2. Stochastic model for demand curve proposed by authors

1) *Input Data:* to achieve demand curves variation according to changes in consumption habits, it was necessary to define conditions for entry to the model, which are the following: Occupant's number information dwelling (limited to 5 people), Selection of use (weekdays or weekend). Related Information with lighting, heat and/or cold appliances, entertainment, kitchen, clothing, shower among others (30 in total), Socio-economic characteristics, Use rate of each appliance by period and Maximum power demand estimate.

2) *Processing:* with input data duly established it was proceeded to identify elements that could help the proposed model to have its processing stochastic elements, which are listed below:

- Random number allocation with Monte Carlo simulation (Ramakrishnan, 2016) for the amount of turned on household appliances.
- Probability of an energy demand event is produced (power on).
- Random intervals to use electrical appliances.
- Operating probability cycles in each period.
- Factor daily use of each appliance (maximum 30).
- Power on determination by means of probability compared with random number.

3) *Output Data:* Output data processing with random components results in different types of variation in demand curve, as follows: Daily specific curve per device group, Total energy curve from a single housing, Total energy by devices groups in a day, Total housing energy in a day, and Consumption percentages by devices groups.

III. Development of Proposed Model

The development of the model, dynamic systems are used, which is a science to study multiplicity systems and their causal relationships, including social and economic systems among others, allowing to analyze behavior and perform various simulations in time (Rasouli , 2010). Similarly it allows the systems characteristics study, analyzing its entire structure, decisions and actions that influence their behavior to future (Borshchev & Filippov, 2004). Its objective is to observe what can happen along the time for different scenarios, through events definition and changes in variables (Castaño, Una aproximación a la adopción de medidores inteligentes en el mercado eléctrico colombiano y su influencia en la demanda, 2013).

The simulation software PowerSim® is used (PowerSim, s.f.), to develop model already proposed that allows to perform modeling of flows between variables, handling units, user interfaces creation, etc. in order to develop this model it was necessary to take into account the following components:

A. Input component

It was necessary to do a selection of eight groups of devices that are commonly used in a household, taking into account the model for 30 appliances in total, as it is shown in Table 1.

TABLE 1. Device Groups

Group	Devices
Lighting	Bulbs.
Fridges	Fridges.
Entertainment	Desktop PC, Laptop, TV, Audio equipment, DVD, Multifunctional Printer.
Kitchen	Coffee machine, Electric stove, Blender, Microwave, Sandwich maker, Toaster.
Heat	Oven, Dryer, Iron, Heating, Iron Hair.
Clothing	Washing machine, Dryer
Shower	Electric shower, Electric heater.
Miscellaneous	Vacuum cleaner, Treadmill machine, Shine machine, Alarm Clock, Gadgets.

Likewise, the variables that determine analysis unit of consumption patterns and whose data were obtained in survey applied were taken into account, as follows:

Knowledge of resource:

- Operation cycles probability: probability that a household appliance is power on in a given period of time. For this model the day was divided in six time periods.
- Devices amount: appliances number per group on average that a house has.
- Devices consumption: is consumption established by manufacturer in Watts. In survey the appliances age was asked.
- Price: value kWh in the month.

Habitual consumption behaviors:

- Day of greater electrical use energy in household: variable where is chosen if midweek or weekend.
- Occupant's number: amount of people living in dwelling and is limited to six.

Behavior:

- Probability of devices power on: probability that a user turns on an appliance in day.
- Daily Usage time: period by time in which the appliance takes on.

B. Stochastic processing

For the process of input data, different operation cycles were programmed and variable cycles with stochastic components, which are presented allowing: assign random numbers, probabilities application and randomness intervals, to determine operating cycles, power on devices, among others.

C. Output component

In terms of output data, after model processing, daily specific curves are obtained per device group as well as general one, a consolidated overview of energy consumed by each of appliances in group for a period by time and estimated bill value by month.

IV. Model Results

As a model result implemented it should be noted that on basis variation in consumption habits and knowledge management, it is possible to establish an approximation to daily demand curve in household, in addition the random nature of energy consumption makes clear display how behavior of users affects not only to household level but also in the entire electrical energy value chain.

As part of proposed model, a survey for a case study in a residential complex with a total of 114 people in Bogota city of Colombia, belonging to socioeconomic stratum 4, was implemented, this stratification was selected because it does not receive subsidies nor contributes as it happens in other strata according to Law 142 for 1994 of stratification and Public Services (Senado República de Colombia, 2016), and it is regarded as middle class, in addition this is only population that pays a real amount of money for public services. In the same way this model can be replicated in any residential setting.

A. Data obtained from survey

Some results obtained in analysis unit for consumption habits are shown below, which are taken to set input variables in proposed model. Figure 3 shows answers to the following question: What is your knowledge about appropriate use of electrical energy?, where it is observed that 50,88% of people consider that they have average knowledge on appropriate use electricity resource in their homes, while a 33,3% answered that their level about knowledge is high. These data are used concerning the socio-economic factor.

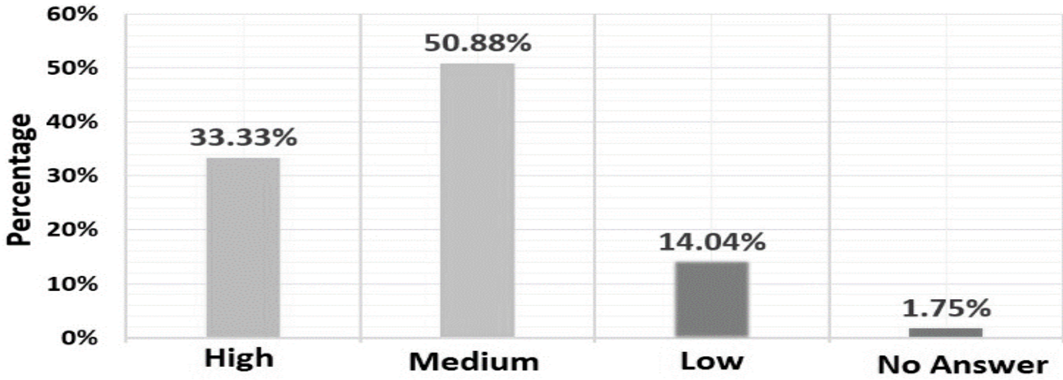

Figure 3. Knowledge about appropriate use of electrical energy

To the question: What day do you consume more electrical energy in your home?, Figure 4 shows that the highest electrical energy consumption is on weekend (Saturday and Sunday) by 77% users surveyed, which is one of inputs for more consumption period.

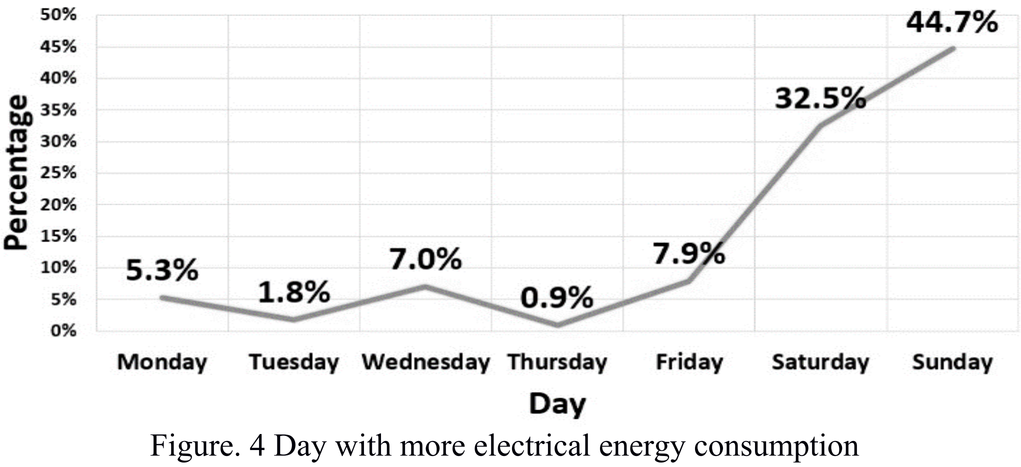

Figure. 4 Day with more electrical energy consumption

Regarding to behavior that users have compared to use lighting devices, it is observed that antiquity lightbulbs is between 2014 - 2016, that is to say that they are mainly compact fluorescent and in some cases LED type, as shown in Figure 5.

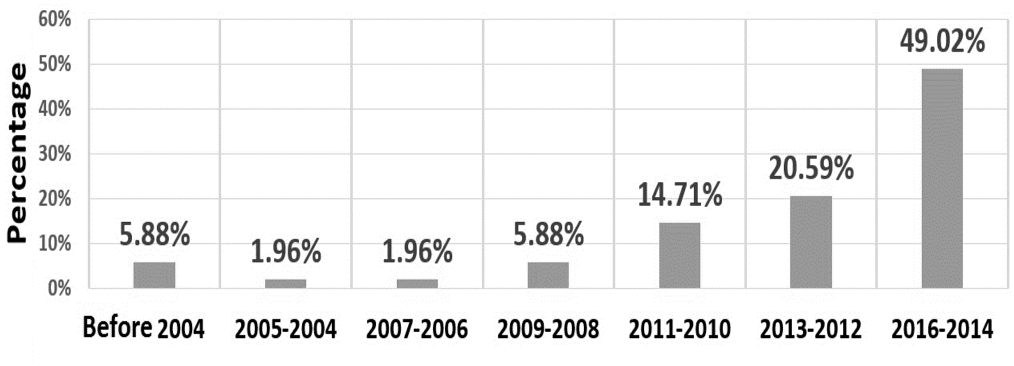

Figure. 5. Antiquity of lighting devices

B. Dynamic model proposed

Figure 6 presents a dynamic model example developed to establish the demand curve of devices group related with lighting in residences. It should be clarified that a sub-model was developed for each devices group involved in simulation.

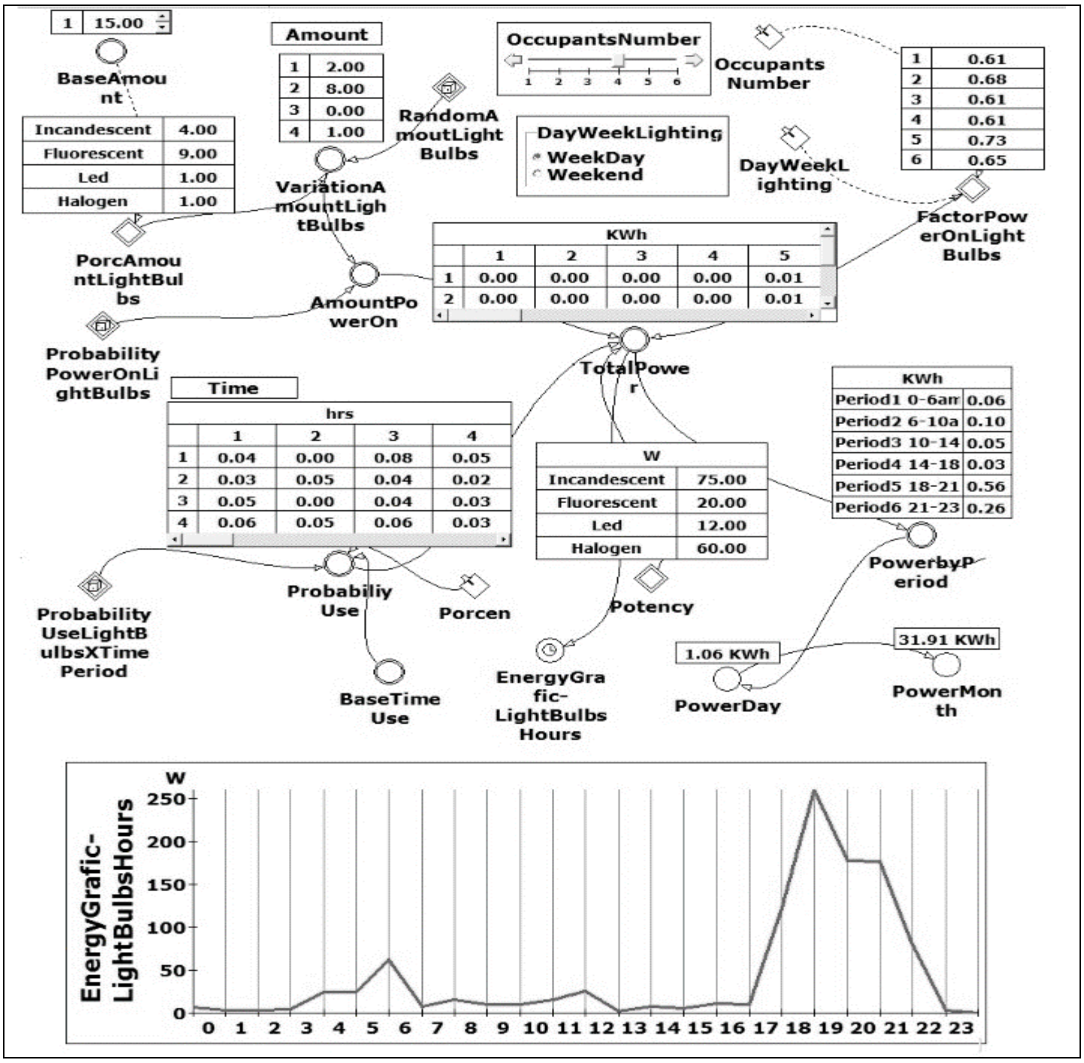

Figure 6. Sub- model for lighting devices group.

In the example of general simulation, the weekend was chosen and consumption was randomly varied in each one of the device groups analyzed. Similarly, sub-models proposed were fed by the percentages obtained from survey related to knowledge of resource, habitual behavior and behavior on users against the use electric energy, which varied 1% according to the average obtained through surveys applied. As a stochastic result processing applied to sub-models for eight devices groups the demand curve was determined for each of them through the consumer variation habits and knowledge management according to what was explained in section 4 (see Figure 7).

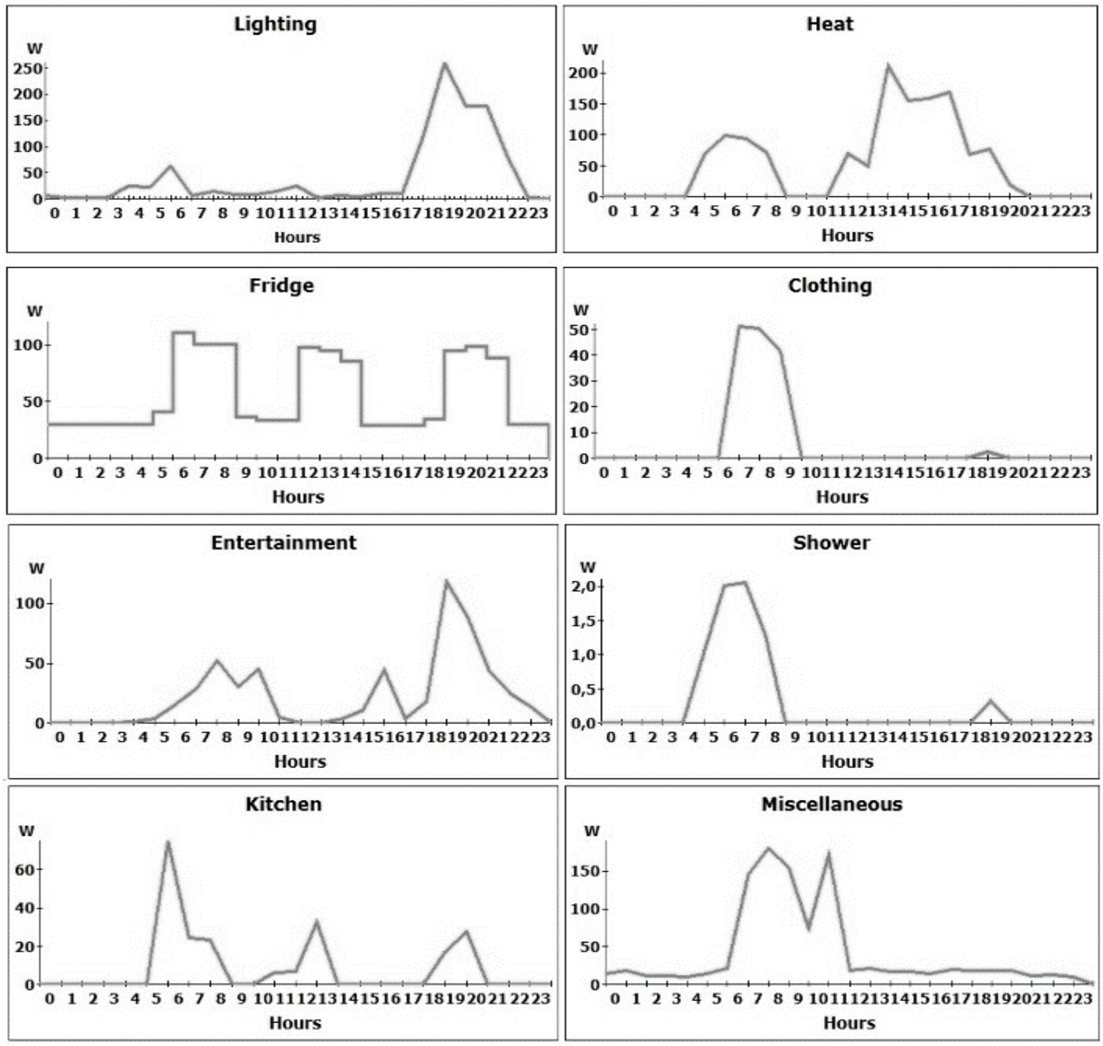

Figure 7. Simulation - Demand curve for each device groups.

In Figure 8 the consolidated consumption values are displayed by devices group, where daily and monthly consumption energy and their respective percentage is observed; as well as the total daily demand curve. In the simulation shown as example for this paper and according to variations made in consumption habits is obtained a consumption of 170,13 kWh, which allows to point out that model represents consumption of residential users from socioeconomic level 4, since average for this type of residential stratum is 175 kWh (Superintendencia de servicios públicos domiciliarios, 2016), and according to stochastic elements included in model there is a variation in consumption of 2.25%. It should be noted that each time that another simulation is performed with same parameters; the consumption is going to be different for stochastic nature of model proposed.

Consumption Appliances Groups

	Day Consum	% Day	Mount Energy
Lighting Energy	1,06 KWh	18,76 %	31,91 KWh
Fridge Energy	1,35 KWh	23,78 %	40,46 KWh
Entretainment Energy	0,55 KWh	9,70 %	16,50 KWh
Kitchen Energy	0,21 KWh	3,77 %	6,41 KWh
Heat Energy	1,31 KWh	23,17 %	39,41 KWh
Clothing Energy	0,15 KWh	2,57 %	4,36 KWh
Shower Energy	6,70e-3 KWh	0,12 %	0,20 KWh
Miscellaneous Energy	1,03 KWh	18,15 %	30,88 KWh
TOTAL ENERGY	**5,67 KWh**		**170,13 KWh**

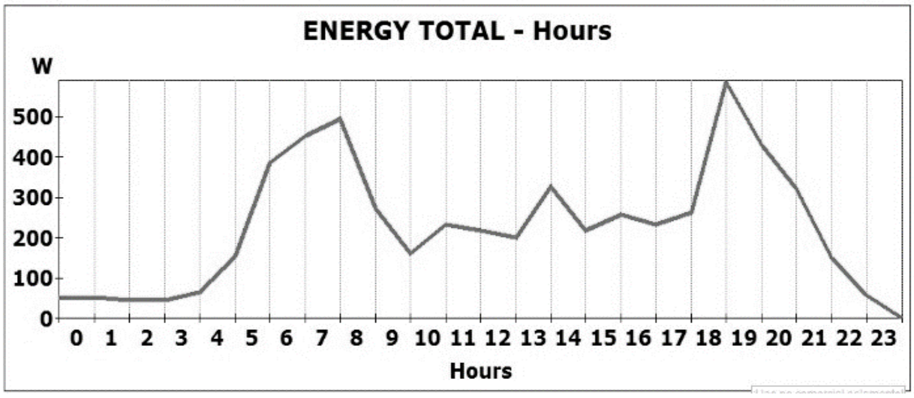

Figure 8. Demand curve all devices analyzed

Conclusions

The possibility of residential users that vary their electrical energy consumption habits has a direct impact on projection for demand curve; however this is achieved on aspects basis related to: knowledge of energy resource, habitual consumption behaviors and behavior on electric energy use. But such changes in consumption habits should be based on aspects related to incorporation of dynamic knowledge of energy resource and everything that surrounds it.

The model design is made through methodology application where there are two important aspects: theoretical reasons raised by different authors who have developed proposals for demand curves related to the consumption habits, knowledge management, and implementation of a survey in which data was obtained in a case study with different aspects based on consumption habits of socioeconomic level 4; according to the example given this methodology can be replicated to other leves and contributes to the same model developed.

In model development elements based on stochastic features were incorporated, which allows input data to be processed in a random way to obtain different demand curves according to variation in consumer habits parameters and knowledge management, so that can perform many simulations on the same parameters to present average power, and its standard deviation.

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