Department of Mechanical and Aerospace Engineering

Development of a simplified hourly electricity demand prediction model

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Signed: ***Francisco Ricardo Martínez Villalvazo*** Date: 07/09/12

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Abstract

Existing software to predict electricity demand profiles for a range of different households in a community requires a certain level of expertise to be operated as well as detailed, and extensive inputs that are difficult to obtain. The motivation of this thesis was to develop a tool capable of providing accurate electricity demand profiles for the domestic sector in small communities with a user-friendly interface, requiring the user to insert simple inputs.

The methodology followed for the creation of the proposed model was based on two main prediction techniques: a tariff-based method which investigates the idea of generating demand profiles from energy bills and different tariffs according to the time of use, and a bottom-up method that requires existing statistical information from the national census. Once both techniques were investigated and developed they were combined into a single excel tool which delivers the following outputs: seasonal electricity consumption, daily average electricity consumption per household and daily average electricity consumption according to household type.

A case study was then carried out in order to test the proposed model. The electricity consumption for the community of Atarjea, Guanajuato in Mexico was modelled for six different household scenarios. This community was chosen to be analyzed due to a series of factors including its location, weather, socioeconomic sector of the population, and essentially to support the Mexican government with their goals to gradually introduce renewable energy systems to provide small and isolated communities with their electricity demand.

The feasibility of the model was then validated by comparing existing real monitored data for the community's electricity consumption with the results obtained by the proposed tool. This was achieved by generating electricity demand curves for a certain group of households and comparing the percentage match between both of them. The proposed method proved to be reliable and capable of providing accurate electricity demand predictions for the domestic sector in small communities.

Table of Contents

List of Figures

List of Tables

1. Introduction

In the past 20 years, within the electricity sector in Mexico, one of the biggest problems has being to provide small isolated communities with this service. Big efforts had been made to construct the proper distribution system to reach these areas but sometimes without success. 2.4% of the total population in this country still has not access to electricity (CFE, 2012). Recently, the Mexican government has started to put special interest to the idea of introducing renewable energy systems to fulfil those communities with their total electricity demand. Since this field is not yet completely explored, the government wants to start with pilot projects in those communities to evaluate the feasibility of the introduction of those systems and at the same time as a way to start the reduction of carbon emissions in order to be more sustainable in the near future.

As a matter of fact, Mexico has a great potential for the development of wind and solar technologies due to its high wind speeds in the south of the country and the general high solar irradiation in almost all of its territory (NREL, 2003). The government's idea about testing new technologies with pilot projects sounds likely to be a good way to join the world's willing to become sustainable. However, renewable energy technologies are known for being intermittent, so a good knowledge of the demand in the domestic households in those communities is vital to plan the correct sizing of the systems.

The differential nature of electricity versus other vital supplies in our technological society is the fact that currently it cannot be stored on a large scale. From a practical point of view, electricity should be generated to match the consumption demand (no more, no less). This requires an accurate planning of the electricity production day after day to decide which power stations should run in order to match the demand.

Predicting hourly or sub-hourly energy demand profiles (electrical and thermal) is crucial for planning electricity distribution networks and optimal production capacity, likewise to assess the feasibility of new and renewable energy systems. Accurate knowledge of household consumer loads is important to optimally size small scale distributed energy technologies into the local network or also when measures on the local demand side management (DSM) are planned. This knowledge is also useful for planning medium and low voltage networks in residential areas.

The data that electric companies typically posses on domestic electricity consumption do not contain much information about this nature. Data is usually aggregated consumption of a series of households without a detailed focus in individual households. Therefore, the fluctuation of electricity consumption regarding a determined individual household remains unrevealed as well as the consumption's division between different types of household appliances. Nevertheless, detailed information can be produced with simulation models.

However, the existent methods to predict hourly demand profiles can be difficult to use for people that is not fully related to the field. Also, the majority of them are based on European electricity consumption and customer's behaviours, making it hard to have an accurate electricity demand prediction for small communities in Mexico. A recent research has shown that small communities in this country with populations ranging from 5000-10,000 inhabitants (composed by 1000-2500 households) have really similar electricity consumption patterns since the majority of them are located in rural areas under the same socioeconomic status (SEDESOL, 2008). That is one of the main reasons for the government to try to introduce renewable energy systems as pilot projects in that context in order to evaluate how good they can fit into the network without compromising a huge investment and associated risks.

For all the reasons explained above, the need for a tool capable of predicting accurate electricity demand profiles for domestic households in small communities in this country has raised as a motivation to help this developing country with its ambitions of providing more people access to electricity which is essential for the sustainable development of the population.

1.1 Scope and objectives

The main purpose of this thesis is the development of a user-friendly hourly electricity demand profile modeller tool with simple and limited inputs that can help to assess the feasibility of new and renewable energy systems in isolated communities in Mexican domestic buildings. This tool will be able to predict electricity demand profiles for six different types of households in Mexico, using existing statistics and energy tariffs as input data elements, with the idea for it to be expanded in the future to incorporate the industrial and government sector as well as adapting it to work for different countries.

Particular objectives of the thesis include:

- Review various techniques for generating electricity demand profiles in order to create a new excel tool that can be operated with simple and limited inputs and that can be capable of provide realistic and reliable electricity load profiles.

- Regenerate demand profiles from monthly energy bills taking into consideration the existing different tariffs according to the time of use.

- To try and validate the tool with existent simulated or monitored data from a determined isolated community in Mexico.

1.2 Outline structure

The work undertaken for this project is broken down into the following chapters:

1. Introduction

The scope and objectives of the project are described in this chapter as well as the motivation for pursuing this project.

2. Existing demand profile modellers

A literature review was carried out to understand the existent methods and investigations regarding the creation of electricity demand profiles.

3. *Developing the tool*

Also, a research on the electrical sector in Mexico and the different tariffs used to calculate the price of electricity was done since the main objective of thesis was to create a tool to predict accurate demand profiles from energy bills.

4. Developing the tool

In this chapter the methodology followed for the creation of the excel tool is described step by step. Two techniques were used to develop the tool, the first one is based on existing statistics and the second was just on different electricity tariffs according to the time of use.

5. Case study

In order to evaluate the functionality of the created tool, a case study was chosen and then the results were analysed and discussed. The community of Atarjea was picked between a few options because it fulfils all the requirements for which the tool is directed: the number of households, the location, the weather, but especially because it was possible to obtain measured data to validate the tool.

6. Validation of the tool

After obtaining the results, it was necessary to validate them by comparing them with existing monitored data in order to determine the feasibility of the results generated by the tool.

Chapter 7: Conclusions

Conclusions were drawn from the results of the analysis carried out and presented in this chapter.

Chapter 8: Further work

Even though the main objectives of the thesis were met, there are still a few recommendations to be made and further work to realize to expand the usage and utility of the proposed tool

2. Existing demand profile modellers

2.1 Different ways to predict energy demand profiles

The electricity demand models are often applied to forecast the demand at the utility level. There have been several investigations dealing with load profiles and domestic electricity consumptions all over the world. According to Gross and Galina, studies started to be conducted in the 70's and 80's. Recently, forecasting methods have been classified by (Aalfares & Nazeeruddin, 2002) where new methods including genetic algorithms, fuzzy logic, and networks (Hippert, et al., 2001) have been included in addition to the conventional econometric models (Pindyck & Rubinfeld, 1997). These kinds of forecasting methods are usually used when there is little or no knowledge about the appliance stocks and other grass-root level consumer details (Zarkinau, 2003).

As an alternative to the conventional ways to forecast electricity demand, end-use models represent a bottom-up demand modelling approach. The accuracy of these models is totally influenced on the availability of raw consumption details. An ideal case would be when the different appliances and their usage patterns in households are known and when the details about the structure of the load are valued, as in "Capasso model" (Capasso, et al., 1994). On the other hand, a bottom-up method presented by Willis in 2002 provides much less details on the individual consumer level, however it shows more details than the typical electric demand forecasting system (Willis, 2002).

The usual limitation for detailed bottom-up methods is a wide need of data about the household, the consumers and their appliances. Normally some part of this data is not easily available. In the Capasso model (Capasso, et al., 1994), detailed data is needed about the behaviour of the consumers. In addition to this behaviour, the Norwegian ERÅD model (Larsen & Nesbakken, 2002) also requires very detailed information about the composition and design of the flat in which the household is located. On the other hand, Sanchez applied his bottom-up model to big databases with partly complete or missing data (Sanchez, et al., 1998); therefore the accuracy of the results was compromised.

Another example of a way to predict energy demand profiles was introduced by R. Yao and K.A Steemers. The input data of the model was based mainly existing statistics, such as the composition of households and the average energy consumption of appliances per household and per capita. The UK average size household was selected as an example of the implication of this method. Daily and overall profiles were generated for the dwellings from the data as well as annual energy consumptions. A survey was undertaken among the people living in the monitored households in order to create a link between the energy consumption profiles and socioeconomic factors. The monitored households were categorised on the subject of number of occupants, ownership of appliances and number of occupants (Yao & Steemers, 2005).

3. Electricity in Mexico

The generation of electricity started in Mexico by the end of XIX century and the first plant was installed in 1879 and it was used to provide electricity to a textile factory, but it was not until 1889 when the first hydroelectric plant was running and providing electricity to big cities. A few years later, three big international companies came to Mexico and started introducing this service to more parts in this country, nevertheless in 1937 Mexico had 18.3 millions of habitants and only 7 millions counted with electricity (CFE, 2012). By that time the installed capacity was 629 MW and the international companies fulfilling the electricity demand were experiencing a lot of problems, as a consequence the government decided to create an organism called the “Federal Electricity Commission (CFE)” to develop a better national system of generation, transmission and distribution of electrical energy. CFE started to construct new generation plants and to extend the transmission and distribution lines causing a considerable increment to 44% of the population benefited with this service by 1960 (CFE, 2012). A big decision was made then by the government stating that the electrical system must be nationalized and therefore the National Electrical System was considered as a priority.

3.1 National electrical system

The national electrical system is strategic for Mexico’s national sovereignty. Article 27 of the Mexican Constitution officially designates electricity generation, transmission, supply and distribution as public services. They were all considered to be sovereign activities (“exclusive responsibility of the nation”) and as a consequence solely under the domain of the Federal government. Until 1992, private companies were not allowed to contribute in electricity generation, except for self supply for use on their own premises (Secretaría de Energia SENER, 2010).

In 1975, the LSPEE or Law of Public Service of Electricity (Ley del Servicio Público de Energía Eléctrica) was established. This law officially stated that only two state-owned electric companies, Compañía de Luz y Fuerza del Centro (LyFC) and Comisión Federal de Electricidad (CFE), were to be the sole public suppliers of electricity. (However, due to financial difficulties, LyFC was taken over by CFE in the second half of 2009.) (Secretaría de Energia SENER, 2010). Through the mid-1990s, the country experienced a number of economic crises, each of which was followed by strong restrictions on public debt. As a consequence, CFE’s ability to expand its capacity in order to meet the increasing demand was limited. In response, the Mexican government began to promote private sector investment in capacity expansion. To achieve that, the LSPEE had to been amended in 1992 to allow the private companies to participate in electricity generation in the form of (Secretaría de Energia SENER, 2010):

1. Self-supply. Is the generation of electricity for self-supply purposes intended to meet the needs of individuals or companies without being an inconvenient for the country.
2. Co-generation.
3. Independent power producers (IPPs). It is the generation of electricity in plants with installed capacity greater than 30 MW; they must sell their total generated electricity to CFE.
4. Small producers. Is the electricity generated designated for various purposes such as to sell it to CFE (maximum 30MW), to self-supply small and isolated communities that lack of electricity service (maximum 1MW) and generation for export (maximum 30MW)
5. Generation for exportation. Electricity generated for exporting purposes, it can be in any of the three modalities: co-generation, small producers and independent power producers. They must fulfil all the legal requirements.

The reforms in the mid 1990s took a while to bear fruit, but at the end were successful in driving growth in the capacity of private sector. The first independent power producer began operation in 2000, and the IPP program accelerated rapidly after that. By 2002, about half of the new capacity came from IPPs, and a significant fraction resulted from self suppliers seeking to lock-in long-term power contracts at a lower price than the rates charged by CFE. Only about one third of the new capacity in these years was built directly by the public sector. The majority of this new capacity, both private and public, was produced by natural gas. (Secretaría de Energia SENER, 2010)

3.2 National electricity generation

According to the Secretariat of Energy (SENER) (Secretaría de Energia SENER, 2010) by the end of 2009, the total electricity generation was 268,200GWh of which 58.5% was generated by CFE, 29.1% by the IPPs, 4.6% by cogeneration, 4.8% came from self-supply customers, and 3% was generated for exportation. The total generation of electricity for the public sector in the period of 1999-2009 is analyzed in Fig. 1 (CFE, 2012). A salient feature is the gradual replacement of conventional thermoelectric plants by combined cycle plants for electricity generation during this period; combined cycle generation capacity has been growing through the years until present times due to its greater efficiency and consequently lower emissions of greenhouse gases. From the 58.5% of electricity generated by CFE, 68.9% came from fossil fuels and only 14.2% from renewable energy sources.

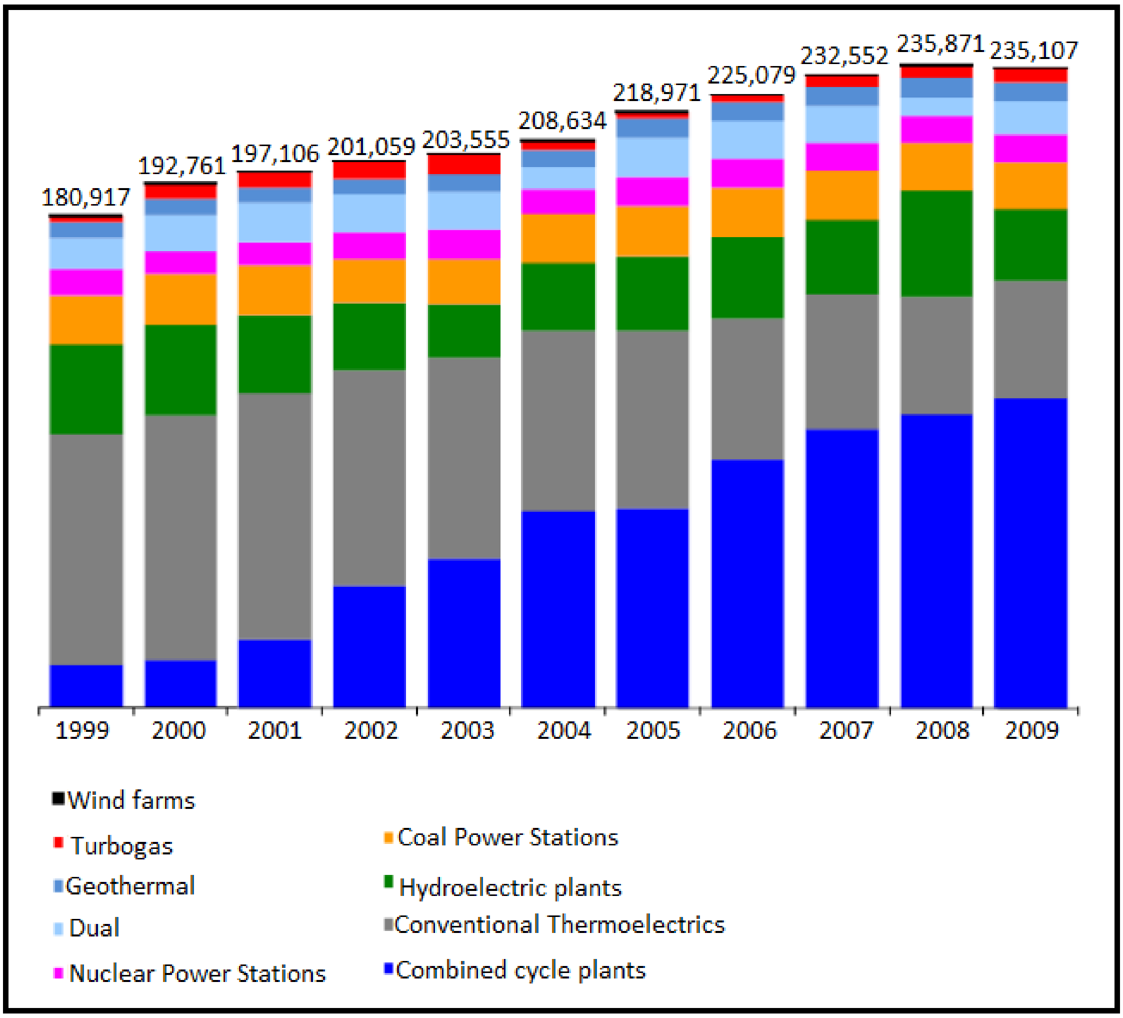


Figure 1. Total electricity (GWh) generation by source of generation for the public sector in the period of 1999-2009 in Mexico. (CFE, 2012)

According to SENER (Secretaría de Energia SENER, 2010), CFE's installed capacity for electricity generation will have a total increment of 26,562 MW which correspond to the 51.4% of the current generation capacity (Fig. 2). It will pass from being 51,686MW to 78,248MW in 2025. The most relevant fact in this projection is the installation of wind farms in the south east of Mexico. Renewable energy systems will be introduced gradually after an exhaust research of their potential has been carried out according to the current legal framework. A big pilot is being planned to generate 5MW by solar PV in the north-east of the country, it is well known that solar irradiation in Mexico is more than optimum and therefore PV panels can be a huge opportunity in the future electricity generation.

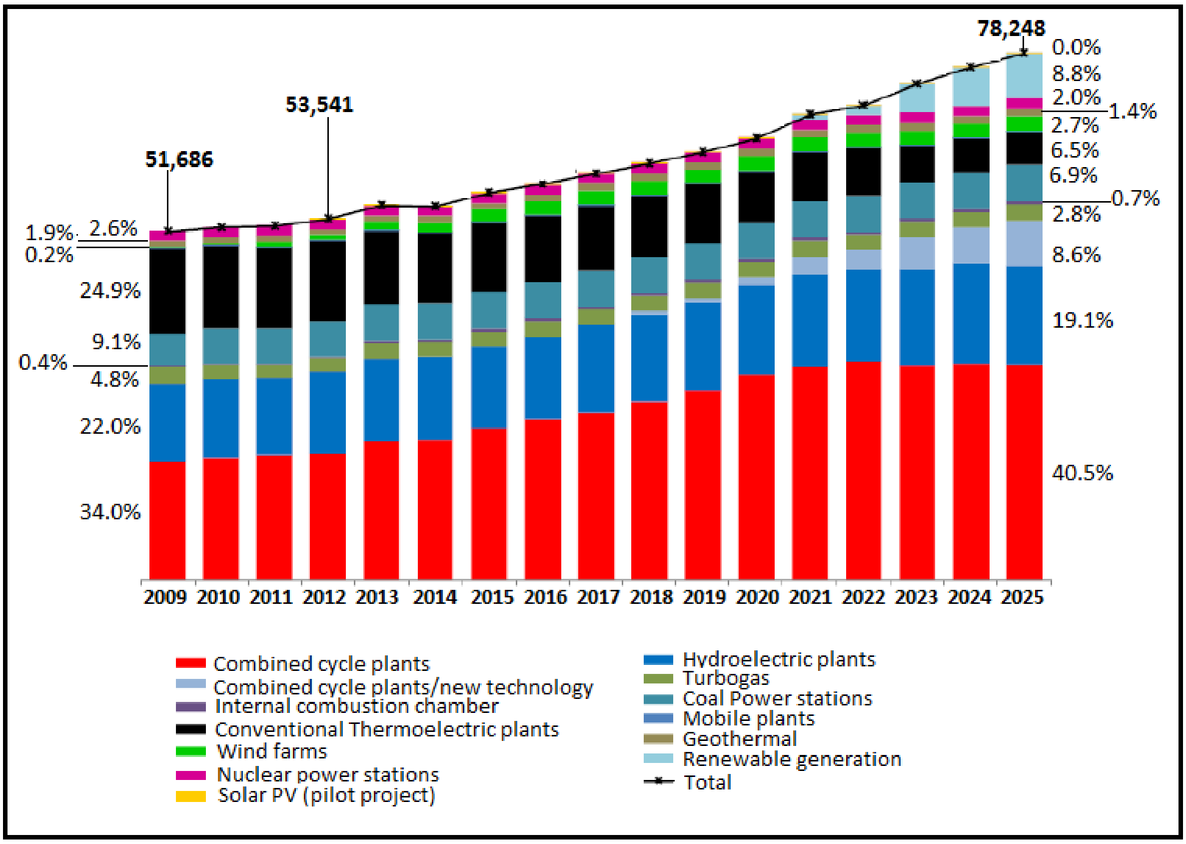


Figure 2. Installed capacity projection by technology source for the production of electricity (MW) in Mexico in the period of 2009-2025. (CFE, 2012)

3.3 Federal electricity commission (CFE)

As commented before, The Federal Electricity Commission (CFE) is a company created and owned by the Mexican government. CFE has the monopoly for generation, transmission, supply and distribution of electricity in Mexico. Nowadays, CFE provides electrical energy to more than 35.9 millions of customers which represent 100 million people and it incorporates more than a million new customers every year. The infrastructure to generate electrical energy is formed by 214 centrals with an installed capacity of 52,862 MW (Fig. 3) from which 71 are hydroelectric plants, 22 thermoelectric, 7 geothermal, two coal power stations, one nuclear power station, only one wind farm in Oaxaca, 54 gas power stations and 14 combined cycle plants (CFE, 2012).

From the total installed capacity, nearby 26% comes from renewable energy. Most of this percentage comes from large hydro. The other forms of renewable energy are wind power, geothermal, biomass and biogas (Fig 4). Also, a lot of efforts have been made to provide isolated communities with photovoltaic modules; PV is likely to be the most useful application in the future to provide electricity to all those small communities in Mexico

On the other hand, only 23.70% of CFE's installed capacity sterns from 25 plants which were built using private capital by Independent Power Producers (IPP). By the end of year 2010 the electricity supply reached more than 190,000 locations covering the 97.60% of the total population for this country (CFE, 2012). In order to take the power from its generating plants to the household of each one of its customers, the CFE has more than 762,000 Km. of power lines that transmit and distribute electric power. The electricity market is composed by nine interconnections between USA and Mexico and one interconnection with Belize. These interconnections have been used principally to import and export electricity just in emergency cases.

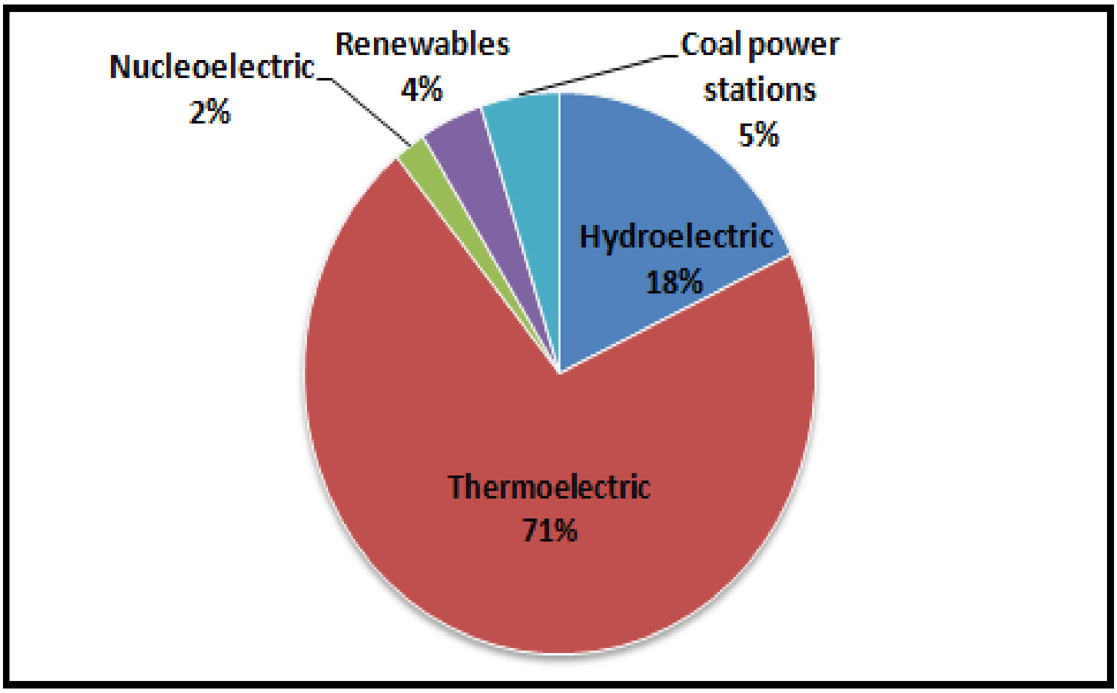


Figure 3. CFE's installed capacity by generating entity. (CFE, 2012)

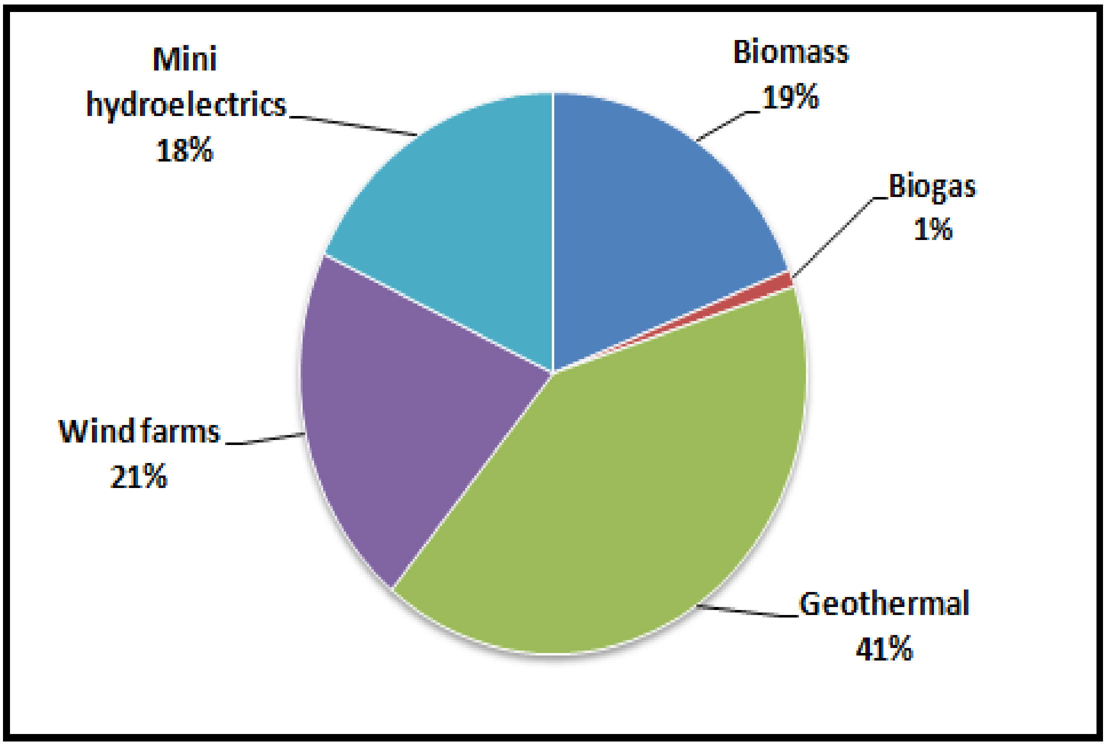


Figure 4.CFE's installed capacity by renewable energy systems excluding large hydro. (CFE, 2012)

3.4 Electricity tariffs

At the present time there are 37 electricity tariffs in Mexico and they can be classified as: specific (7 domestic, 3 for public services, 4 for agricultural irrigation and one for temporal service) and general usages (12 for high tension, 6 for medium tension and 2 for low tension) (Table 1).

Table 1. Electricity tariffs in Mexico. (Comisión Federal de Electricidad, 2012)

TARIFF	DESCRIPTION
1	Domestic service: 1, 1A, 1B, 1C, 1D, 1E, DAC
2	General service for demand up to 25kW
3	General service for demand of more than 25Kw
5, 5ª	Service for street lighting
6	Service for public water pumping
7	Temporal service
9	Service for water pumping in agricultural irrigation
O-M	Ordinary tariff for general service in medium tension for demand less tan 100kW.
H-M	Hourly tariff for general service in medium tension for demand higher than 100kW.
H-MC	Hourly tariff for general service in medium tension for demand higher tan 100kW for short utilization.
H-S, H-T, H-SL, H-TL	Hourly tariffs for general services in high tension
HM-R, HM-RF, HM-RM, HS-R, HS-RF, HS-RM, HT-R, HT-RF, HT-RM	Hourly tariffs for backup services.
I15, I30	Tariff for general usage for interruptible services. (For more than 7000 kW)

3.5 Electricity tariffs in Mexico: Domestic households

The Federal Electricity Commission (CFE) has established 8 different tariffs for domestic electricity consumption, of which seven are applied to different regions in the country according to the average minimum temperature in summer. (Table 2)

Moreover, each of the 7 tariffs mentioned above are sub classified in two categories according to different consumption limits. The first category includes basic and medium consumption while the second category adds one more type called excess consumption. Therefore, energy bills are calculated differently for every city within Mexican territory. For example: a city located in the north of Mexico, where temperatures are higher than in many parts of the country, is likely to have a higher electricity consumption (due to refrigeration, air conditioned, etc) than a city located in the centre.

8th tariff does not depend on the local average minimum temperatures but on the kind of consumption. This tariff is called "high consumption domestic tariff", better known as DAC; it is applied when a determined household exceeds the average monthly consumption limit established for its location during the last 12 months. When a household joins this tariff it is likely to pay more than the double for electricity than customers under normal tariffs.

Table 2. Electricity tariffs in Mexico excluding tariff DAC. (Comisión Federal de Electricidad, 2012)

TARIFF	LOCATIONS WITH AVERAGE SUMMER TEMPERATURE OF:
1	< 25° C
1A	≥ 25° C < 28° C
1B	≥ 28° C < 30° C
1C	30° C
1D	31° C
1E	32° C
1F	≥ 33° C

3.6 Electricity bill for a household in Mexico

Since one of the objectives of this thesis is to predict hourly electrical demand profiles for domestic households, it is important to illustrate the way a normal electricity bill is composed in Mexico (Fig. 5). The elements of the electricity bill are provided as well as a brief description of them.

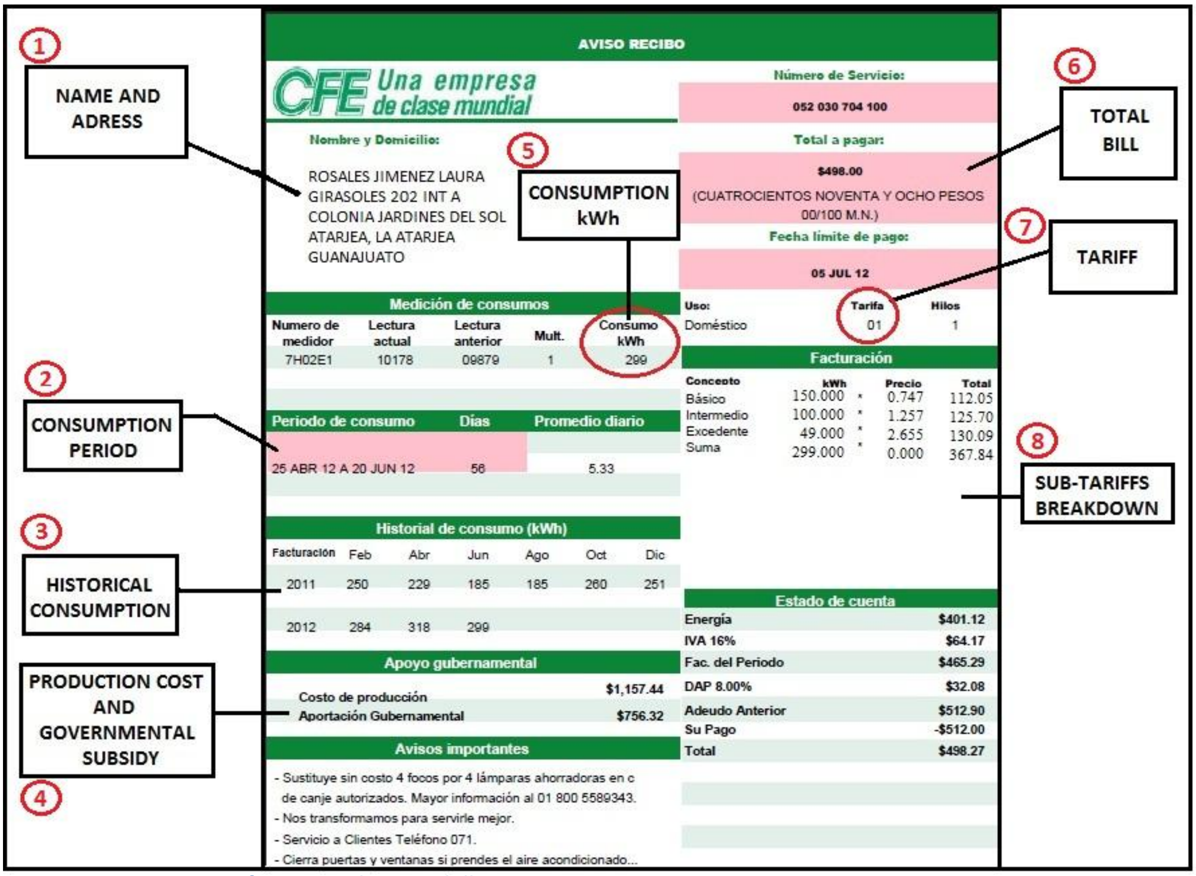


Figure 5. Description for a typical energy bill in Mexico

1. *Name and address*: Customer's name and address are displayed here.

2. *Consumption period*: The period in which electricity was consumed. For domestic households it is always a 2 month period. When it comes to businesses and industrial sector the consumption period is always 1 month.

3. *Historical consumption*: This part of the energy bill shows a historical consumption for the household which also works as a way to compare the actual consumption

period versus the one in the last year. This part contains historical information for at least 1 year.

4. *Production cost and governmental subsidy:* This area provides the customer with the real cost of electricity consumed and the subsidy given by the government. This subsidy can be as high as 85% and it depends on the amount of energy consumed and on the tariff assigned to the household. For example: The energy bill of a bimonthly consumption of 280 kWh in “tariff 1” will be subsidized by 82% while a consumption of 281 kWh under the same tariff will only acquire a 65% subsidy.

5. *Consumption (kWh):* Is the total energy consumed during 2 months by the household or during 1 month if the customer is an industry or business.

6. *Total bill*: This is total price that the customer has to pay for the electricity consumed in the specified period of time. This total includes taxes (16% VAT).

7. *Tariff:* There are several different tariffs that are applied according to the average temperature over a year in the place where the household is located. A city in the north of Mexico will have a different tariff than another one located in the south of the country. Every tariff is divided in sub-tariffs: Basic, Medium and Excess.

8. *Sub-tariffs breakdown*: A breakdown of the tariff and sub-tariffs is provided in this part of the energy bill. The calculation of how the total amount to be paid is calculated is shown here.

3.7 Tariff 1: Locations with average medium temperature in summer of less than 25 degrees Celcius

This tariff is applied to all residences, apartments or condominiums that are allocated energy for domestic use only and which loads are not considered as high consumption according to tariff DAC. When the average monthly consumption registered during the past 12 months exceeds 500kWh/month, the household will be reclassified to tariff DAC. Season does not matter for pricing electricity under this scheme. (Comisión Federal de Electricidad, 2012)

<u>Sub classification 1</u>

This sub classification applies when households under tariff 1 consume less than 280 kWh bimonthly. The first 150 kWh consumed are charged as basic consumption while the rest are priced under the medium consumption scheme (Fig. 6). It can be observed that the price for medium sub tariff is much higher compared to basic consumption.

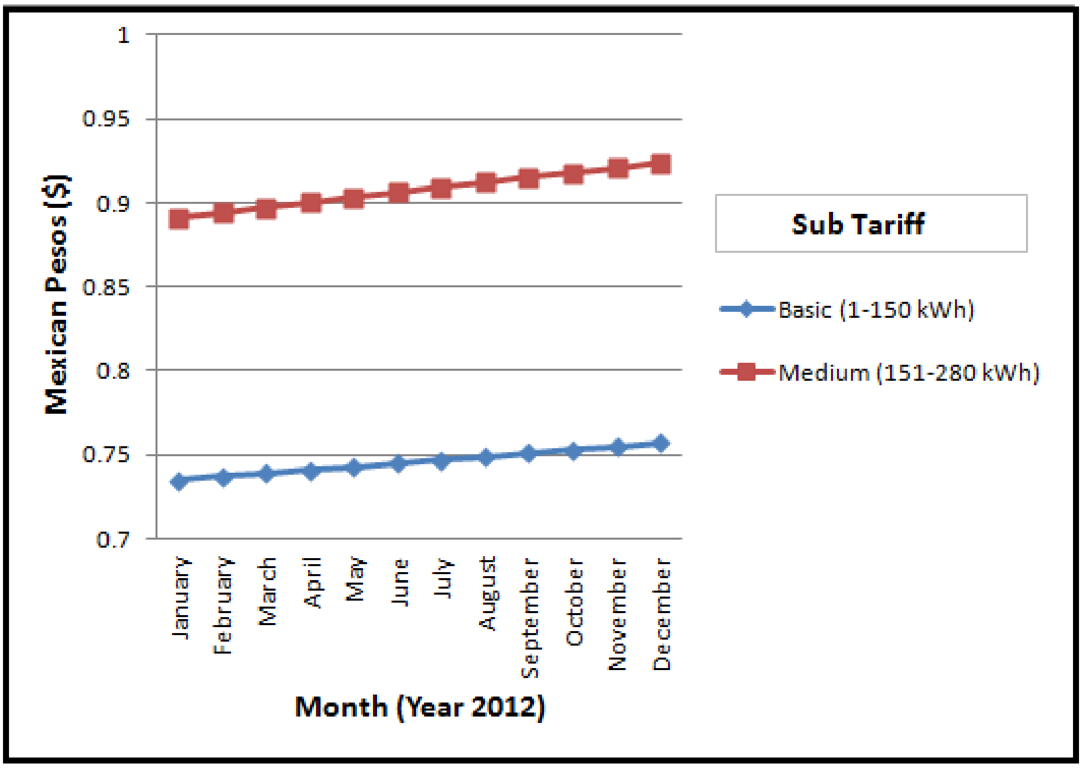


Figure 6. Price of electricity per kWh for bimonthly consumptions below 280 kWh. (Comisión Federal de Electricidad, 2012)

Sub classification 2

Households under tariff 1 that consume more than 280 kWh bimonthly are allocated to sub classification 2. In this case the first 150 kWh consumed are charged as basic consumption, from 151-250 kWh are priced as medium consumption, while the rest are charged as excess consumption (Fig. 7).

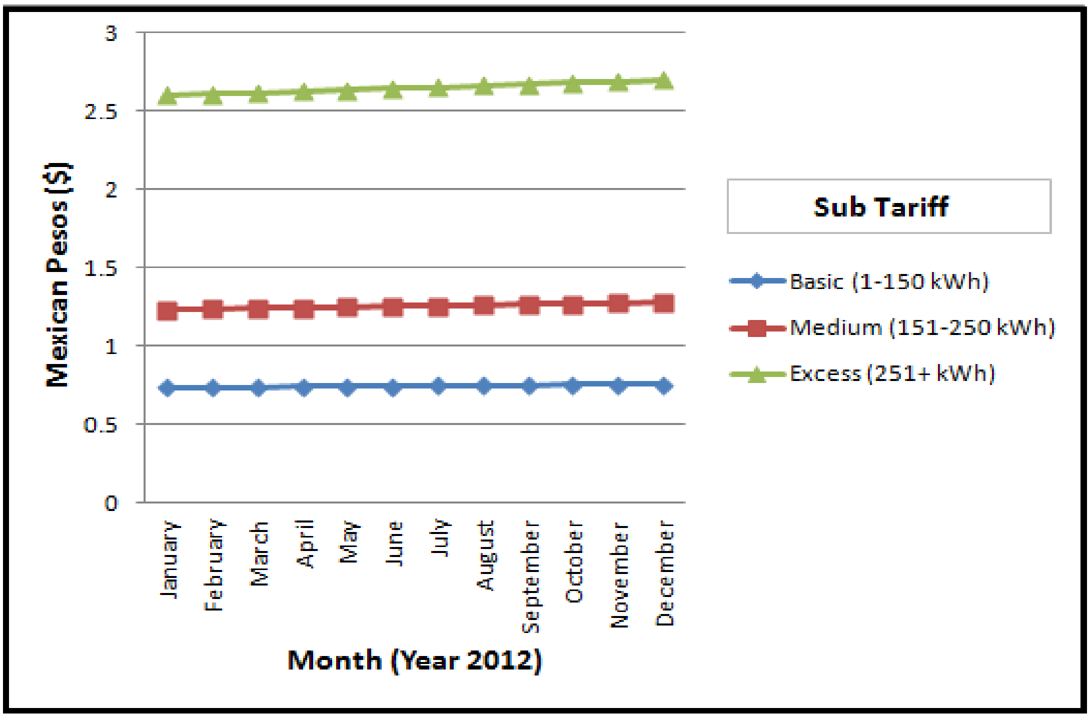


Figure 7. Price of electricity per kWh for bimonthly consumptions above 280 kWh. (Comisión Federal de Electricidad, 2012)

Example of energy bills under tariff 1

Table 3. Electricity bill breakdown for a two adult's household under tariff 1 in Salamanca, Mexico

Consumption period:	**May 25th to July 20th 2012**			
Consumption (kWh):	**299**			
Sub Classification:	**2**			
Sub-tariff breakdown:	**Sub Tariff**	**kWh**	**Price**	**Total(MXN)**
	Basic	150	0.747	$112.05
	Medium	100	1.257	$125.70
	Excess	49	2.655	$130.00
Total bill including taxes:	**$426.70 MXN**			

3.8 Tariff 1A: For locations with average medium temperature in summer of ≥ 25° C < 28° C

This tariff applies for households located in places where the average minimum temperature in summer ranges from 25° C to 28° C. When the average monthly consumption registered during the past 12 months exceeds 600kWh/month, the household will be reclassified to tariff DAC. Unlike tariff 1, the price for electricity under this tariff varies according to the season of the year and also according to the amount of energy consumed; there are only two seasons considered: winter and summer (6 months each). A summary of how households are charged under this tariff is provided below (Table 4 and 5):

Table 4. Description of tariff 1A during the summer season. (Comisión Federal de Electricidad, 2012)

SEASON:	SUMMER	
Sub classification:	1	2
Consumption:	Up to 300 kWh bimonthly	More than 300 kWh bimonthly
Tariff/Range:		
Basic:	1-200 kWh	1-200 kWh
Medium:	201-300 kWh	201-300 kWh
Excess:	NA	301+ kWh

Table 5.Description of tariff 1A during the winter season. (Comisión Federal de Electricidad, 2012)

SEASON:	WINTER	
Sub classification:	3	4
Consumption:	Up to 280 kWh bimonthly	More than 280 kWh bimonthly
Tariff/Range:		
Basic:	1-150 kWh	1-150 kWh
Medium:	151-280 kWh	151-250 kWh
Excess:	NA	251+ kWh

The cost per kWh varies with the season and within the ranges of consumption. Sub classifications 1 and 3 are charged with basic and medium sub tariff (Fig. 8). While sub classification 2 and 4 also include the excess sub-tariff (Fig. 9)

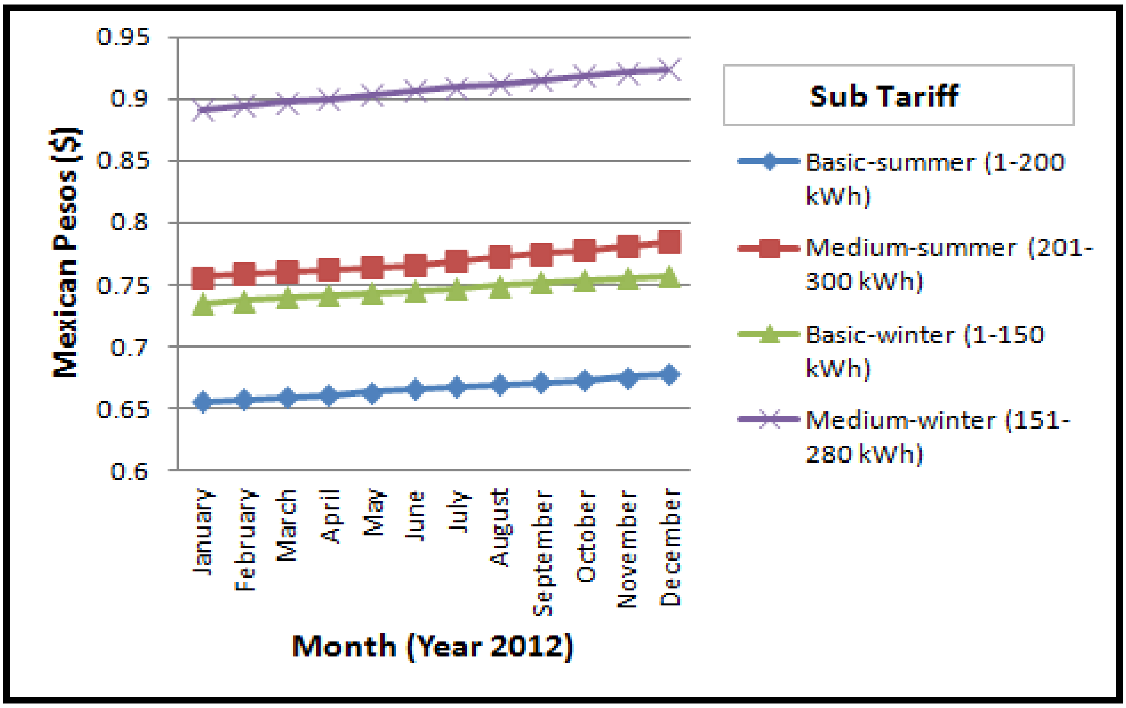


Figure 8. Price of electricity per kWh in tariff 1A for sub classifications 1 and 3. (Comisión Federal de Electricidad, 2012)

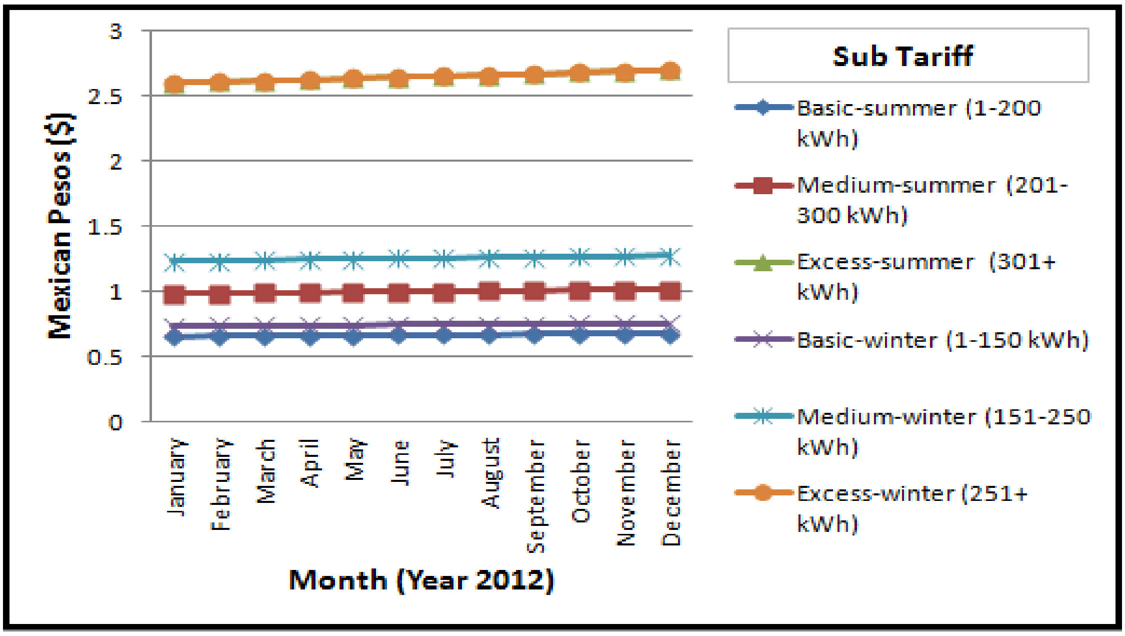


Figure 9. Price of electricity per kWh in tariff 1A for sub classifications 2 and 4. (Comisión Federal de Electricidad, 2012)

3.9 Tariff 1B: For locations with average medium temperature in summer of ≥ 28° C < 30° C

This tariff applies for households located in places where the average minimum temperature in summer ranges from 28° C to 30° C. This tariff is likely to be present in central north Mexico in states like San Luis Potosi or Zacatecas. When the average monthly consumption registered during the past 12 months exceeds 800kWh/month, the household will be reclassified to tariff DAC. As well as tariff 1A, this tariff uses the same structure to price the electricity. (Table 6 and 7):

Table 6.Description of tariff 1B during the summer season. (Comisión Federal de Electricidad, 2012)

SEASON:	SUMMER	
Sub classification:	1	2
Consumption:	Up to 450 kWh bimonthly	More than 450 kWh bimonthly
Tariff/Range:		
Basic:	1-250 kWh	1-200 kWh
Medium:	251-450 kWh	251-400 kWh
Excess:	NA	401+ kWh

Table 7.Description of tariff 1B during the winter season. (Comisión Federal de Electricidad, 2012)

SEASON:	WINTER	
Sub classification:	3	4
Consumption:	Up to 350 kWh bimonthly	More than 350 kWh bimonthly
Tariff/Range:		
Basic:	1-150 kWh	1-150 kWh
Medium:	151-350 kWh	151-300 kWh
Excess:	NA	301+ kWh

The cost per kWh varies with the season and within the ranges of consumption. Sub classifications 1 and 3 are charged with basic and medium sub tariff with a different cost between winter and summer (Fig. 10).While sub classifications 2 and 4 also include the excess sub-tariff. (Fig. 11).

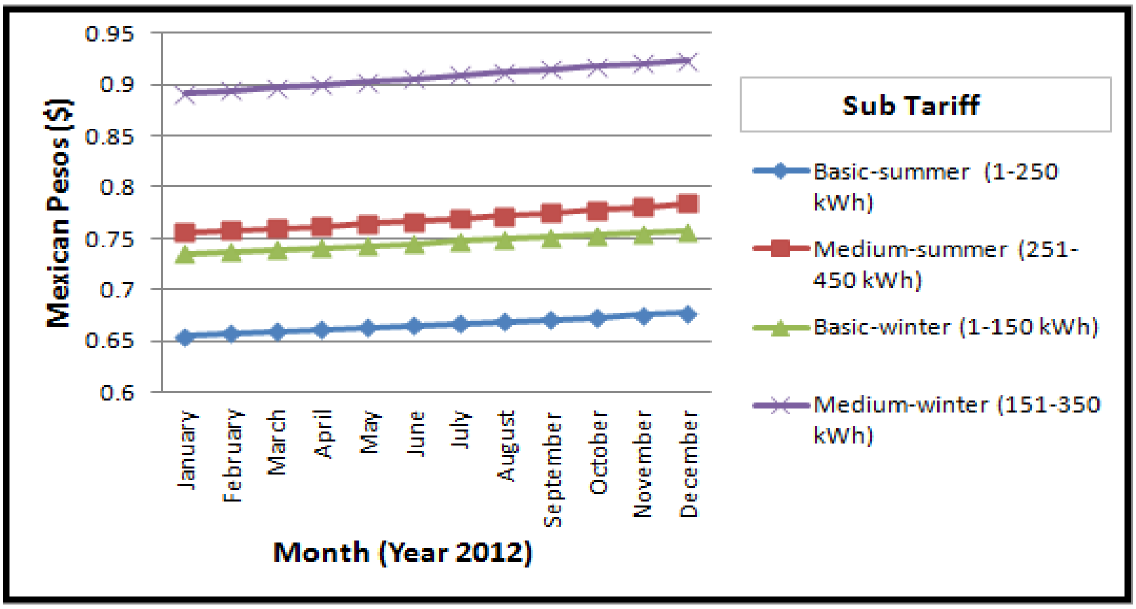


Figure 10. Price of electricity per kWh in tariff 1B for sub classifications 1 and 3. (Comisión Federal de Electricidad, 2012)

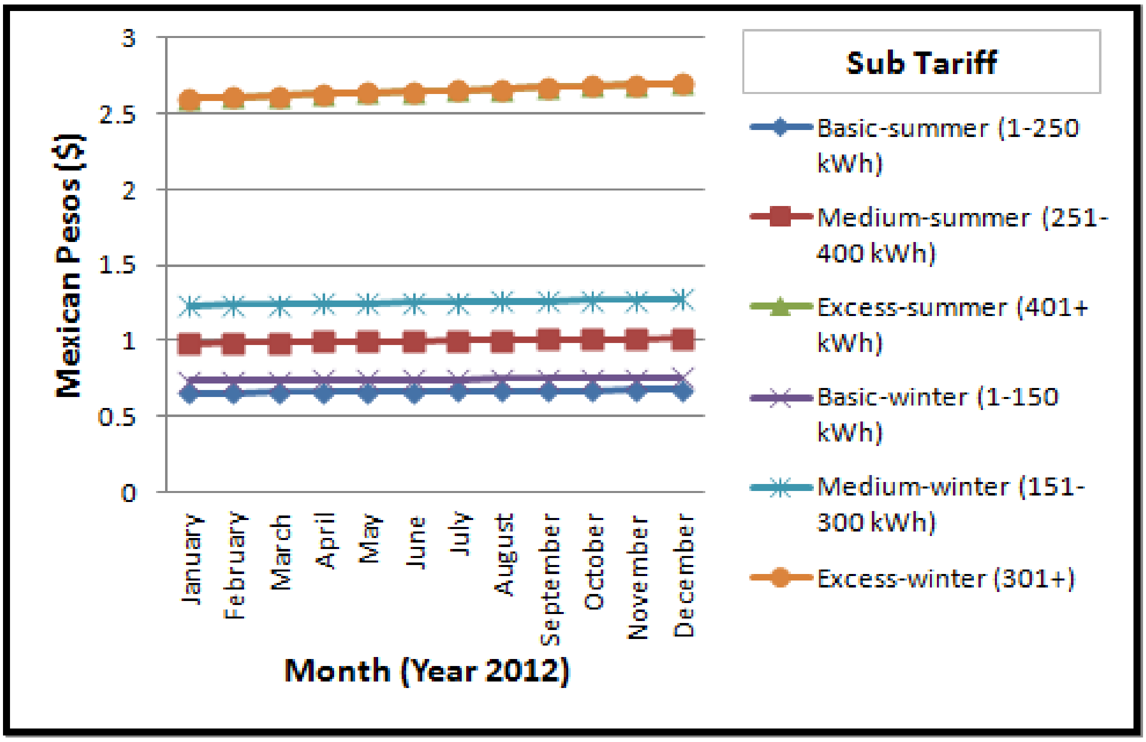


Figure 11. Price of electricity per kWh in tariff 1B for sub classifications 2 and 4. (Comisión Federal de Electricidad, 2012)

3.10 Tariffs 1C, 1D, 1E, 1F

In tariffs 1C, 1D, 1E and 1F the price for electricity varies according to the season of the year and also according to the amount of energy consumed; there are only two seasons considered: winter and summer (6 months each).

3.11Tariff 1C: For locations with average medium temperature in summer of 30° C

When the average monthly consumption registered during the past 12 months exceeds 1700kWh/month, the household will be reclassified to tariff DAC. A description of how is electricity is charged under this tariff is provided in (Tables 8 and 9)

Table 8. Description of tariff 1C during the summer season. (Comisión Federal de Electricidad, 2012)

SEASON:	SUMMER	
Sub classification:	1	2
Consumption:	Up to 600 kWh bimonthly	More than 600 kWh bimonthly
Tariff/Range:		
Basic:	1-300 kWh	1-300 kWh
Medium:	301-600 kWh	301-900 kWh
Excess:	NA	901+ kWh

Table 9. Description of tariff 1C during the winter season. (Comisión Federal de Electricidad, 2012)

SEASON:	WINTER	
Sub classification:	3	4
Consumption:	Up to 350 kWh bimonthly	More than 350 kWh bimonthly
Tariff/Range:		
Basic:	1-150 kWh	1-150 kWh
Medium:	151-350 kWh	151-300 kWh
Excess:	NA	301+ kWh

3.12 Tariff 1D: For locations with average medium temperature in summer of 31° C

When the average monthly consumption registered during the past 12 months exceeds 2000kWh/month, the household will be reclassified to tariff DAC. A description of how is electricity is charged under this tariff is provided in (Tables 10 and 11)

Table 10.Description of tariff 1D during the summer season. (Comisión Federal de Electricidad, 2012)

SEASON:	SUMMER	
Sub classification:	1	2
Consumption:	Up to 800 kWh bimonthly	More than 800 kWh bimonthly
Tariff/Range:		
Basic:	1-350 kWh	1-350 kWh
Medium:	351-800 kWh	351-1200 kWh
Excess:	NA	1201+ kWh

Table 11.Description of tariff 1D during the winter season. (Comisión Federal de Electricidad, 2012)

SEASON:	WINTER	
Sub classification:	3	4
Consumption:	Up to 400 kWh bimonthly	More than 400 kWh bimonthly
Tariff/Range:		
Basic:	1-150 kWh	1-150 kWh
Medium:	151-400 kWh	151-350 kWh
Excess:	NA	351+ kWh

3.13 Tariff 1E: For locations with average medium temperature in summer of 32° C

When the average monthly consumption registered during the past 12 months exceeds 4000kWh/month, the household will be reclassified to tariff DAC. A description of how is electricity is charged under this tariff is provided in (Tables 12 and 13)

Table 12.Description of tariff 1E during the summer season. (Comisión Federal de Electricidad, 2012)

SEASON:	**SUMMER**	
Sub classification:	1	2
Consumption:	Up to 1500 kWh bimonthly	More than 1500 kWh bimonthly
Tariff/Range:		
Basic:	1-600 kWh	1-600 kWh
Medium:	601-1500 kWh	601-1800 kWh
Excess:	NA	1801+ kWh

Table 13.Description of tariff 1E during the winter season. (Comisión Federal de Electricidad, 2012)

SEASON:	**WINTER**	
Sub classification:	3	4
Consumption:	Up to 500 kWh bimonthly	More than 500 kWh bimonthly
Tariff/Range:		
Basic:	1-150 kWh	1-150 kWh
Medium:	151-400 kWh	151-400 kWh
Excess:	401+ kWh	401+ kWh

3.14 Tariff 1F: For locations with average medium temperature in summer of 33° C

When the average monthly consumption registered during the past 12 months exceeds 5000kWh/month, the household will be reclassified to tariff DAC. A description of how is electricity is charged under this tariff is provided (Tables 14 and 15)

Table 14.Description of tariff 1F during the summer season. (Comisión Federal de Electricidad, 2012)

SEASON:	SUMMER	
Sub classification:	1	2
Consumption:	Up to 2400 kWh bimonthly	More than 2400 kWh bimonthly
Tariff/Range:		
Basic:	1-600 kWh	1-600 kWh
Medium low:	601-2400 kWh	601-2400 kWh
Medium high:	NA	2401-5000 kWh
Excess:	NA	5001+ kWh

Table 15.Description of tariff 1F during the winter season. (Comisión Federal de Electricidad, 2012)

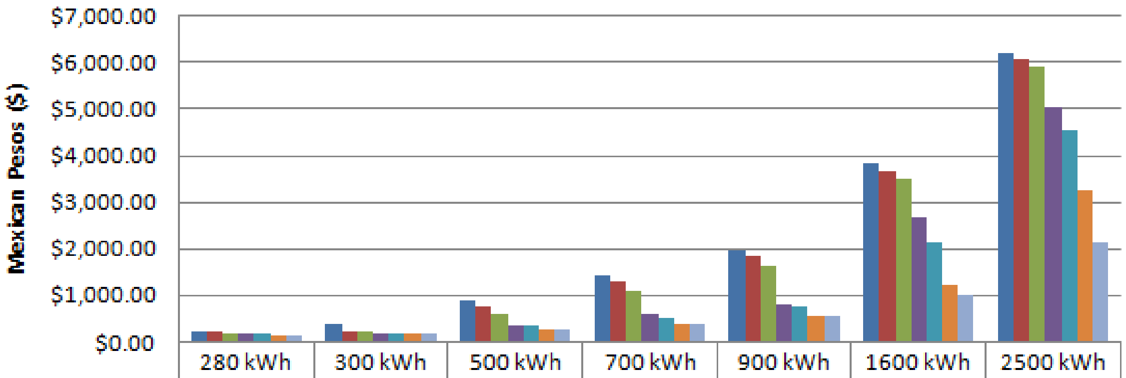
SEASON:	WINTER	
Sub classification:	3	4
Consumption:	Up to 500 kWh bimonthly	More than 500 kWh bimonthly
Tariff/Range:		
Basic:	1-150 kWh	1-150 kWh
Medium:	151-400 kWh	151-400 kWh
Excess:	401+ kWh	401+ kWh

3.15 Subsidies

Mexico has huge direct and hidden electricity subsidies. Nevertheless, not every sector receives a subsidy. Electricity prices for the industrial and commercial sectors are charged very rational and therefore they do not receive any subsidy. On the other hand, the domestic and agricultural sectors are benefited with sometimes massive subsidies. This thesis is focused in the domestic sector only where the average electricity price for households in Mexico is $0.0888 USD/kWh (IEA, 2011a), only three other Latin American countries: Argentina, Paraguay and Ecuador have electricity tariffs below $0.5 USD/kWh (IEA, 2011a). During the last decade, electricity tariffs for the domestic sector have been under the real cost, this with the finality of maintaining the economic and social stability of the country. In 2009 for example, the average domestic tariff accounted only to the 43% of the real electricity production cost (International Bank of Reconstruction and Development, 2005).

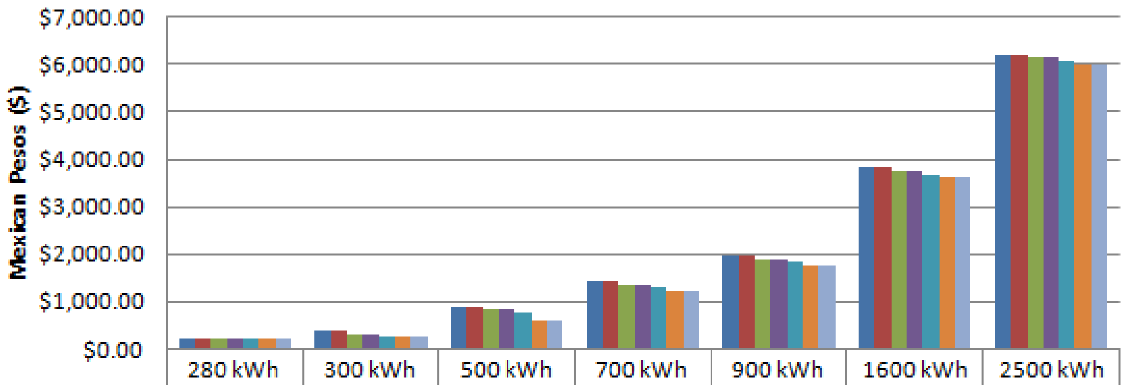
The percentage of the real cost of electricity that is subsidised varies within the location of households in the Mexican territory and their different electricity consumption. As commented before in this chapter, there are 7 different tariffs for electricity in domestic households which are determined by the average temperature in summer in the location in which the household is located. Tariff 1 receives fewer subsidies than Tariff 1F; this is because the last one is applied for locations with an average temperature in summer of 33° C where more electricity is consumed and therefore more subsidies are provided. It can be said that the highest the temperature in the location, the bigger the subsidy. The price for electricity also varies according to the range of consumptions, as explained before every tariff is composed by various sub tariffs: basic, medium and excess. Basic consumption is more subsidised than excess consumption.

To explain how subsidies work in the different tariffs for domestic households in summer (Fig. 12) and in winter (Fig. 13) a sensitivity analysis was performed giving the results shown in the graphs below:



	280 kWh	300 kWh	500 kWh	700 kWh	900 kWh	1600 kWh	2500 kWh
1	$230.22	$370.50	$901.50	$1,432.50	$1,963.50	$3,822.00	$6,211.50
1A SUMMER	$206.12	$224.30	$764.50	$1,295.50	$1,826.50	$3,685.00	$6,074.50
1B SUMMER	$189.82	$205.20	$582.40	$1,113.40	$1,644.40	$3,502.90	$5,892.40
1C SUMMER	$186.76	$200.10	$353.90	$600.50	$800.70	$2,659.20	$5,048.70
1D SUMMER	$186.76	$200.10	$348.80	$502.60	$784.00	$2,146.30	$4,535.80
1E SUMMER	$153.72	$164.70	$274.50	$399.20	$538.80	$1,229.40	$3,267.90
1F SUMMER	$153.72	$164.70	$274.50	$399.20	$538.80	$1,027.40	$2,116.40

Figure 12. Electricity bills (in Mexican pesos) for different consumption scenarios in summer for the seven different tariffs applied to domestic households in Mexico (excluding tariff DAC)



	280 kWh	300 kWh	500 kWh	700 kWh	900 kWh	1600 kWh	2500 kWh
1	$230.22	$370.50	$901.50	$1,432.50	$1,963.50	$3,822.00	$6,211.50
1A WINTER	$230.22	$370.50	$901.50	$1,432.50	$1,963.50	$3,822.00	$6,211.50
1B WINTER	$230.22	$300.60	$831.60	$1,362.60	$1,893.60	$3,752.10	$6,141.60
1C WINTER	$230.22	$300.60	$831.60	$1,362.60	$1,893.60	$3,752.10	$6,141.60
1D WINTER	$230.22	$248.40	$761.70	$1,292.70	$1,823.70	$3,682.20	$6,071.70
1E WINTER	$230.22	$248.40	$604.80	$1,222.80	$1,753.80	$3,612.30	$6,001.80
1F WINTER	$230.22	$248.40	$604.80	$1,222.80	$1,753.80	$3,612.30	$6,001.80

Figure 13. Electricity bills (in Mexican pesos) for different consumption scenarios in winter for the seven different tariffs applied to domestic households in Mexico (excluding tariff DAC)

4. Developing the tool

As commented before, identifying patterns of energy uses of a household and the prediction of domestic demand profiles are essential in order to match the energy demand to the power generated. This thesis focuses on electricity demand profiles for different types of domestic households in isolated communities in Mexico.

Electricity demand profiles vary according to many variables, such as household composition, weather, family income, occupant's behaviour patterns, socioeconomic sector, equipment, etc. The use of electricity of dwellings is affected by the number of electrical appliances owned by the occupants and by the way they use them. In that way, the consumption per hour is given by the sum of the consuming appliances.

On the other hand, there are also many factors influencing the occupancy patterns such as, the unoccupied period during the day, the getting up time in the morning and the sleeping time, the number of people living in the house, the economic activities carried out by the occupants, etc.

Taking all the that information altogether with the literature review into consideration, the scope, objectives and methodology for the tool were defined and are described following in this chapter. A deep description of how the tool was constructed is provided too.

4.1 Scope and objectives

To decide how the tool was going to operate, a series of requirements with their justification were established as main objectives to follow:

- The tool had to be focused (to start with) on small communities with a range of 1000-2500 households at the maximum. This because most of them are under the same socioeconomic sector and the lifestyle of the people is really similar. Therefore, the tool would be able to provide accurate results within the similar communities.

- Only the domestic sector was taken into consideration for the development of the tool, because normally in communities with those characteristics there are only a couple of public buildings (e.g. school and a small health clinic). However, in the future the public sector could be included.

- Electricity demand profiles were going to be generated from energy bills, this due to the extensive access to information on electricity bills in small communities in Mexico.

- Likewise, available statistical information regarding the household's composition and appliances ownership levels was also going to be taken into consideration, this to try to get the most accurate results possible.

- Producing daily and seasonal electricity demand profiles for different types of households was considered a must do. As a way to show the findings.

- The tool had to be easy to use and understand so it can be operated by all kind of people interested in the topic. This would be really helpful because at the moment the Mexican government is starting to run pilot projects for the installation of renewable energy systems in small communities and not there is a lack in knowledge and experts in that field at the moment.

4.2 Methodology

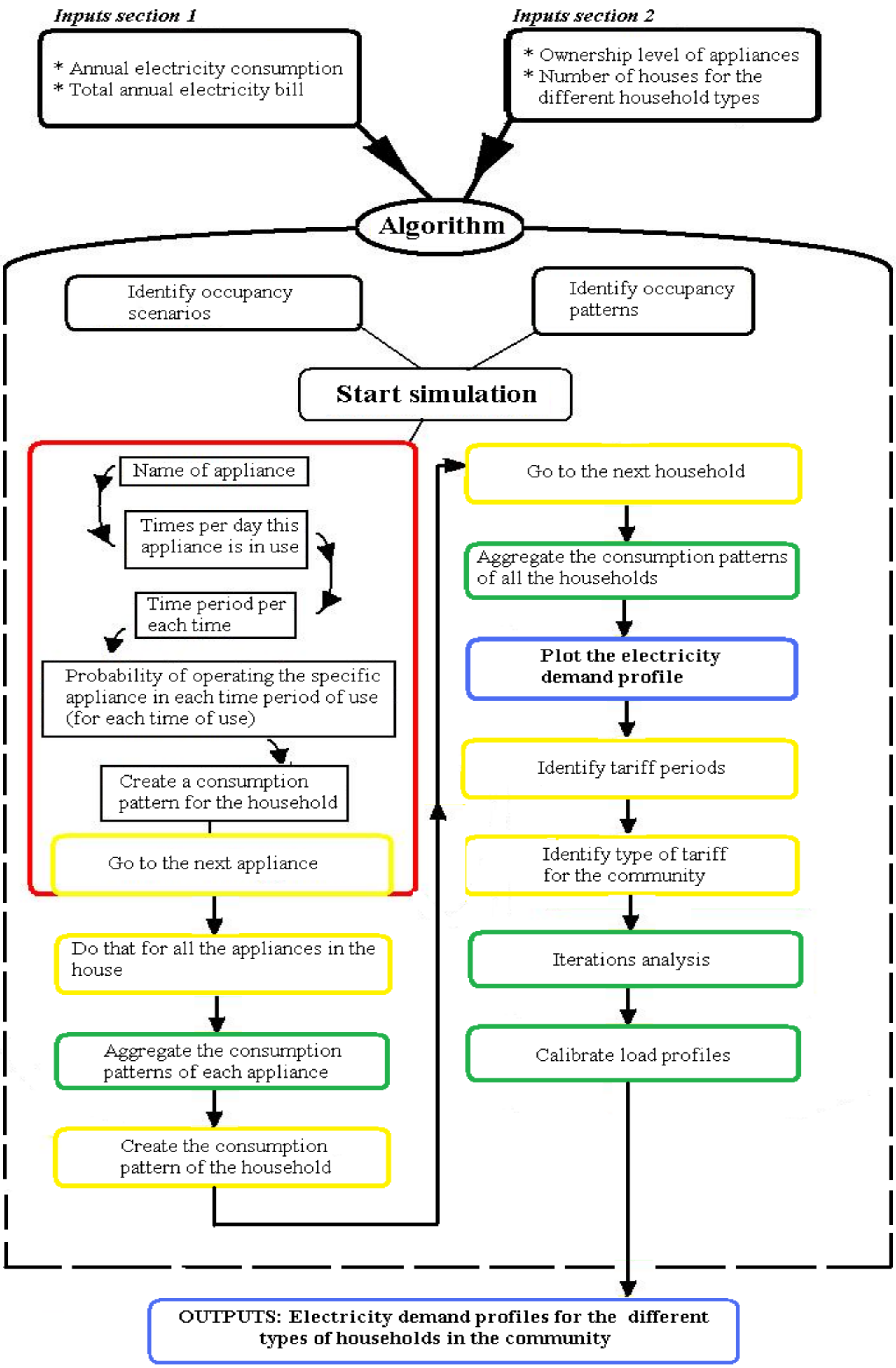


Figure 14. Methodology for the creation of the proposed model

4.3 Defining the inputs

The program requires a few inputs that are really easy to fulfil because all of them are offered by the national census on the INEGI webpage. The inputs required for the program to operate are the following:

- Total electricity demand for the community
- Total Annual energy bill for the community
- Annual consumption per household type in both summer and winter
- Number of houses for the different household types
- Ownership level of appliances in the community

A. <u>Household composition</u>

Mexico has a population of around 112 million in 2012 and a total of 28 million households with an accelerated increase tendency. Since 2000 the total of households has by 6.0 million and the total population by around 15 million. The average household size is 3.9 (INEGI, 2010). For the purposes of the thesis, the most typical types of households in Mexico have been assumed for the analysis. According to the National Institute of Statistic and Geography (INEGI), households can be classified in six main categories (INEGI, 2011):

- Single adult household
- Over 60s adults
- Two adults
- Two adults with children
- 1 adult with children
- Three adults or more

The tool requires the user to enter the number of households per type in the community as one of its inputs (blue area in Fig. 16). Once the blue boxes have been filled up, the percentage share will be updated automatically as well as the total of households in the community. The number of people per household is fixed as provided in the national statistics.

Table 16.Input A. Household composition

Type of household	No of household	No of people per household*	% Share
Single Adult		1	
Over 60s Adults		2	
Two adults		2	
Two adults with children		5	
1 Adult+children		4	
Three adults or more		3	
Total			

B. <u>Ownership level of appliances</u>

Electrical domestic appliances can be classified into the following categories (Mansouri, et al., 1996):

- Brown goods: Televisions, VCRs (video cassette recorders), non-portable audio equipment: hi-fi systems, record players etc. satellite control boxes for TVs, cable control boxes for TVs, portable audio equipment: cassette recorders, radios, clock radios, X-boxes (games etc.)
- Cold appliances: Refrigerators: one door refrigerators with or without frozen compartment, fridge-freezers: two door combination refrigerators, upright freezers, chest freezers
- Cooking appliances: Electric ovens: including grills electric hobs microwaves: includes combination microwave/grill/convection ovens electric kettles: includes all types of electric kettle mixer (hand mixer or stand-up mixer), hot drinks makers: coffee and tea makers, sandwich toasters pop-up toasters deep fat fryers, electric frying pans slow cookers cooker hoods, food preparation appliances: mixers, blenders, processors, whisks etc.
- Wet appliances: Washing machines: any automatic washing machine including the washing cycle of washer-dryers, tumble dryers: all types of dryers including the drying cycle of washer-dryers, dishwashers

- Miscellaneous appliances: Irons: steam irons and dry irons, vacuum cleaners, DIY equipment: drills, torches, battery chargers, garden equipment: lawn mowers, trimmers, hedge trimmers, other home care equipment: sewing machines, floor polishers, lights on extension cords, hair styling equipment: hair dryers, curling tongs small personal care appliances: electric toothbrushes, electric razors, electric towel rails, electric blankets, electric instantaneous showers, central heating pumps, personal computers, computer printers, slide projectors, electric typewriters etc.

The information of the average daily consumption for major appliances in the UK household is also provided by the INEGI and by other important sources (INEGI, 2011). Data can be found regarding the type and the average annual consumption (kWh) per household per day, the average annual consumption (kWh) per capita per day and the ownership level (Table 17).

Table 17. National average energy consumption per capita and per household for different electrical appliances. (INEGI, 2011)

Category	Appliance	Average consumption per capita (kWh/day)	Average consumption per household (kWh/day)
Cooking Appliances	Microwave	0.07	0.24
Cold Appliances	Refrigerator with freezer	1.1	2.82
Brown Goods	Television	0.25	0.8
Wet Appliances	Washing Mashine	0.15	0.6
Other appliances	Computers/Laptops	0.25	0.5
	Iron	0.08	0.25
	Radio	0.06	0.15
	Celular	0.06	0.15

Small communities in Mexico are usually under a low socioeconomic profile which means that they mainly own basic appliances; this makes it easier for the program calculations to include an analysis of electrical appliances. The tool requires the user to introduce the ownership level of appliances (blue boxes in Table 18)

Table 18. Input B. Ownership level of appliances

Category	Appliance	Ownership level (%)		Number of Ownership in community
		National	Community	
Cooking Appliances	Microwave Oven	78.20%		
Cold Appliances	Refrigerator	83.92%		
Brown Goods	Television	94.67%		
Wet Appliances	Washing Mashine	67.93%		
Other appliances	Computers/Laptops	30.09%		
	Iron	64.97%		
	Radio	81.31%		
	Celular	66.57%		

The following assumptions and observations have been made in order to generate appliances load profile:

- Each household has only one of each appliances listed above.
- The space heating and hot water systems are excluded from this study since they are not really required in Mexico
- Only microwave ovens have been considered for the cooking appliances section
- The ownership level of appliances have been distributed equally between the different types of households according to the ownership level of the community
- The weekend hourly load curves have been considered to be equal to those for the workdays to simplify the calculations.

C. Electricity consumption and energy bills

As another input, the tool requires the user to introduce manually some information regarding the electricity consumption for the community and from energy bills (blue spaces in Table 19):

- Total annual electricity demand for the community
- Total annual energy bill for the community
- Annual consumption per household type in both summer and winter

Table 19. Input C. Electricity consumption and energy bills

Total electricity demand for the community		kWh
Energy bills for the community		MXN

SUMMER	Single Adult	Over 60s adults	Two adults	2 adults with children	1 adult with children	Three adults or more	Totals
Consumption (kWh)							
Cost of electricity ($ MXN)							

WINTER	Single Adult	Over 60s adult	Two adults	2 adults with children	1 adult with children	Three adults or more	Totals
Consumption (kWh)							
Cost of electricity ($ MXN)							

4.3.1 Other considerations

A. Occupancy scenarios

The occupancy period is associated with the usage of the different electrical appliances owned by the occupants. The total electricity demand profile can vary extensively from time to time depending on the household's occupancy level and their lifestyle. For example, when there is no one at home, most of the electrical appliances will not be in use, and some others can be in use but in a total percentage of their capacity. Normally the occupants consume practically low power during the night, but it increments when they wake up and it changes during the day depending of the household composition. But every household behaves in a different way and some scenarios need to be taken into consideration in order to continue with the analysis.

The most typical scenarios of occupancy patterns in Mexico have been assumed according to the household type. As described by the National Institute of Statistic and Geography, the six scenarios are as follow (INEGI, 2010):

Scenario 1: Single adult household

- Unoccupancy period: 08:00-16:00 on weekdays
- Occupied by a full time working adult.
- The average daily consumption of every appliance will be distributed throughout the day into two main periods 05:00-08:00 and 16:00-24:00

Scenario 2: Over 60's adults household

- Unoccupancy period: Occupied all time
- Most loads are distributed throughout the day in a random way and only what is related to cooking has a specified period (for breakfast, lunch, dinner and supper).

Scenario 3: Two adults household

- Unoccupancy period: 07:00-15:00 on weekdays
- Usage pattern is similar to one adult household

Scenario 4: Two adults with children household

- Unoccupancy period: 07:00-15:00 on weekdays
- One member has a full time job.
- The second adult holds a part time job in the morning in order to take care of the children after school.

Scenario 5: One adult with children household

- Unoccupancy period: 07:00-15:00 on weekdays
- Occupied by a mom and her children, mom stays at home while children go to school.
- Usage pattern similar to over 60s adults

Scenario 6: Three adults or more household

- Unoccupancy period: 09:00-14:00 on weekdays
- Two of the house members have a full time job.
- The third one has a part time job in the morning session.

B. Electric lighting patterns

The electric light depends on the occupancy levels and patterns and is heavily affected by the season and the presence of occupants in the house, (e.g.in winter, people need to switch on lighting in the morning to carry on their activities but in summer due to the daylight no artificial lighting is required. The following equation can be used to calculate the electric lighting energy consumption:

$$E_l = N_b \times E_{rb} \tag{1}$$

Where, “Nb” is the number of light bulbs per household distributed between the different areas of the house and “Erb” is the energy rating per bulb per hour. Based on existing statistics provided by the INEGI, the tool uses the following values: 6, 9, 9, 14, 14, 15 bulbs of 20W respectively of the household type (INEGI, 2011). Lighting patterns are shown (Fig. 14 and Fig. 15)

Figure 15. Lighting patter in winter for the different type of households

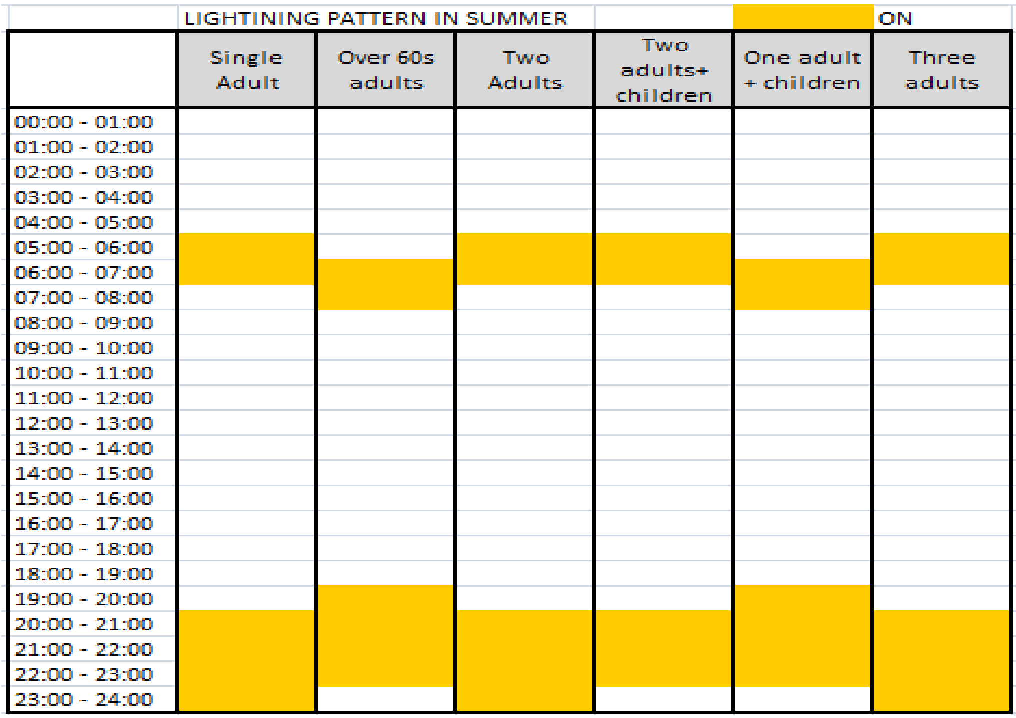


Figure 16. Lighting patter in summer for the different type of households

4.3.2 Generating a typical load profile

To create typical load profiles for Mexican domestic households using the six different scenarios, daily electricity consumption demand profiles of electric appliances need to be calculated for a winter and summer seasons (spring and autumn are ignored because CFE only considers winter and summer for the calculation of the energy bills). To do so, two different techniques were used to create the tool: a bottom-up model using statistics and electrical appliances patters and a second one focused on generating the required demand profiles from energy bills using the different tariffs according to the time of use. The integration of both of them will provide the final results on the tool.

A. <u>Tariff-based method</u>

The first thing that had to be taken into consideration to introduce this method to the program was to get to know the different tariff periods used in Mexico to calculate the energy bills. A summary of the different tariff periods according to the season for locations in central, north-east, north and south of Mexico is provided in (Fig. 20)

Table 20.Different tariff periods according to the season for central, north-east, north and south of Mexico

REGION	SEASON	TARIFF PERIOD	WEEKDAYS	SATURDAY	SUNDAY
Central, North-east, North and South	Summer	Base	00:00-06:00	00:00-07:00	00:00-19:00
		Intermediate	06:00-20:00 22:00-24:00	07:00-24:00	19:00-24:00
		Peak	20:00-22:00		
	Winter	Base	00:00-06:00	00:00-08:00	00:00-18:00
		Intermediate	06:00-18:00 22:00-24:00	08:00-19:00 21:00-24:00	18:00-24:00
		Peak	18:00-22:00	19:00-21:00	

As mentioned in chapter 2 of this thesis, in Mexico there are 8 different tariffs for electricity in the domestic sector. This tool is capable of providing results only for tariff 1 (which does not consider a difference in prices between summer and winter) at the moment, but with the intention to be able to evaluate all the rest of the tariffs in the near future. To continue with the development of this method in the excel tool, it was necessary to create calculators for the different existent tariffs, however as mentioned before only the calculator for tariff 1 is used in this tool (Fig. 21).

Table 21. Tariff 1 calculator

Tariff	Consumption (kWh)	Días	
1	300	56	

	kWh	Price per kWh	Subtotals
Basic	150	0.747	112.05
Medium	100	1.257	125.7
Excess	50	2.655	132.75
Total	300		370.5

The only input for this calculator to work is the bimonthly electricity consumption; this can be obtained easily from the energy bills as shown in Fig. 5 located on chapter 2 of this thesis. Tariff periods (Base, intermediate and peak) must not be confused with sub-tariffs within Tariff 1 (Basic, medium and excess), the first ones are used to price the electricity according to time of use during the day while sub-tariffs are the different prices per kWh within tariff periods.

It is possible to generate electricity demand profiles by knowing the tariff periods used to price the electricity and the annual total energy bill for the community (with a breakdown according to the different type of households, e.g. single adult household, etc.). However, in order to get to a feasible result, the trial and error method was used with different assumptions and scenarios through various iterations in order to get to the desired result. A random bimonthly energy bill was taken for the initial analysis, being 130 kWh the consumption with a correspondent electricity bill of $97.11 MXN. The idea was to distribute the consumption through the different tariff periods and evaluate at the end the difference in percentage between the original electricity bill and the calculated one. To calculate the electricity bill, the different sub-tariffs within tariff one were paired to the tariff periods. At the end of every iteration analysis, the one with the lowest difference and closer to the original electricity bill would be considered as the best option. To do that it was required to know the percentage share within the hours of the day.

A summary of the iterations that were carried out for this study are shown in (Table 22) and described below:

- *Iteration 1:* According to the average national daily electricity demand profile, 20% of the demand corresponds to the tariff period "base" from 00:00-06:00, 60% to intermediate demand from 00:06-18:00 and 22:00-24:00, 20% to peak demand from 18:00-22:00. The percentage share was also obtained from national statistics. Base demand was priced using the sub-tariff basic, the intermediate demand using the sub-tariff medium and peak demand was paired with the excess sub-tariff. While allocating the consumption according to the percentage of share within the different hours of the day, it was found a difference between the original electricity bill and this 1st iteration of +26.76%. This proved to be a high difference, requiring a new iteration to be created.

- *Iteration 2:* The same procedure and assumptions as in iteration 1 were followed, except for the pricing of the different tariff periods. In this case, the base demand was priced under the medium sub-tariff, the intermediate demand as well as the peak demand were priced using the basic sub-tariff. Once again the difference between the original electricity bill and the one obtained after running the 2nd iteration was way too big (-16.54%). So it was decided to proceed to a new iteration.

- *Iteration 3:* In this case, the percentage of share within the different hours of the day was totally changed. Instead of using national statistics, it was determined by the bottom-up statistic model created as another technique to create the different demand profiles in this paper. Base demand was paired with medium sub-tariff, and peak and intermediate demand were priced under the basic sub-tariff. For the 3rd time the results were not satisfactory and a new iteration needed to be carried out.

- *Iteration 4:* The assumptions were used as in iteration 3, with the only difference of pricing the different tariff periods under the different sub-tariffs. In this case, base demand was paired with basic sub-tariff, intermediate with medium sub-tariff and peak with excess sub-tariff. In this case the results were the ones expected with a difference between the original electricity bill and the one obtained after the iteration of only +1.70%.

For this reason, iteration 4 was chosen as the method to use for the development of the required demand profiles. Now it was possible to add this technique to the results section of the proposed tool which will be described later on in this chapter.

Table 22. Iterations carried out to set up the tariff-based technique

						energy bill ($)	$97.11						
						consumption (kWh)	130						
		ITERATION 1			ITERATION 2			ITERATION 3			ITERATION 4		
		% share	kW	$	% share	kW	$	% share	kW	$	% share	kW	$
00:00 - 01:00		3.32%	4.32	$3.22	3.32%	3.45	$3.14	1.31%	1.70	$1.27	1.31%	1.70	$1.55
01:00 - 02:00	BASE	3.32%	4.32	$3.22	3.32%	3.45	$3.14	1.31%	1.70	$1.27	1.31%	1.70	$1.55
02:00 - 03:00		3.32%	4.32	$3.22	3.32%	3.45	$3.14	1.31%	1.70	$1.27	1.31%	1.70	$1.55
03:00 - 04:00		3.32%	4.32	$3.22	3.32%	3.45	$3.14	1.31%	1.70	$1.27	1.31%	1.70	$1.55
04:00 - 05:00	INTERMEDIATE	3.32%	4.32	$3.22	3.32%	3.45	$3.14	1.31%	1.70	$1.27	1.31%	1.70	$1.55
05:00 - 06:00		3.32%	4.32	$3.22	3.32%	3.45	$3.14	8.21%	10.67	$7.97	8.21%	10.67	$7.97
06:00 - 07:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	9.60%	12.49	$11.35	9.60%	12.49	$9.33
07:00 - 08:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	1.36%	1.77	$1.61	1.36%	1.77	$1.32
08:00 - 09:00	PEAK	4.28%	5.56	$5.06	4.28%	4.45	$3.33	1.31%	1.70	$1.55	1.31%	1.70	$1.27
09:00 - 10:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	1.31%	1.70	$1.55	1.31%	1.70	$1.27
10:00 - 11:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	1.31%	1.70	$1.55	1.31%	1.70	$1.27
11:00 - 12:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	1.31%	1.70	$1.55	1.31%	1.70	$1.27
12:00 - 13:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	1.31%	1.70	$1.55	1.31%	1.70	$1.27
13:00 - 14:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	1.31%	1.70	$1.55	1.31%	1.70	$1.27
14:00 - 15:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	1.31%	1.70	$1.55	1.31%	1.70	$1.27
15:00 - 16:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	1.31%	1.70	$1.55	1.31%	1.70	$1.55
16:00 - 17:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	2.94%	3.82	$3.47	2.94%	3.82	$2.85
17:00 - 18:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	2.91%	3.78	$3.44	2.91%	3.78	$2.82
18:00 - 19:00		5.00%	6.50	$8.17	5.00%	5.20	$3.88	9.76%	12.68	$15.94	9.76%	12.68	$9.47
19:00 - 20:00		5.04%	6.55	$8.24	5.04%	5.24	$3.92	9.93%	12.91	$16.23	9.93%	12.91	$9.64
20:00 - 21:00		5.06%	6.58	$8.27	5.06%	5.26	$3.93	10.03%	13.04	$16.39	10.03%	13.04	$9.74
21:00 - 22:00		5.06%	6.58	$8.27	5.06%	5.26	$3.93	9.92%	12.90	$16.21	9.92%	12.90	$9.63
22:00 - 23:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	9.83%	12.78	$11.62	9.83%	12.78	$9.55
23:00 - 24:00		4.28%	5.56	$5.06	4.28%	4.45	$3.33	8.47%	11.01	$10.01	8.47%	11.01	$8.22
TOTALS		100.00%	130.00	123.10	1.00	104.00	81.04	1.00	130.00	132.99	1.00	130.00	98.77
DIFFERENCE IN COST				126.76%			83.46%			136.95%			101.70%

B. Statistical prediction method

This technique aims to simulate random action of a determined household at hourly basis in order to generate electrical demand profiles that match the consumption target. It is based on probability that enable the user to predict the possibility of each occupant to operate a number of appliances on a determined time of the day for the six different occupancy scenarios (commented before in this chapter) by describing the behaviour of each appliance by a probability between 0-1. A random profile of each individual appliance for each scenario will be generated using the "Random Number Generator Technique" (RNG) (Table 23). The aggregation of all the generated random profiles for all appliances plus the addition of the lighting patterns will generate a daily consumption electricity demand profile for a known scenario.

Table 23.Random Generator Technique (RNG)

CUT OFF	Microwave		Microwave (2)	
	Cut off	Random ta	Cut off	Random ta
	0	1	0	1
	0.2	2	0.60	2
	0.8	3	0.85	3
PROBABILITY	Generated	Target	Generated	Target
1	0.03	0.2	0.08	0.60
2	0.09	0.6	0.04	0.25
3	0.02	0.2	0.02	0.15
4				
5				
6				
7				
8				
Household	Tag	Random	Tag	Random
1	1	0.18	2	0.63
2	2	0.66	2	0.65

The daily energy consumed by each appliance can be calculated using one of the following equations:

$$E_a = N \times \sum E_{apc} \quad (2)$$

$$E_a = \sum E_{aph} \quad (3)$$

Where Ea is the daily energy consumption of the household delivered by the different appliances; N is the number of occupants, *E*apc is the appliance energy consumption per capita (values described previously on this chapter) and *Eaph* is the appliance energy consumption per household (fixed values).

In order to create sensible demand profiles, a good knowledge of occupancy patterns is needed. The usage pattern and probability of occurrence of each appliance was determined by using information provided by SENER according to previous studies. Likewise the time of use probability was determined based on an existing questionnaire carried out by the same energy institute. Also one simple assumption was made for the model to work: although the demand for cold appliances varies normally during its duty cycles, the assumption of constant load is assumed to be sufficiently accurate. An example of the data used for the calculations of single adult demand profile is shown (Table 24). For more information please go to the different pages in the excel tool provided together with this paper.

Table 24. Appliances usage pattern for a single household in small communities in Mexico. (SENER, 2012)

Category	Appliance	Time most likely to operate	Number of times per day	Energy per time of usage (kWh)
Cooking Appliances	Microwave	05:00-08:00, 16:00-19:00, 19:00-22:00	3	0.02
Cold Appliances	Refrigerator with freezer	All day	24	0.05
Brown Goods	Television	06:00-07:00, 16:00-17:00, 17:00-18:00, 18:00-19:00, 19:00-20:00, 20:00-21:00, 21:00-22:00, 22:00-23:00	8	0.03
Wet Appliances	Washing Mashine	16:00-24:00	1	0.15
Other appliances	Computers/Laptops	19:00-20:00,20:00-21:00, 21:00-22:00, 22:00-23:00, 23:00-24:00	5	0.05
	Iron	16:00-24:00	1	0.08
	Radio	16:00-24:00	1	0.06
	Celular	16:00-24:00	1	0.06

4.4 Outputs and results

The tool provides a results section where the different electricity demand profiles are shown. It consists in 3 parts:

The first part displays the seasonal electricity consumption according to the household type. This section of the results comes mainly from the tariff-based method altogether with the percentage of share within the hours of the days obtained with the statistic method. It is possible for the user to choose between different seasons and different household types. 2 graphs are displayed (Fig. 16):

- The first one shows the total energy bill breakdown for the community for a determined season (winter or summer) within the different hours of the day. At the same time it gives an idea of an approximate demand curve for the chosen data.
- The second one shows the electricity consumption per hour during the chosen season for a determined household type. It also provides an accurate electricity demand curve for the chosen data.

The second part of this section displays daily electricity consumption demand profiles per household according to the household type. As well as in the 1^{st} section of the results, the user is intended to select the season and the type of household desired. After that selection has been made, the program displays a graph showing the required hourly electricity demand profile. The general overview of this section is shown in (Fig. 17)

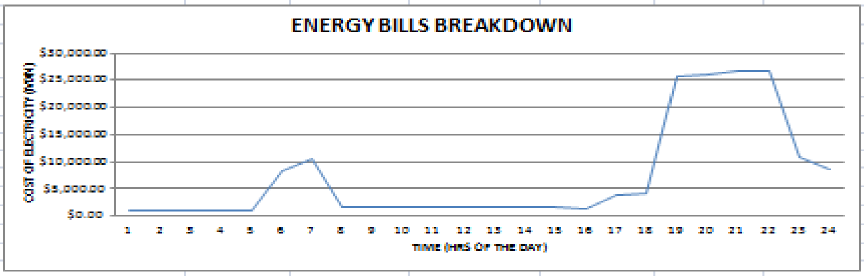
While the third part of this section displays the daily electricity consumption demand profiles according to the household type. The general overview of this section is shown in (Fig.18). Both sections are the joint of the two different techniques used to predict the demand profiles. Accurate and feasible results are obtained.

1. SEASONAL ELECTRICITY CONSUMPTION ACCORDING TO HOUSEHOLD TYPE

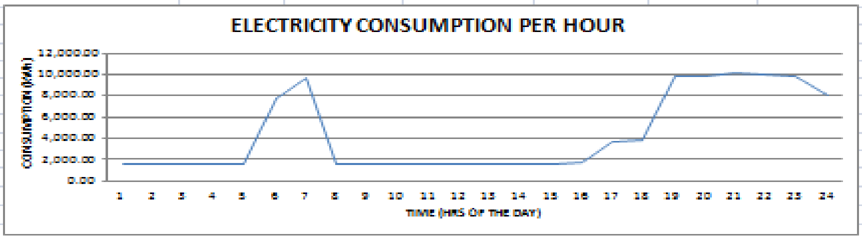
SEASON: Winter

TYPE OF HOUSEHOLD: Two adults

1A. COST OF ELECTRICITY PER HOUR CALCULATED FROM DIFFERENT EXISTING TARIFFS ACCORDING TO THE TIME OF USE FROM ENERGY BILLS



1B. ELECTRICITY CONSUMPTION PER HOUR CALCULATED FROM DIFFERENT EXISTING TARIFFS ACCORDING TO THE TIME OF USE FROM ENERGY BILLS



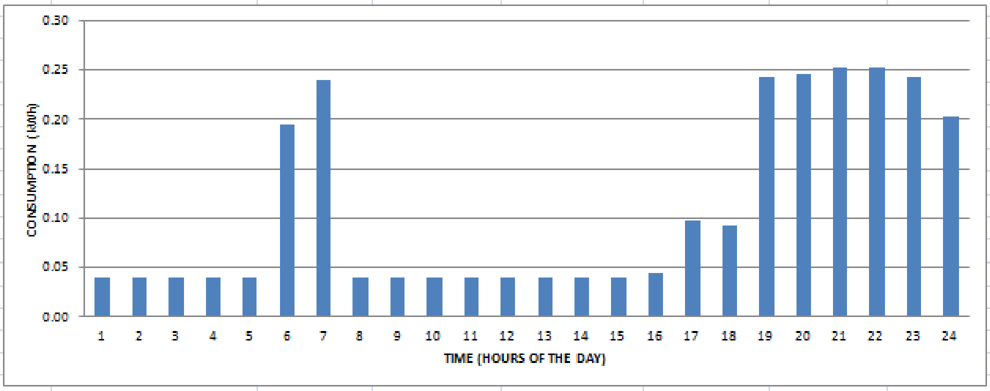
TIME	CONSUMPTION (kWh)	COST OF ELECTRICITY
00:00 - 01:00	1,568.70	$1,171.82
01:00 - 02:00	1,568.70	$1,171.82
02:00 - 03:00	1,568.70	$1,171.82
03:00 - 04:00	1,568.70	$1,171.82
04:00 - 05:00	1,568.70	$1,171.82
05:00 - 06:00	7,780.30	$8,426.06
06:00 - 07:00	9,626.35	$10,425.33
07:00 - 08:00	1,568.70	$1,698.91
08:00 - 09:00	1,568.70	$1,698.91
09:00 - 10:00	1,568.70	$1,698.91
10:00 - 11:00	1,568.70	$1,698.91
11:00 - 12:00	1,568.70	$1,698.91
12:00 - 13:00	1,568.70	$1,698.91
13:00 - 14:00	1,568.70	$1,698.91
14:00 - 15:00	1,568.70	$1,698.91
15:00 - 16:00	1,763.20	$1,317.11
16:00 - 17:00	3,651.32	$3,954.38
17:00 - 18:00	3,828.70	$4,146.48
18:00 - 19:00	9,756.13	$25,853.75
19:00 - 20:00	9,879.75	$26,181.34
20:00 - 21:00	10,113.93	$26,801.92
21:00 - 22:00	10,056.99	$26,651.01
22:00 - 23:00	9,892.53	$10,713.61
23:00 - 24:00	8,042.22	$8,709.72
TOTAL	104,784.55	$172,631.07

Figure 17. Results section part 1. Seasonal electricity consumption according to household type

2. DAILY ELECTRICITY CONSUMPTION PER HOUSEHOULD ACCORDING TO HOUSEHOLD TYPE

SEASON: Winter

TYPE OF HOUSEHOLD: Two adults



TIME	CONSUMPTION (kWh)
00:00 - 01:00	0.04
01:00 - 02:00	0.04
02:00 - 03:00	0.04
03:00 - 04:00	0.04
04:00 - 05:00	0.04
05:00 - 06:00	0.20
06:00 - 07:00	0.24
07:00 - 08:00	0.04
08:00 - 09:00	0.04
09:00 - 10:00	0.04
10:00 - 11:00	0.04
11:00 - 12:00	0.04
12:00 - 13:00	0.04
13:00 - 14:00	0.04
14:00 - 15:00	0.04
15:00 - 16:00	0.04
16:00 - 17:00	0.10
17:00 - 18:00	0.09
18:00 - 19:00	0.24
19:00 - 20:00	0.25
20:00 - 21:00	0.25
21:00 - 22:00	0.25
22:00 - 23:00	0.24
23:00 - 24:00	0.20
TOTAL	2.62

Figure 18. Results part 2. Daily electricity consumption per hjousehold according to household type

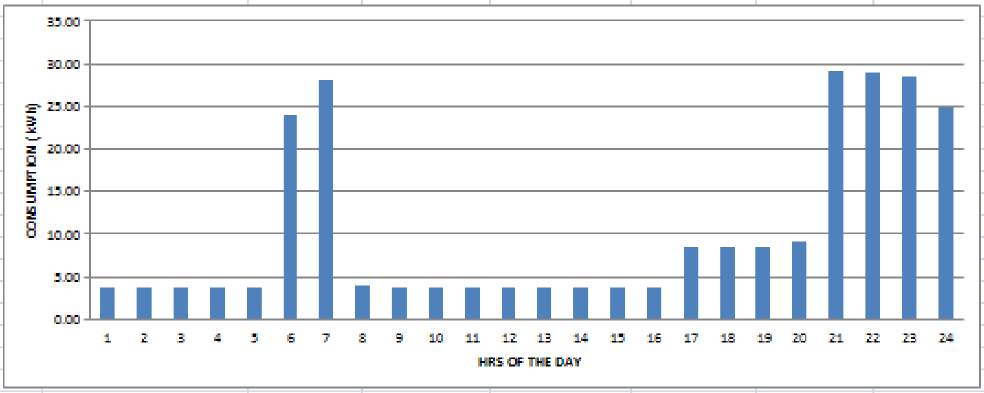
3. DAILY ELECTRICITY CONSUMPTION ACCORDING TO HOUSEHOLD TYPE

HOUSEHOLD TYPE	Single Adult	Over 60s adults	Two Adults	Two adults+ children	One adult + children	Three adults
NUMBER	196	113	220	340	234	115

Please select the type of househould and the season required

SEASON

TYPE OF HOUSEHOLD



TIME	CONSUMPTION (kWh)
00:00 - 01:00	3.82
01:00 - 02:00	3.82
02:00 - 03:00	3.82
03:00 - 04:00	3.82
04:00 - 05:00	3.82
05:00 - 06:00	23.93
06:00 - 07:00	28.03
07:00 - 08:00	3.93
08:00 - 09:00	3.82
09:00 - 10:00	3.82
10:00 - 11:00	3.82
11:00 - 12:00	3.82
12:00 - 13:00	3.82
13:00 - 14:00	3.82
14:00 - 15:00	3.82
15:00 - 16:00	3.82
16:00 - 17:00	8.53
17:00 - 18:00	8.40
18:00 - 19:00	8.44
19:00 - 20:00	9.15
20:00 - 21:00	29.10
21:00 - 22:00	28.97
22:00 - 23:00	28.49
23:00 - 24:00	24.83
TOTAL	251.44

Figure 19. Results section 3. Daily electricity consumption according to household type

5. Case Study: Atarjea

Atarjea is a Mexican municipality located in the northeast region of the state of Guanajuato, within the Sierra Gorda range (Fig. 20 and Fig. 21). It has an area of 318 square kilometres which represent the 1.04% of the state of Guanajuato and is bordered to the east and south by the state of Querétaro, to the north by the state of San Luis Potosí and to the west by the municipality of Xichú. Atarjea (Fig. 19) is also formed by many smaller outlying communities such as: El Carricillo, Aldama, Álamos, Mangas Cuatas and La Tapona. (Secretaría de Gobernación, 2010)

Regarding the climate, the municipality presents a variety of microclimates due to its geographical condition: Tropical, semi-arid semi-hot and temperate semi-moist. The average annual precipitation varies between 500 and 600mm, while the average temperature is 16 °C. The maximum temperature registered was 40 °C and the minimum 0.5 °C. The municipality has a total population of 5,610 people living in a total of 1,378 private dwellings. Only 1,218 of the dwellings have access to electricity and the average household size is 4.1 people according to the 2010 census (INEGI, 2011).

Figure 20. Location of Atarjea in Mexico

Figure 21. The main entrance to Atarjea

Figure 22. A typical household in Atarjea

5.1 Inputs

Table 25.Number of households per household type in Atarjea. (INEGI, 2011)

HOUSEHOLD TYPE	Single Adult	Over 60s Adults	Two adults	Two adults with children	One adult with children	Three Adults	TOTAL
NUMBER	196	113	220	340	234	115	1218

Table 26.Ownership level of appliances in the community. (INEGI, 2011)

CATEGORY	APPLIANCE	OWNERSHIP LEVEL (%)		NUMBER OF OWNERSHIP IN ATARJEA
		NATIONAL	ATARJEA	
Cooking Appliances	Microwave	78.20%	41.22%	502
Cold Appliances	Refrigerator	83.92%	50.00%	609
Brown Appliances	Television	94.67%	74.55%	908
Wet appliances	Washing Machine	67.93%	27.18%	331
Other appliances	Computer/Laptop	30.09%	4.60%	56
	Iron	64.97%	22.00%	268
	Radio	81.31%	47.87%	583
	Mobile Phone	66.57%	2.22%	27

Table 27.Electricity consumption breakdown for summer and winter seasons. (INEGI, 2011)

SUMMER	Single Adult	Over 60s Adults	Two adults	Two adults with children	One adult with children	Three Adults or more	TOTAL
CONSUMPTION (kWh)	46,013	59,264	92,463	222,918	175,214	74,272	670,145
COST OF ELECTRICITY (MXN)	$65,424	$84,265	$131,469	$316,959	$249,130	$105,605	$952,854

WINTER	Single Adult	Over 60s Adults	Two adults	Two adults with children	One adult with children	Three Adults or more	TOTAL
CONSUMPTION (kWh)	53,331	65,593	104,784	252,539	195,600	85,006	756,855
COST OF ELECTRICITY (MXN)	$75,829	$93,264	$148,989	$359,076	$278,116	$120,868	$1,076,145

5.2 Results

Typical load profiles for Atarjea's households for the six different scenarios were generated using the proposed tool. The daily electricity consumption demand profiles of electric appliances and lighting loads were generated for a winter and a summer seasons. The total daily electricity demand profile for the Atarjea was generated by adding the load profiles of the six known scenarios.

5.2.1 Seasonal electricity consumption according to household type

This section of the results provides the electricity demand curves for both winter and summer for the different types of households in the Atarjea. This information is provided by the tariff-based technique described in the previous chapter. The modelling results for the whole scenarios in both seasons are shown below:

a) Single adult household

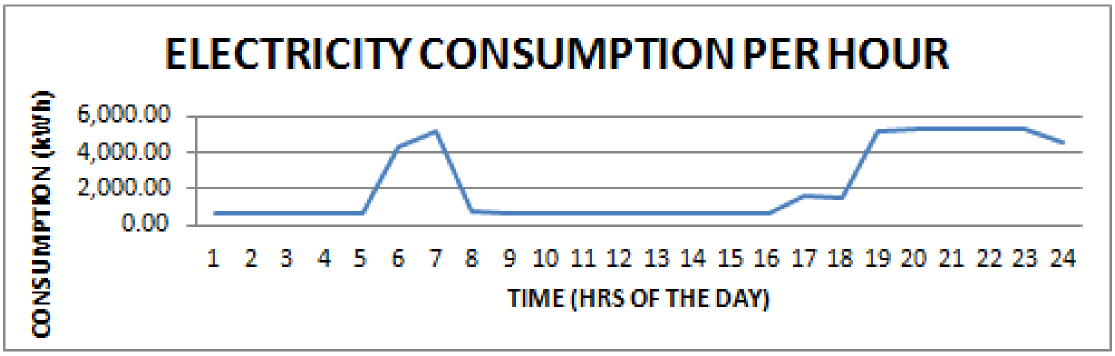


Figure 23. Electricity consumption per hour during winter (6 months period) for all single adult's households in Atarjea

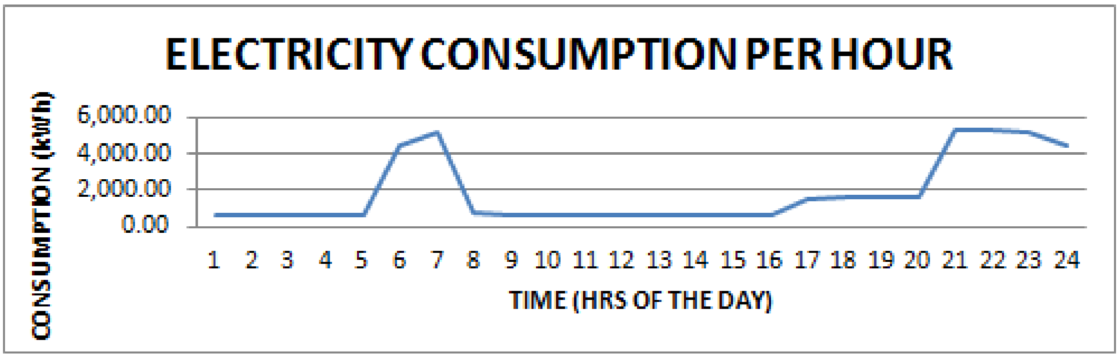


Figure 24. Electricity consumption per hour during summer (6 months period) for all single adult's households in Atarjea

b) Over 60's adult household

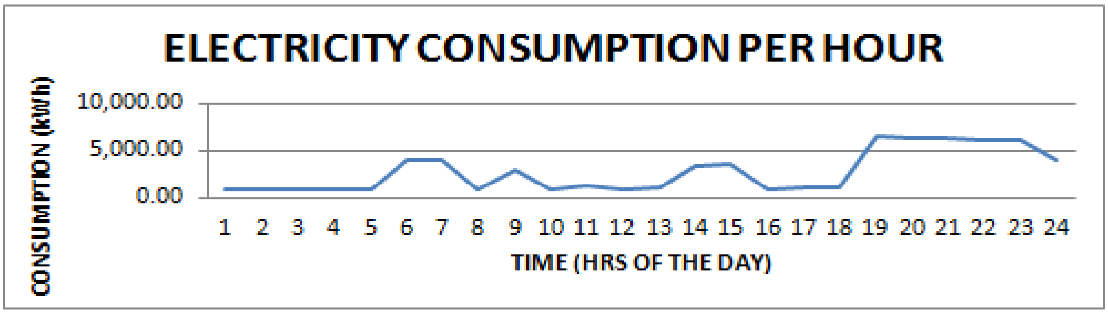


Figure 25. Electricity consumption per hour during winter (6 months period) for all over 60's adult's households in Atarjea

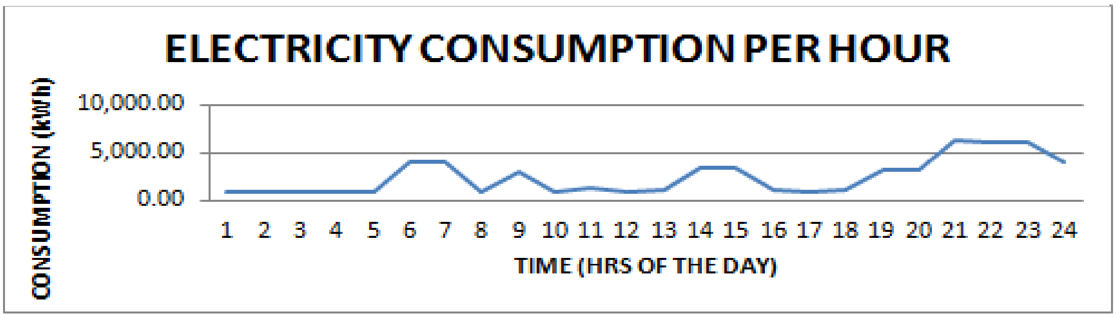


Figure 26. Electricity consumption per hour during summer (6 months period) for all over 60's adult's households in Atarjea

c) Two adults household

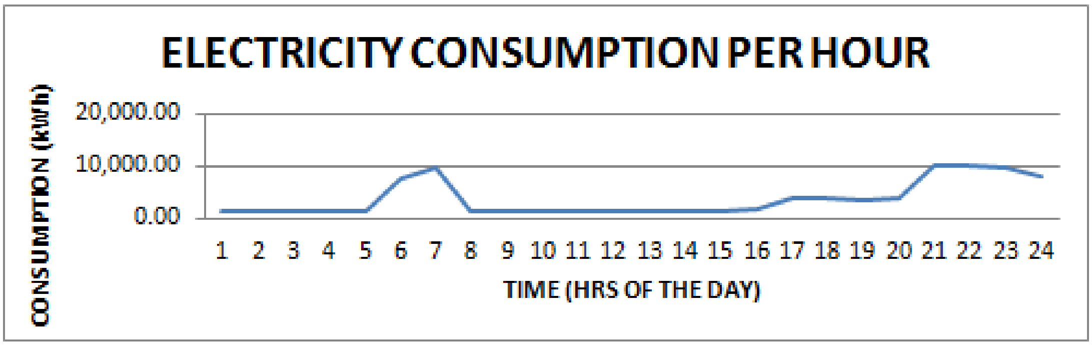


Figure 27. Electricity consumption per hour during winter (6 months period) for all two adult's households in Atarjea

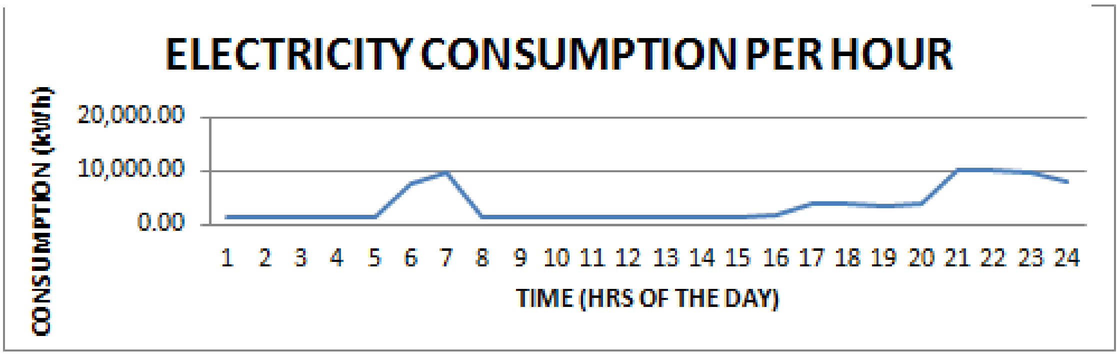


Figure 28. Electricity consumption per hour during summer (6 months period) for all two adult's households in Atarjea

d) Two adults with children household

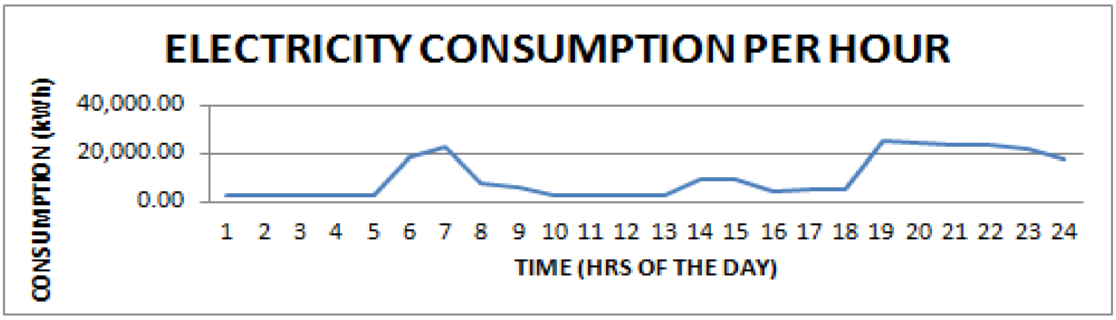


Figure 29. Electricity consumption per hour during winter (6 months period) for all two adult's with children households in Atarjea

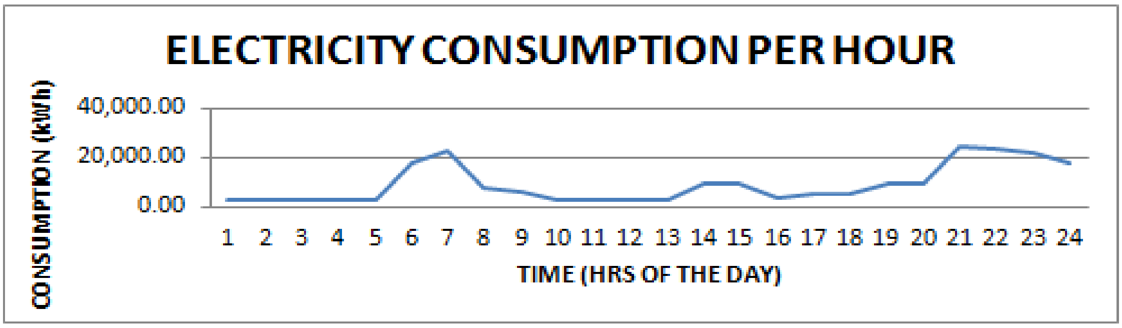


Figure 30. Electricity consumption per hour during summer (6 months period) for all two adult's with children households in Atarjea

e) One adult with children household

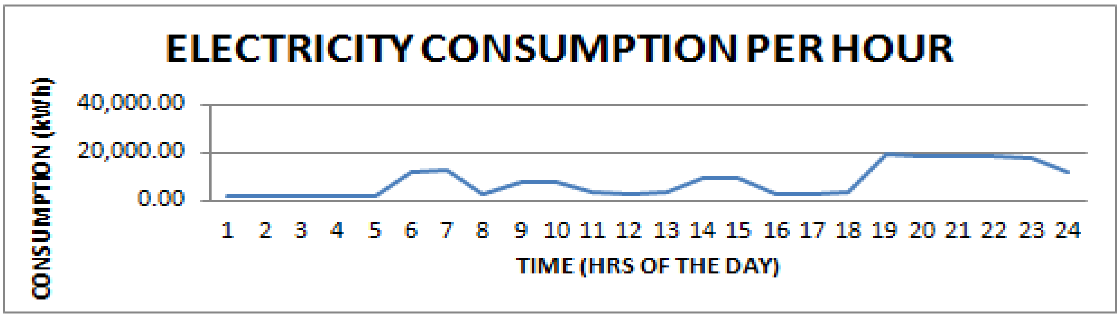


Figure 31. Electricity consumption per hour during winter (6 months period) for all one adult with children households in Atarjea

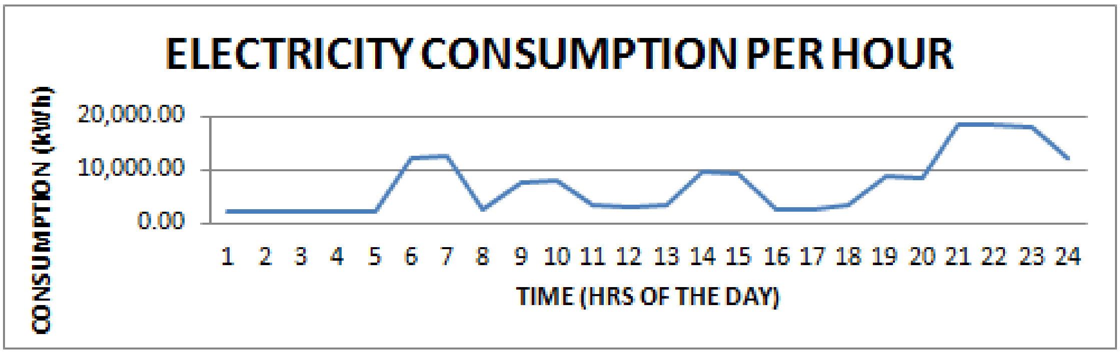


Figure 32. Electricity consumption per hour during summer (6 months period) for all one adult with children households in Atarjea

f) Three adults or more

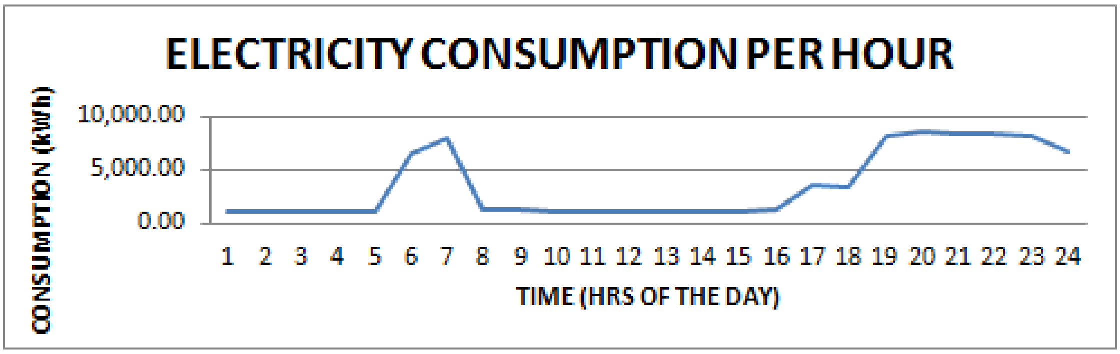


Figure 33. Electricity consumption per hour during winter (6 months period) for all three adults or more households in Atarjea

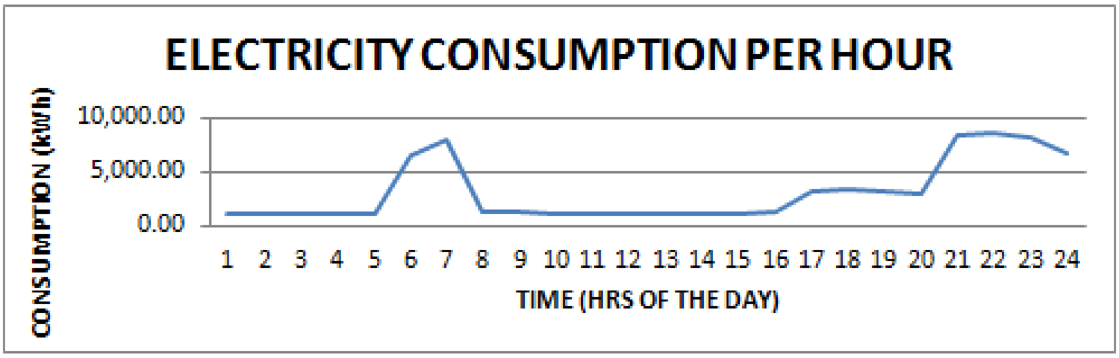


Figure 34. Electricity consumption per hour during summer (6 months period) for all three adults or more households in Atarjea

5.2.2 Average daily energy consumption per household according to household type

The average daily energy consumption of a single household for each household type was obtained by dividing the total electricity consumption for the total number of households for each scenario at a specific time by the total number of households for the same scenario at the same time for both summer and winter season. The modelling results for the whole scenarios in both seasons are shown below:

a) Single adult household

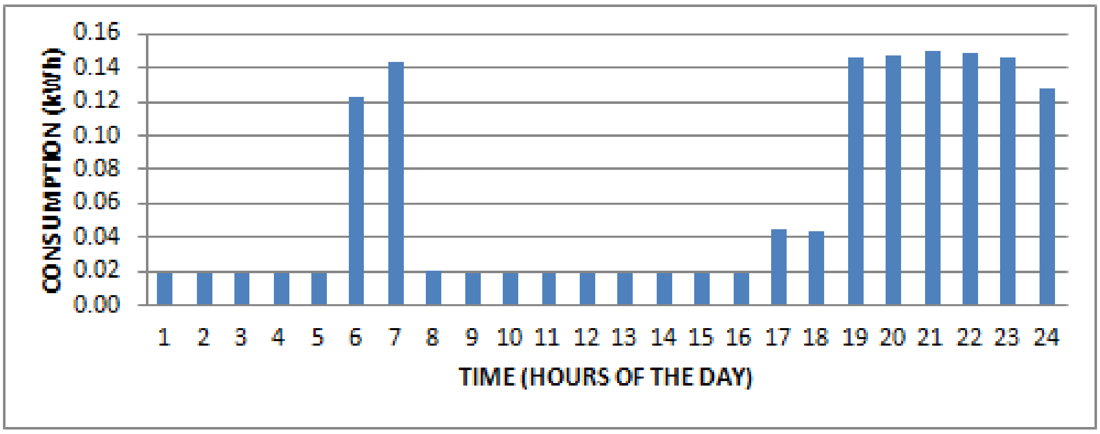


Figure 35. Average daily electricity consumption of a single adult household in winter

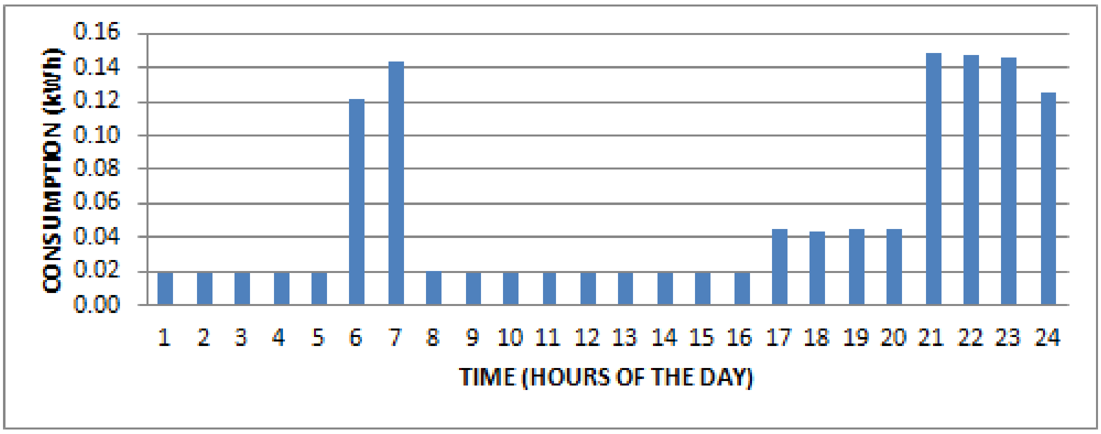


Figure 36. Average daily electricity consumption of a single adult household in summer

b) Over 60's adults household

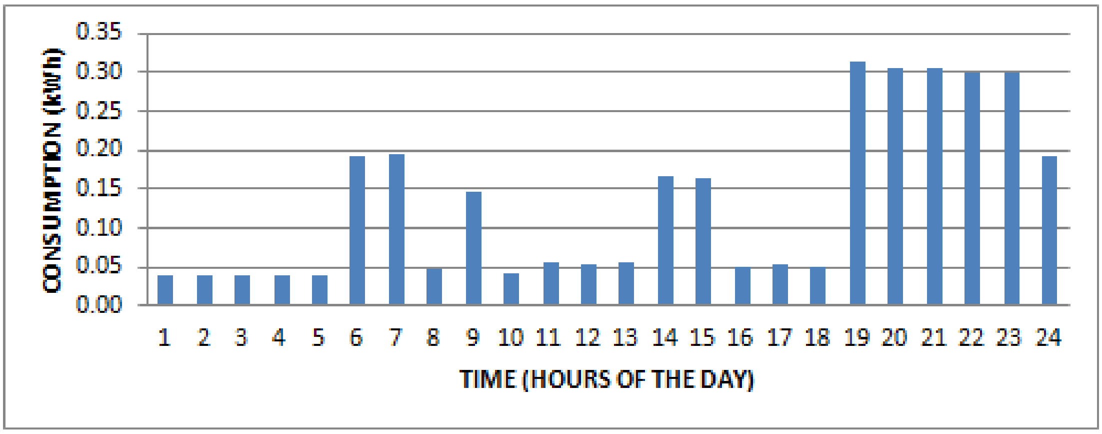


Figure 37. Average daily electricity consumption of an over 60's adult's household in winter

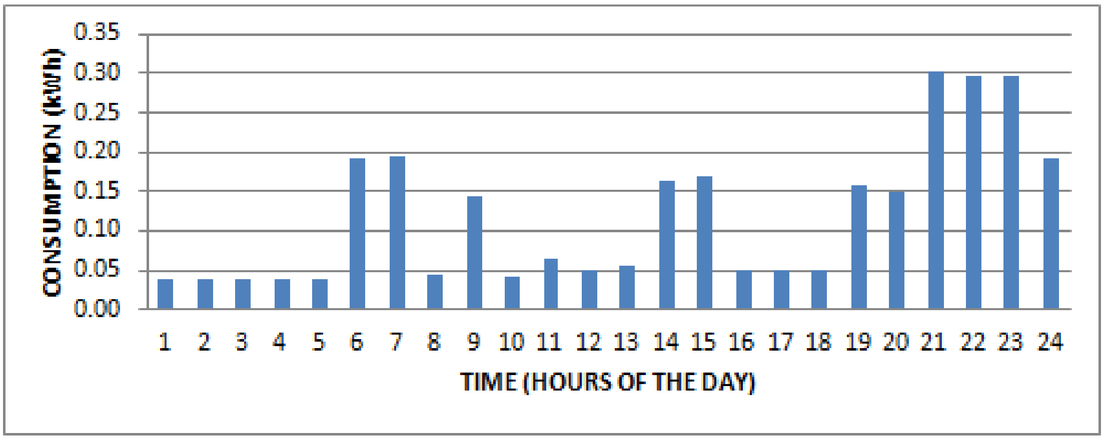


Figure 38. Average daily electricity consumption of an over 60's adult's household in summer

c) Two adults household

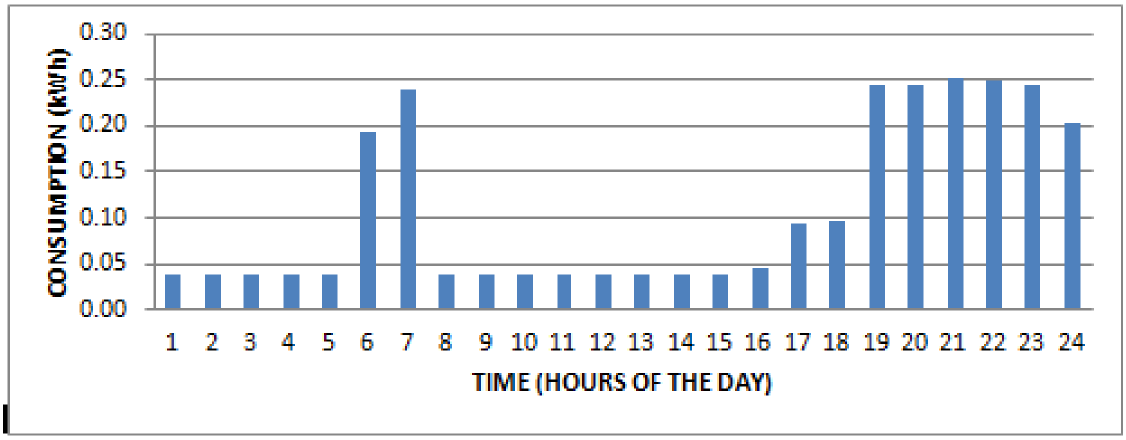


Figure 39. Average daily electricity consumption of a two adult's household in winter

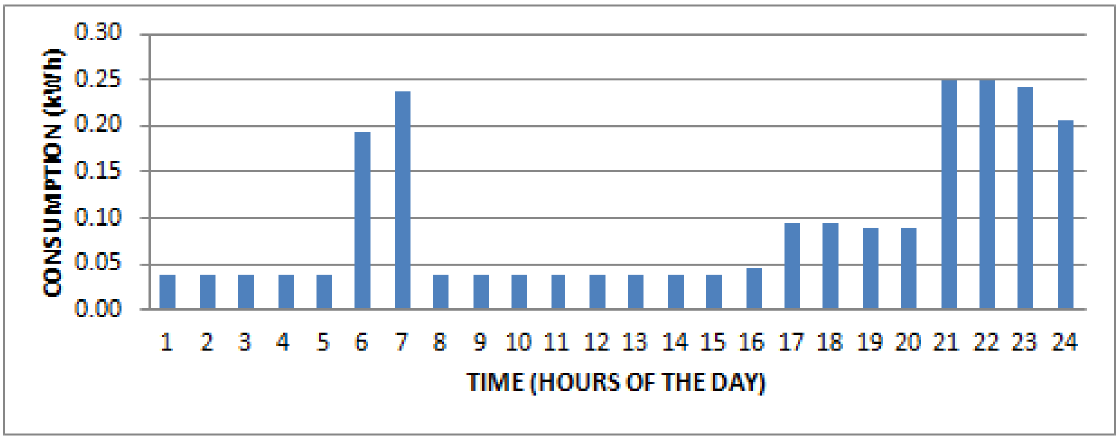


Figure 40. Average daily electricity consumption of a two adult's household in summer

d) Two adults with children household

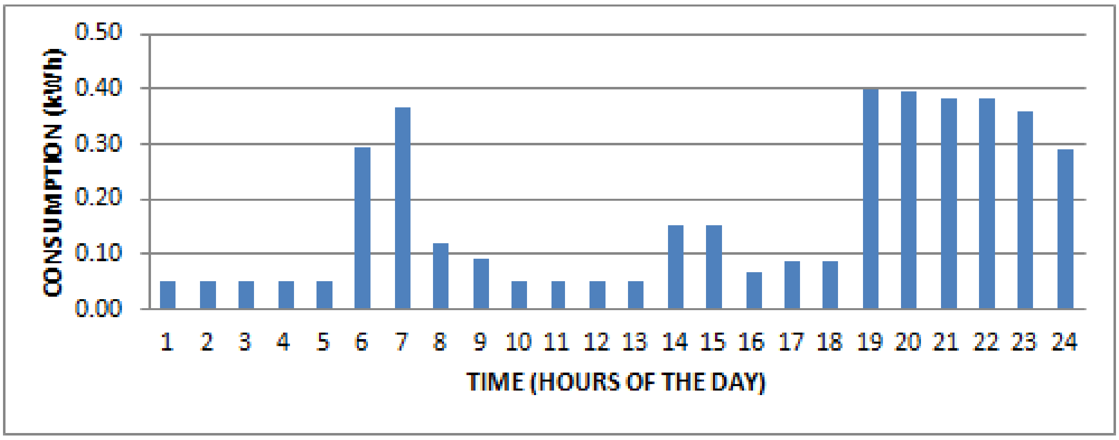


Figure 41. Average daily electricity consumption of a two adult's with children household in winter

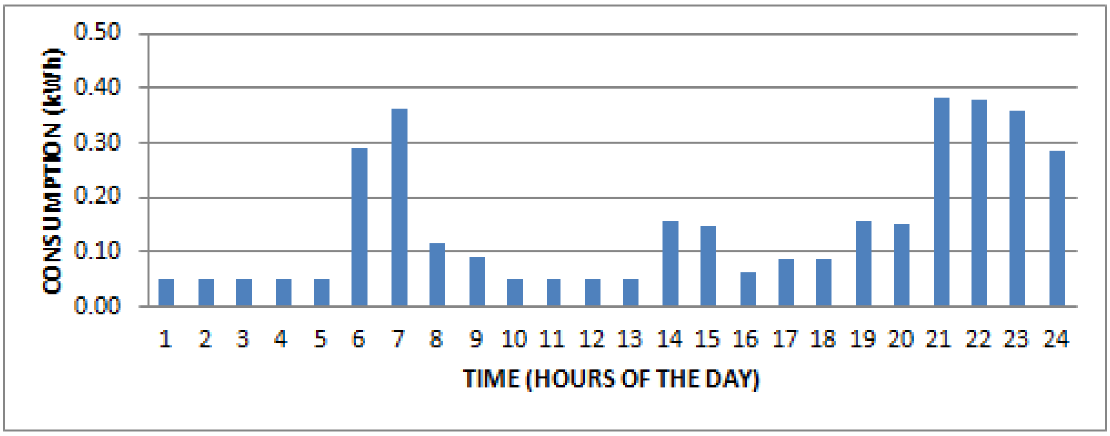


Figure 42. Average daily electricity consumption of a two adult's with children household in summer

e) One adult with children household

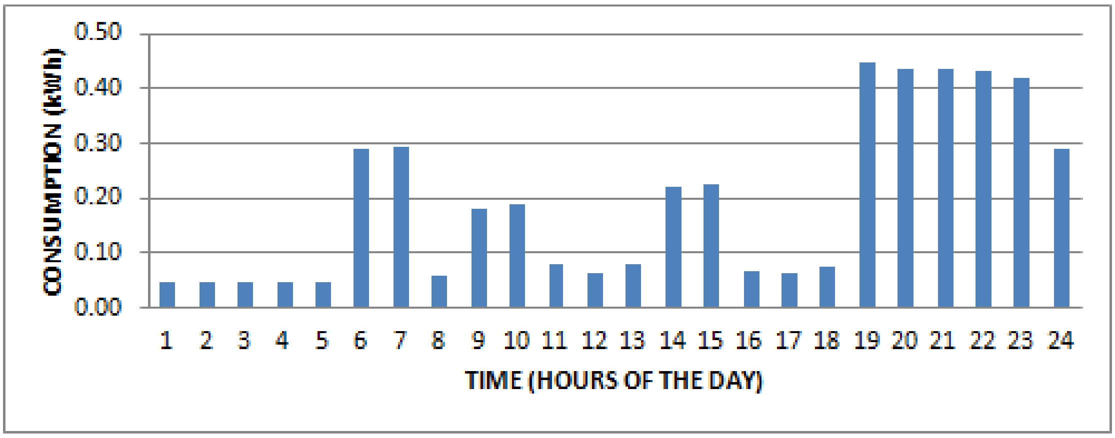


Figure 43. Average daily electricity consumption of an one adult with children household in winter

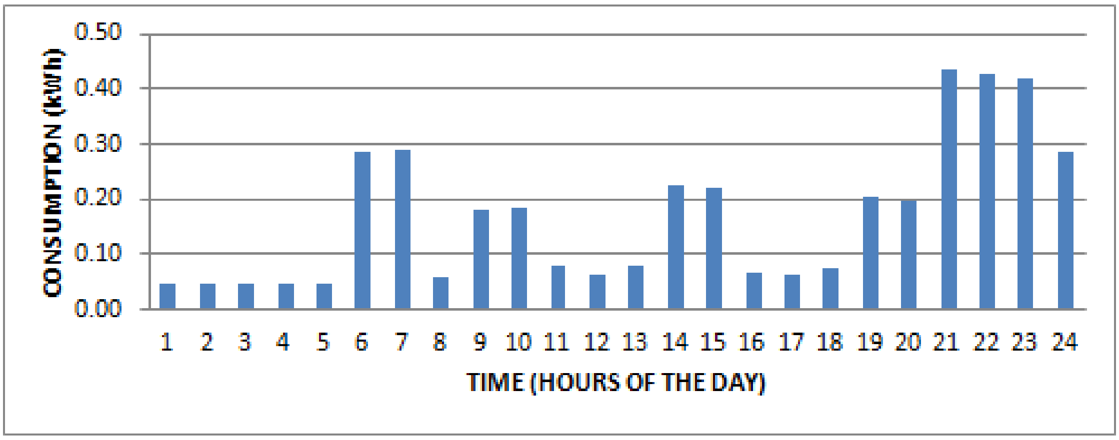


Figure 44. Average daily electricity consumption of an one adult with children household in summer

f) Three adults or more household

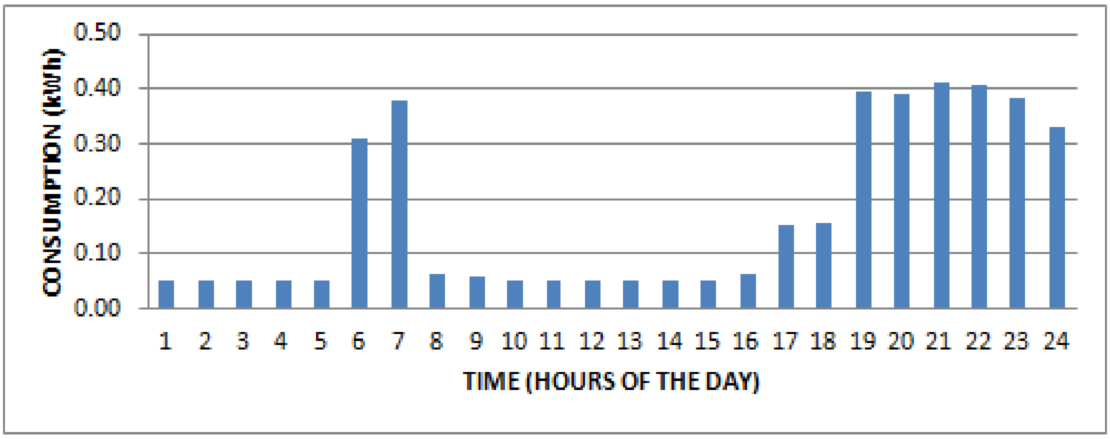


Figure 45. Average daily electricity consumption of a three adult's or more household in winter

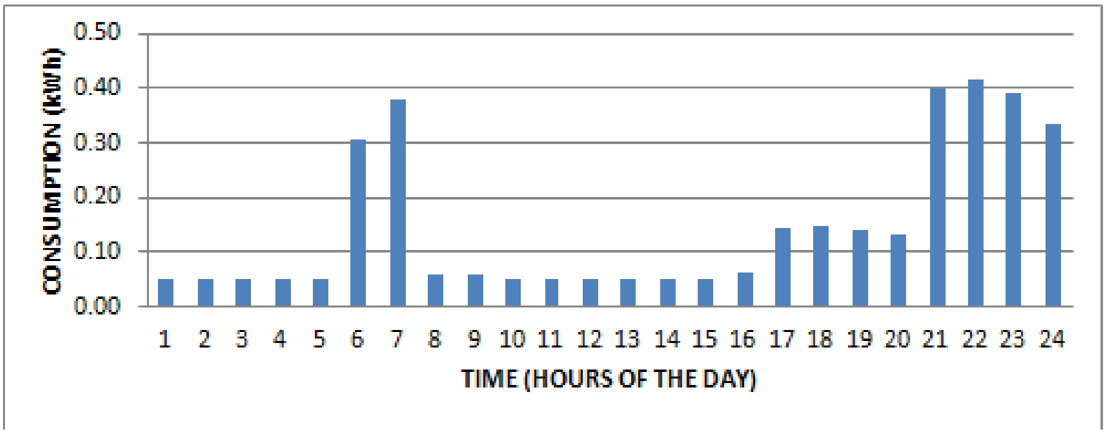


Figure 46. Average daily electricity consumption of a three adult's or more household in summer

5.2.3 Average daily electricity consumption according to household type (whole community)

The electricity demand profiles for the different types of households for the whole community were obtained for both summer and winter seasons in this section of the excel tool. The modelling results for the whole scenarios in both seasons are shown below:

a) Single adult household

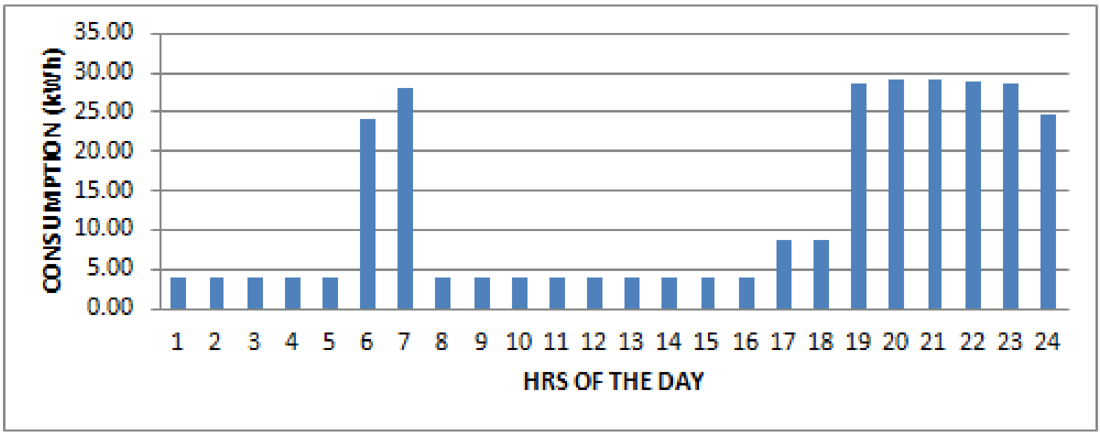


Figure 47. Energy consumption for all single adult's households in Atarjea during a day in winter

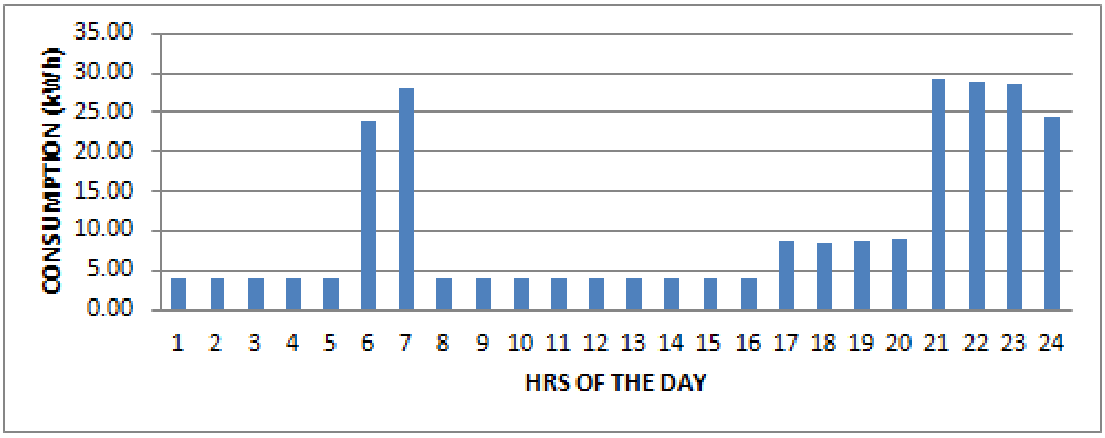


Figure 48. Energy consumption for all single adult's households in Atarjea during a day in summer

b) Over 60's adults household

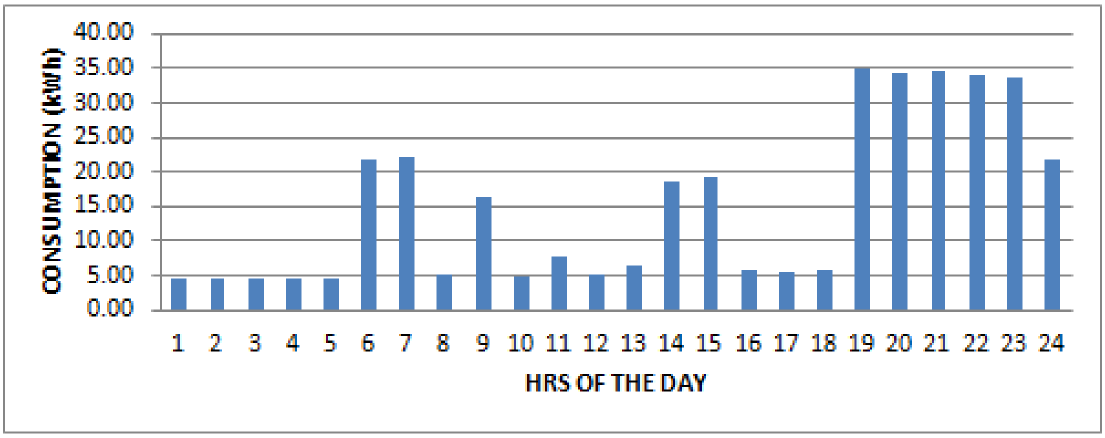


Figure 49. Energy consumption for all over 60's adult's households in Atarjea during a day in winter

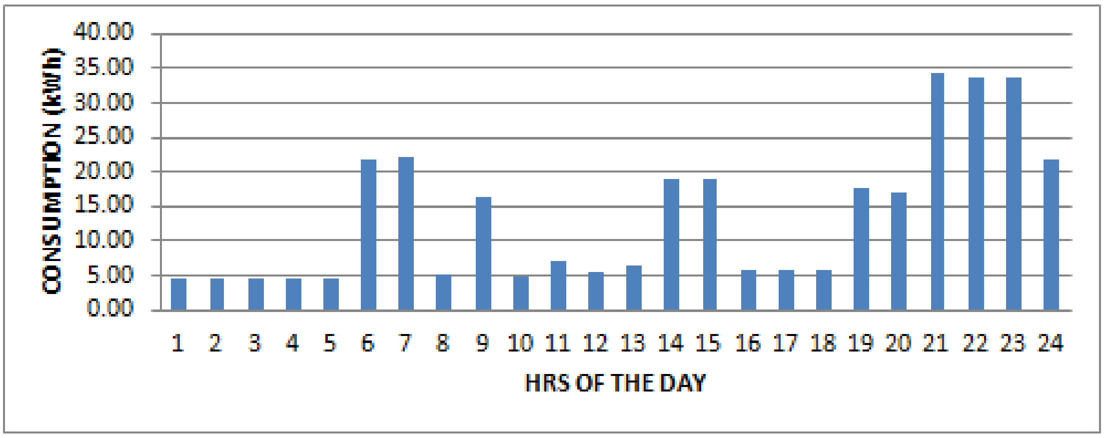


Figure 50. Energy consumption for all over 60's adult's households in Atarjea during a day in summer

c) Two adult's household

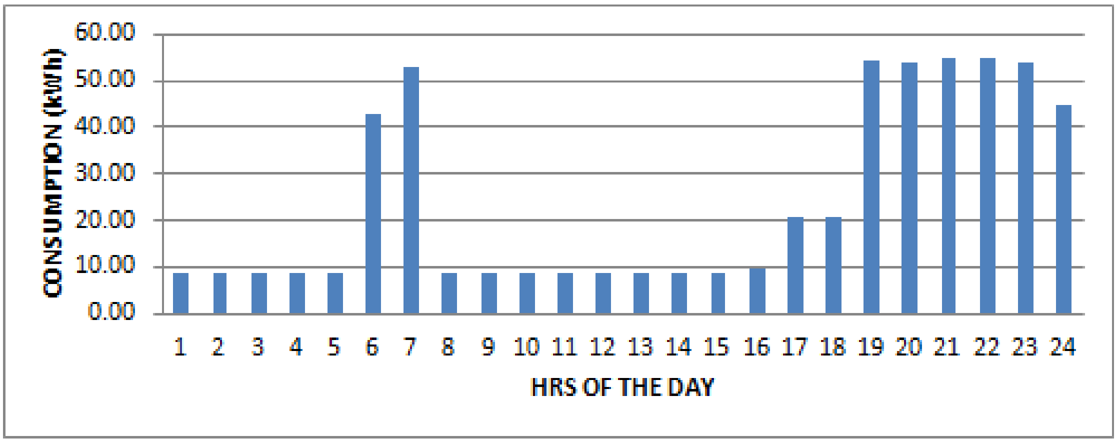


Figure 51. Energy consumption for all over two adult's households in Atarjea during a day in winter

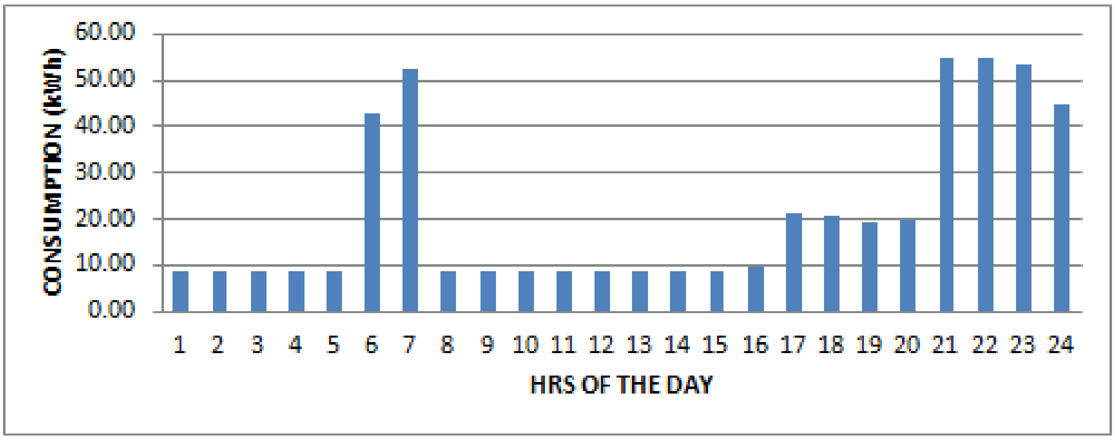


Figure 52. Energy consumption for all over two adult's households in Atarjea during a day in summer

d) Two adult's with children household

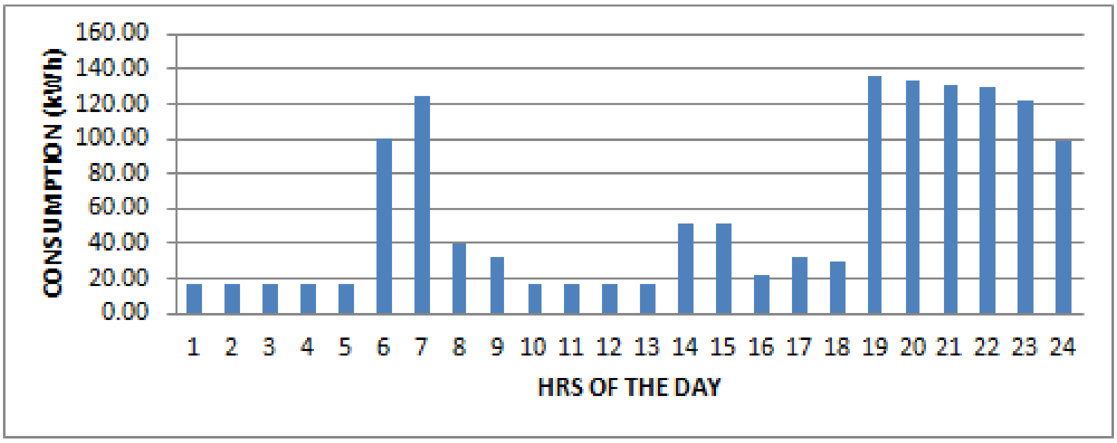


Figure 53. Energy consumption for all over two adult's with children households in Atarjea during a day in winter

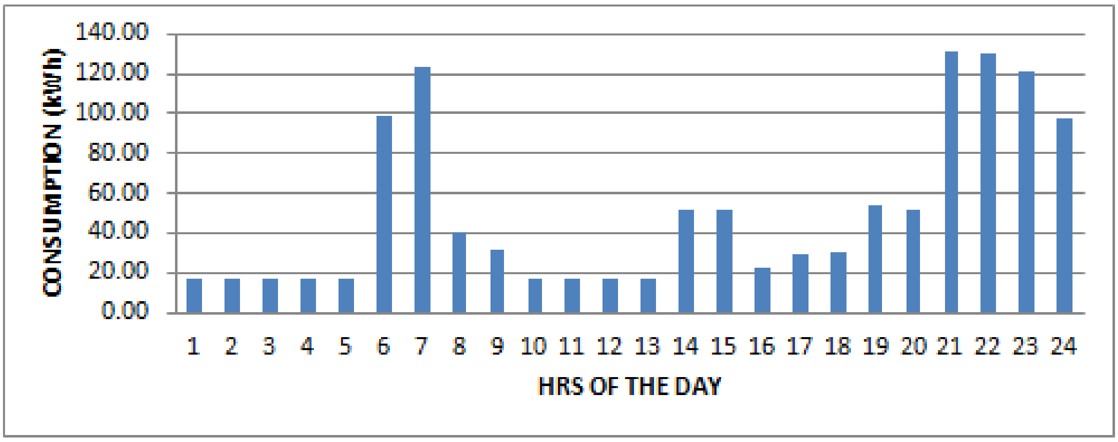


Figure 54. Figure 50. Energy consumption for all over two adult's with children households in Atarjea during a day in summer

e) One adult with children household

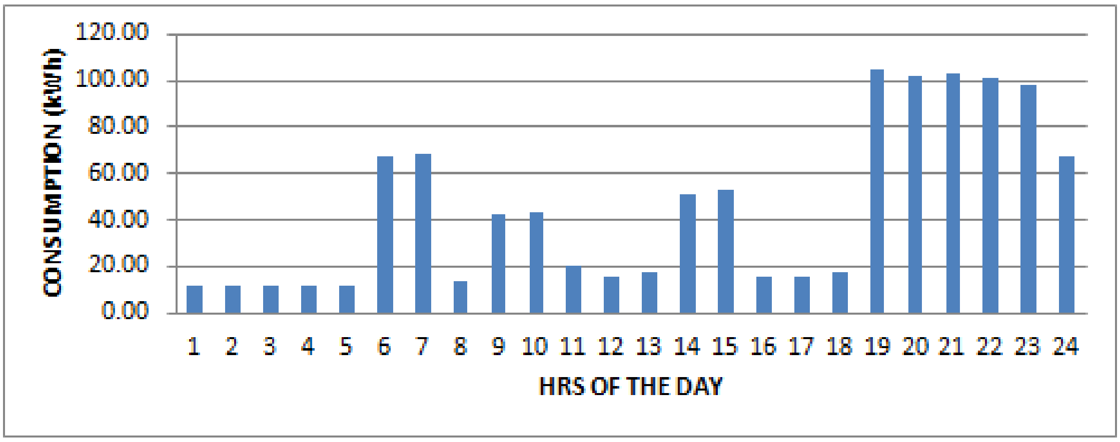


Figure 55. Energy consumption for all over one adult's with children households in Atarjea during a day in winter

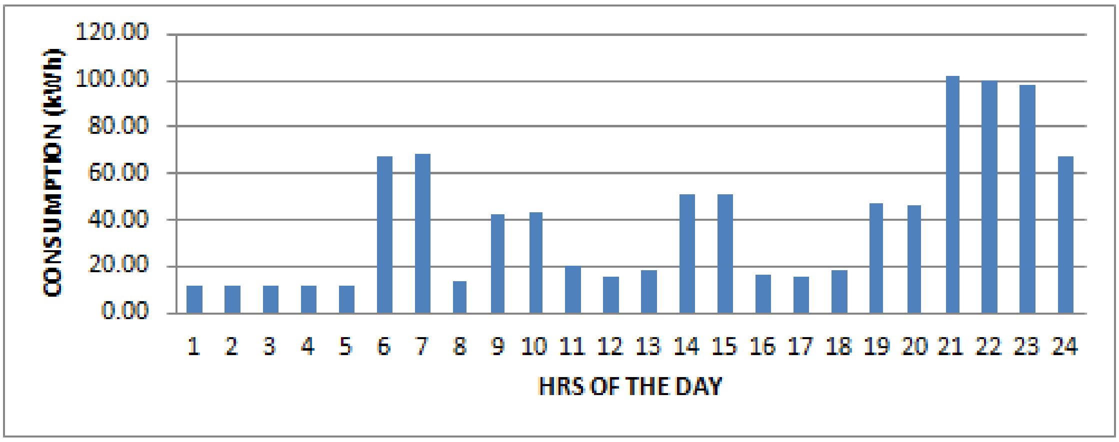


Figure 56. Energy consumption for all over one adult's with children households in Atarjea during a day in summer

f) Three adults or more household

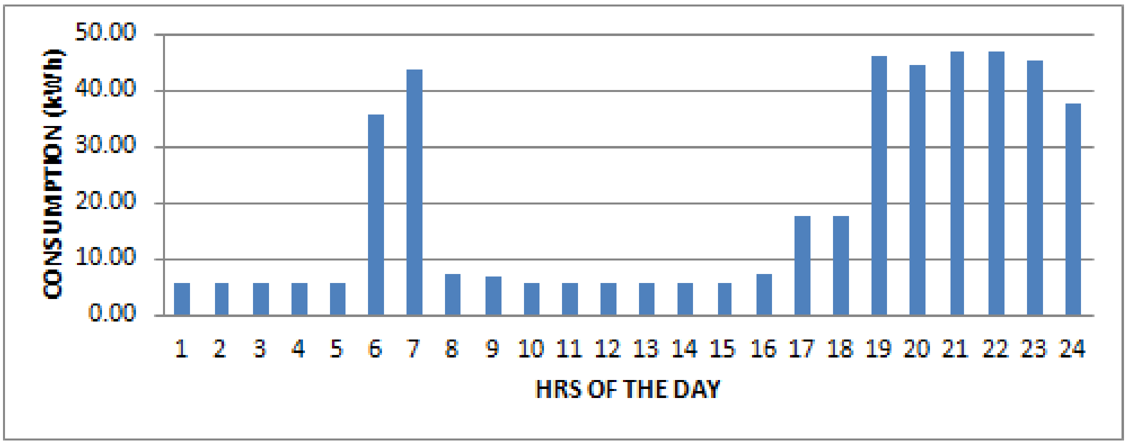


Figure 57. Energy consumption for all three adult's or more households in Atarjea during a day in winter

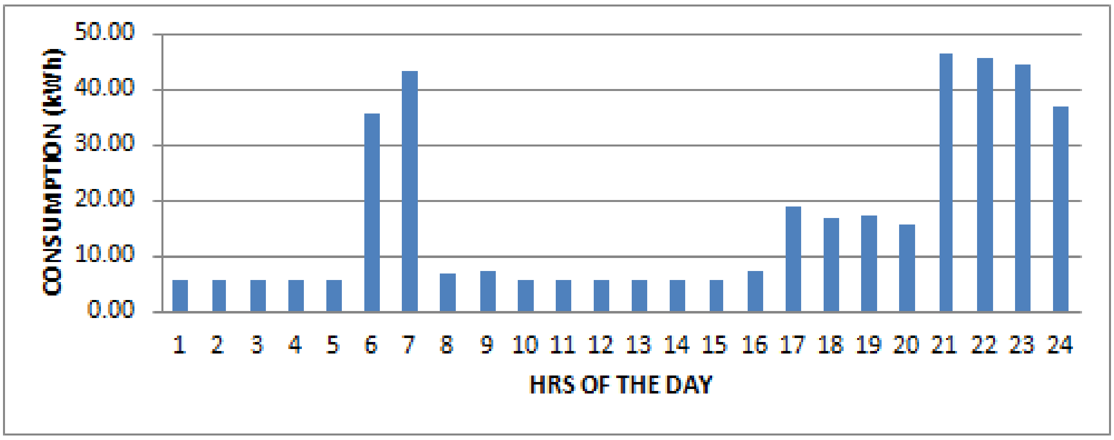


Figure 58. Energy consumption for all three adult's or more households in Atarjea during a day in summer

5.3 Interpretation of the obtained results

Using energy bills as a way to predict electricity demand profiles was really useful to create sensible hourly electricity demand curves for each of the type of households taken into consideration in the analysis. However, the use of existent statistics was more than necessary in order to obtain the desired results. When analyzing the outputs provided by the tool in its three different results sections regarding the case study a few observations can be made:

Altogether with the statistics-based model it was possible to identify three different periods during the day. There is a base period which in every scenario starts at 00:00 and finishes at 05:00; this is influenced by the sleeping patterns of the occupants. Then there is a considerable increment in the electricity demand after 05:00 until around 09:00 but it varies within the different types of household according to the time that they wake up in the morning. The electricity consumptions then goes down again for mostly every scenario (except the over 60's adults) until around 15:00 when people start coming back to their houses after work and other activities. However, the peak demand is allocated between 18:00-22:00 in the winter season and between 20:00-22:00 in the summer season. Therefore 14 hours in a day correspond to intermediate demand and 6 hours to the base demand in both seasons. Even though, these patterns were obtained for the community analyzed in the case study; they give us a very good idea of the usage patterns and consumer's behaviours in isolated communities in Mexico. Normally people living in small communities carry on the same activities, so there must not be a huge variation in the results if another community is analyzed. The three consumption periods will remain probably the same.

A higher demand of electricity was observed during the winter than during the summer. Lighting accounted for 35-50% of the total electricity demand in the community during the winter and 25-40% during the summer. Refrigerators and televisions proved to consume the most of the electricity when it comes to electrical appliances consumption (35-45%) for every different household type.

The highest electricity demand both during the summer and the winter corresponds to “one adult with children households”, this is because in this scenario mom was always at home while the kids were at school. The average daily consumption for this scenario is 4.59 kWh for the winter and 4.09 kWh for the summer seasons. The lowest demand corresponds to “single adult’s households” with an average consumption in winter of 1.50 kWh and 1.28 kWh in summer. On the other hand, the average consumption in a random day in the winter for the community is 3.34 kWh and 2.94 kWh during the summer. This is considerable behind the average national consumption for domestic households per day (5.1 kWh), this is because these communities have a low socioeconomic profile and they normally don’t consume that much electricity due to the low ownership of appliances.

It can be said that every type of household has proved to have a different consumption pattern influenced by their lifestyles, the number of occupants in the house and the ownership level of electrical appliances. But at the same time, all the scenarios are more or less under the same consumption curve which can be a good thing when planning the introduction of renewable energy systems to generate the required electricity in the community. Atarjea has the proper weather and required conditions required for the installation of PV panels and since the federal government is supporting the idea to start producing electricity from renewable resources, the information provided by this tool can be useful to evaluate the viability of a pilot project in this community.

However, in order to determine the accuracy of the obtained results, it was necessary to undertake a comparison between them and the real measured or monitored data for the community. In the next chapter a deep explanation of the validation is explained and discussed as well.

6. Validation of the model

A study was carried out by CFE in 2011 and it includes the electricity consumption measurements for all the types of households for a whole month in month in January (winter) and July (summer); nevertheless, the full study is only available in hard copy and it is stored in the CFE's regional quarters in Guanajuato. However, it was possible to obtain an excel file with the measurements of electricity consumed in some households of the analyzed community during a random day in both seasons winter in summer for just one type of household: "Three adults or more". When compared the average daily consumption for a single adult household with the existent measured data provided by CFE during the winter season (Fig. 58), it is possible to note that there is a good agreement between the both electricity consumption curves and the general patterns are still clearly captured by the proposed model. For example, three tariff periods can be identified in both curves during the same hours within the day. The minimum consumption is occurring between 00:00-05:00 and 09:00-14:00), almost the same pattern can be observed in the peak hours in the period from 18:00 to 22:00.

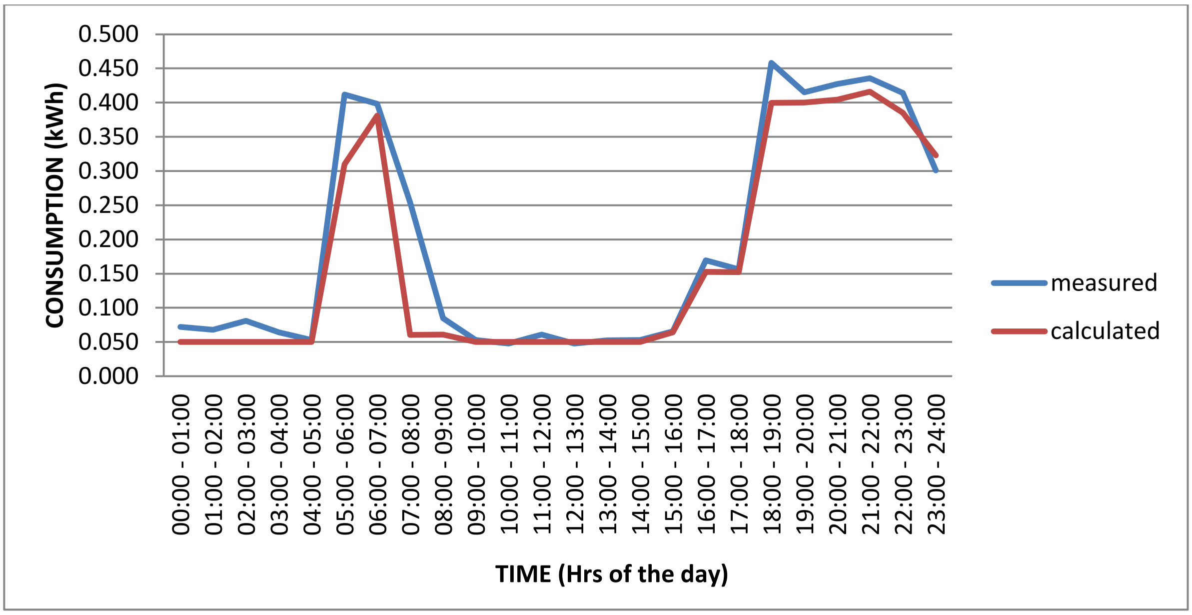


Figure 59.Comparison of the modeled load profile with measure data for a daily average consumption of a three adults or more household during a month in winter

The average daily electricity consumption from the produced model data in the winter season is 4.06 KWh while the average coming from the measured data is 4.64 kWh. The profile from the modelled data is slightly lower than the measured data showing a difference of 14.37%; this difference can be related to the assumptions made to create the excel tool. For example: it was assumed that certain electrical appliances like the refrigerator had the same consumption within the hours of the day while in reality this is not what happens.

While analysing the difference between the daily electricity consumption for the totality of the "three adult's households" in the community during a random day in the winter (Fig. 59). The total electricity consumption during a day in winter calculated with the model for this type of household is 467 kWh while the measured data provides a value of 541 kWh; this is a 15.88% difference within both cases. However similar periods during the day can be observed and there is not a very significant variation between the curves.

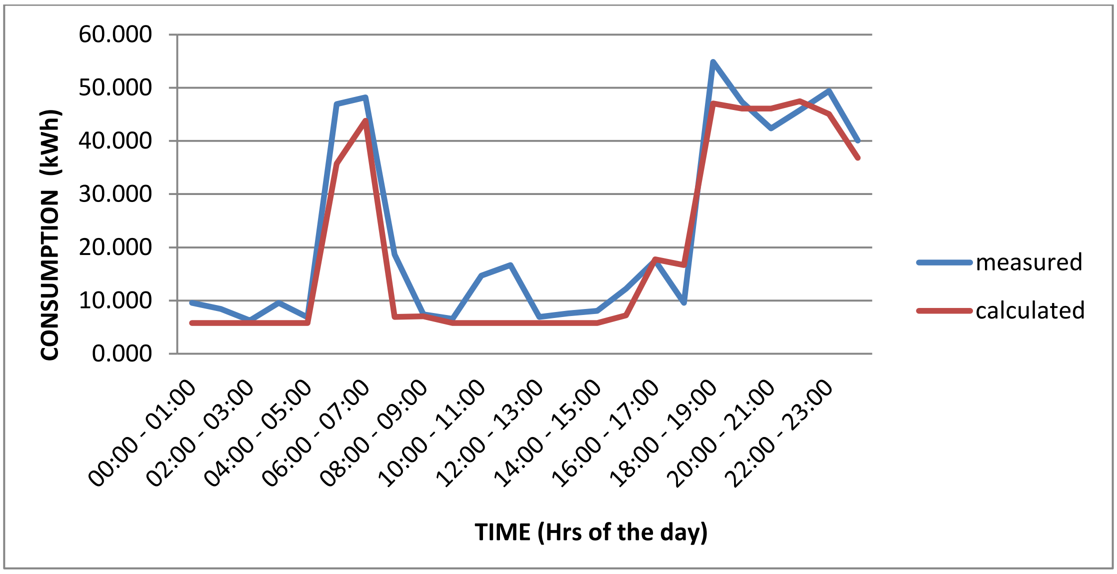


Figure 60. Comparison of the modeled load profile with measure data for a the total consumption during a day in winter of the totality of three adults or more household in the community

The same comparison is made but now on the summer season. In this case there is also a similar pattern through the energy curve and it is again easy to identify 3 periods during the day (Fig. 60). The consumption in summer is significantly lower than the one in the winter; this is explained by the quantity of hours of light in a normal day in this season. Therefore, the lighting patterns change and less electricity is required.

The total electricity consumption during a day in summer calculated with the proposed tool for this type of household is 405 kWh while the measured data provides a value of 444.62 kWh; this give us a 9.55% difference within both cases. The peak demand is allocated now in only 2 hours during the day while the rest remains quite similar to energy curve obtained for the winter season.

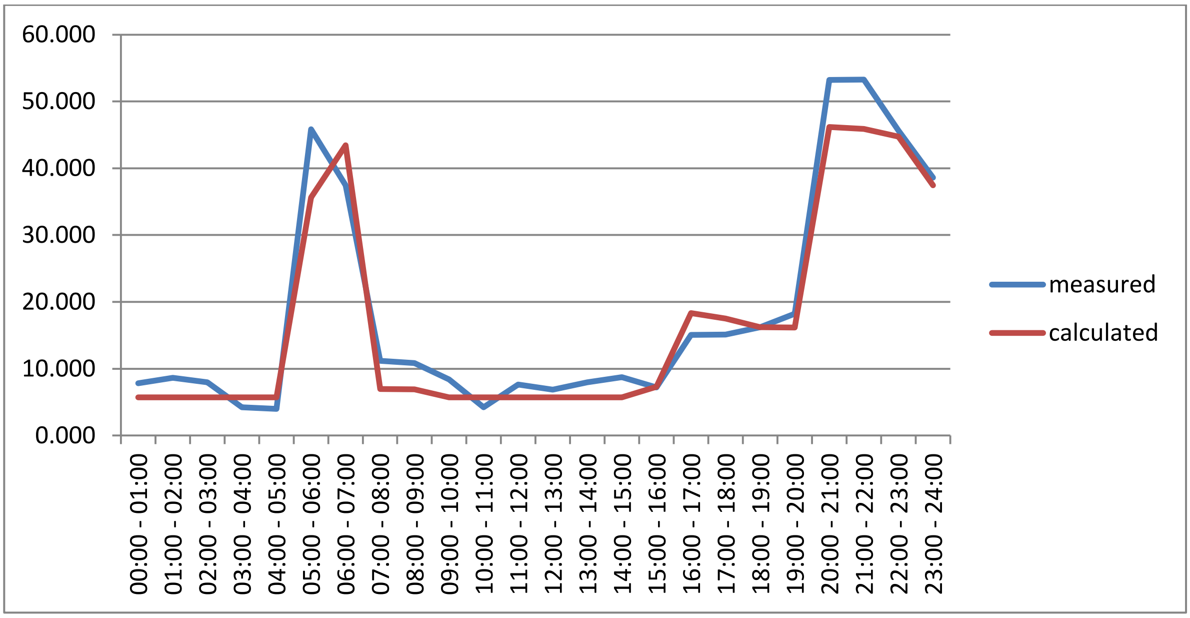


Figure 61. Comparison of the modeled load profile with measure data for a the total consumption during a day in summer of the totality of three adults or more household in the community

Finally, the same analysis was made to compare how related the measured data is compared to the results provided by the proposed model regarding to the average daily electricity consumption during a day in summer (Fig. 61). The tool allocates this type of household with a daily average consumption of 3.52 kWh while the measured data shows a consumption of 3.73 kWh per day. The difference between the two values is only 5.6% and since the curve pattern is really similar in the majority of the hours within the day it can be say that the proposed tool is capable of providing feasible results.

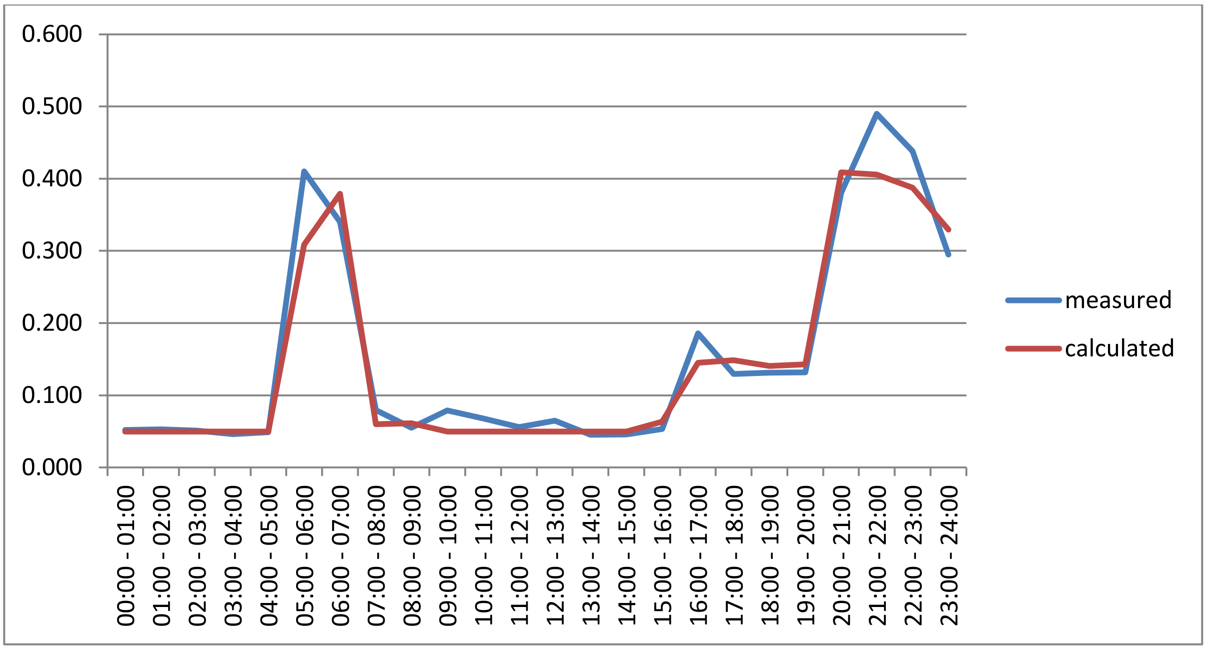


Figure 62. Comparison of the modeled load profile with measure data for a daily average consumption of a three adults or more household during a month in summer

7. Conclusions

In this thesis a method of generating realistic electricity demand profiles for the domestic sector of small communities in Mexico has been presented. This method is based partly on the information and results of previous investigations using statistics like for example a bottom-up model but it also includes an innovative part which is the proposed tariff-based technique that was introduced to create the electricity demand curves for all the type of households analysed in this paper. Both techniques together provide the user the alternative to obtain feasible results with limited and easy to fill inputs.

Six scenarios which present the behavioural characteristics and the occupancy patterns in Mexican households have been proposed to predict the diversity in electricity consumption between households. A case study was carried out for a small community located in the state of Guanajuato: Atarjea. The idea was to evaluate the functionality of the tool and its capacity to provide feasible results when compared to existent measured data.

Hourly daily electricity demand profiles for the community in question of 1218 households have been generated for the six proposed scenarios and then the average electricity consumption for an individual house which means that the whole community has been evaluated. The generated load profiles have shown a reasonable agreement compared with the measured data from the community provided by CFE.

The main objectives of this thesis were accomplished in their totality but there is still lot more work to do in order to make this tool able to cover other sectors of the community. Since it’s an easy-to-use tool that provides feasible results it is likely to be used as the first step to evaluate the suitability of introducing renewable energy systems as a way to provide the electricity demand in its totality in a wide range of isolated communities in Mexico.

8. Further work

1. Although the proposed tool is ready to use, it is not able to provide a full analysis for a complete community; modifications and additions need to be made to the model in order to add the remaining consumer's of electricity such as the industrial and public sector.

2. The idea is also to expand it so it can provide accurate results for bigger communities within the country. Right now is only focused on communities that possess between 1000-2500 households.

3. Even though all the existent tariffs for the domestic sector in Mexico were analyzed in this paper, only tariff 1 was used for the construction and analysis of the tool. Including the rest of the tariffs will be a good idea to provide a full coverage of small communities in the whole country.

4. Since this tool was constructed using the different electricity tariffs in Mexico, it does not work properly when analyzing communities in other countries. A deep individual analysis for a new country needs to be carried out in order to obtain feasible results.

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Appendix A: Prices for electricity according to the different tariffs and sub-tariffs for the domestic sector.

Tariff 1C

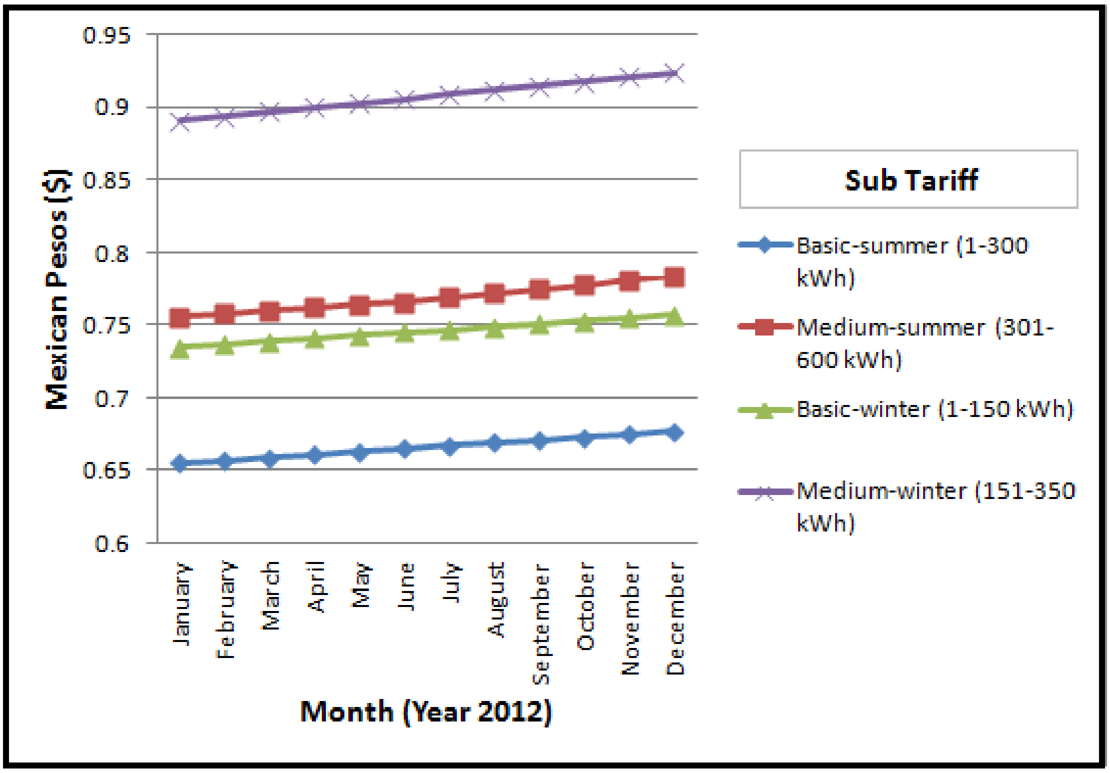

Figure 63. Price of electricity per kWh in tariff 1C for sub classifications 1 and 3

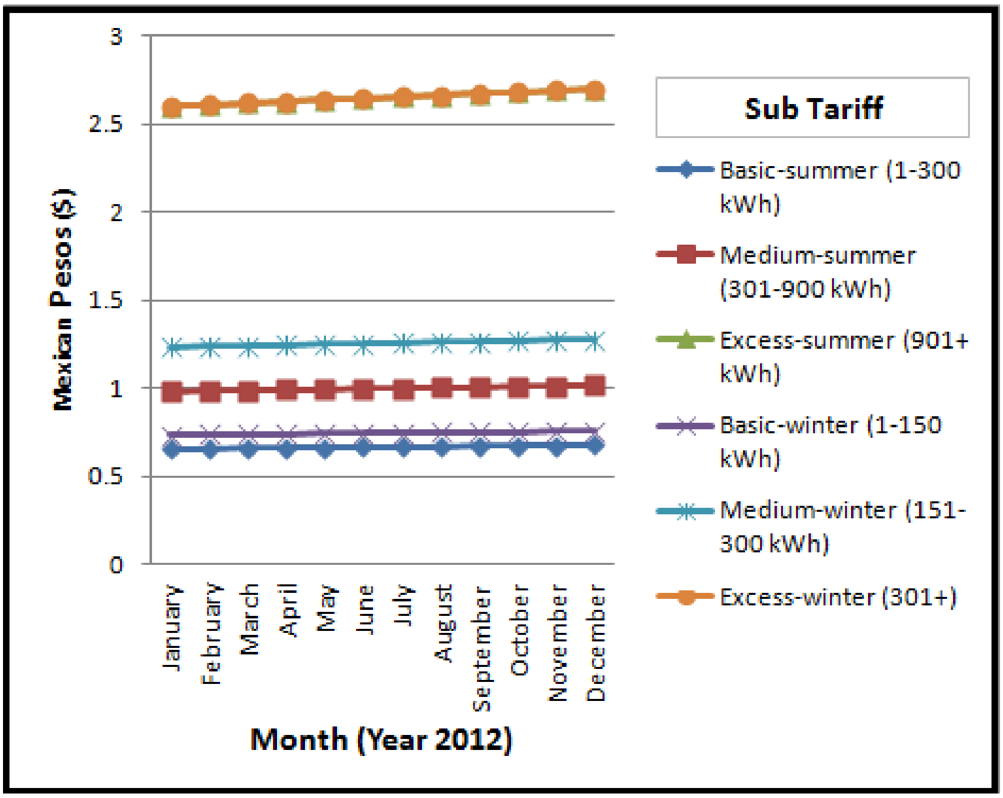

Figure 64. Price of electricity per kWh in tariff 1C for sub classifications 2 and 4

Tariff 1D

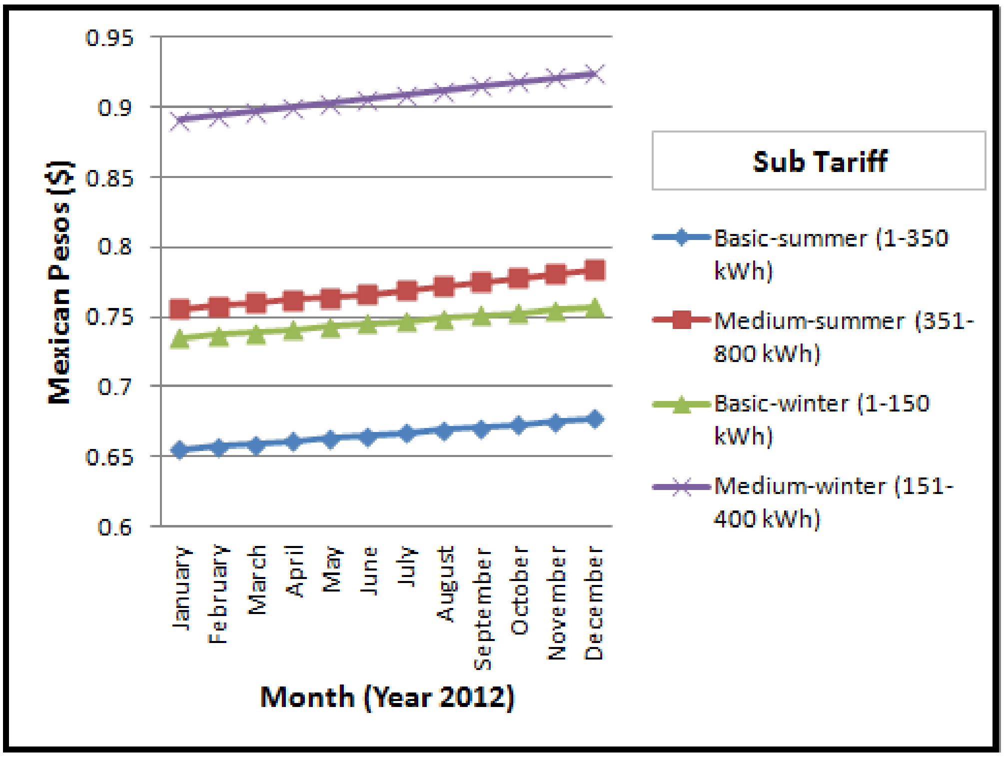

Figure 65. Price of electricity per kWh in tariff 1D for sub classifications 1 and 3

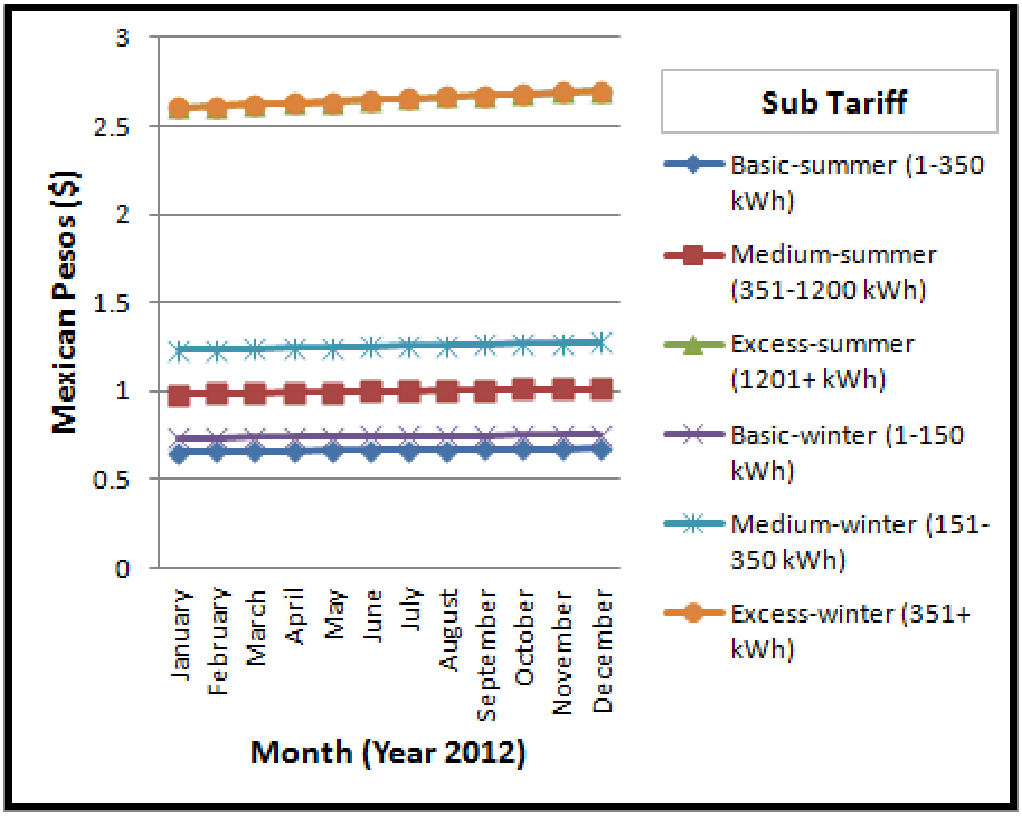

Figure 66. Price of electricity per kWh in tariff 1D for sub classifications 2 and 4

Tariff 1E

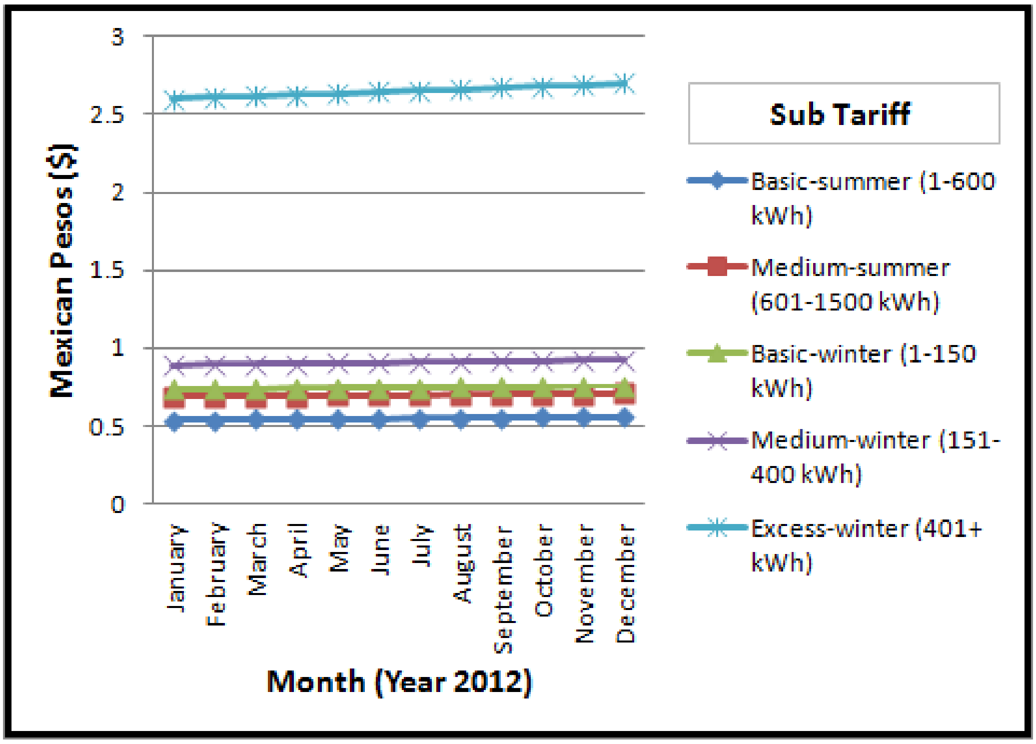

Figure 67. Price of electricity per kWh in tariff 1E for sub classifications 1 and 3

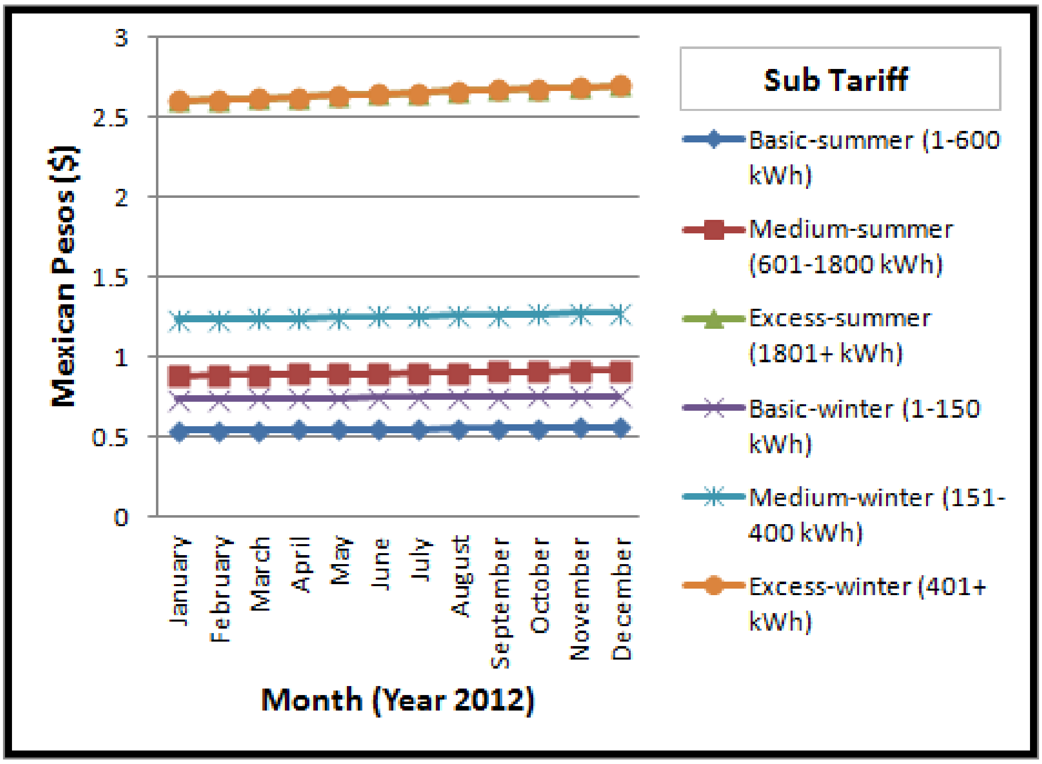

Figure 68. Price of electricity per kWh in tariff 1E for sub classifications 2 and 4

Tariff 1F

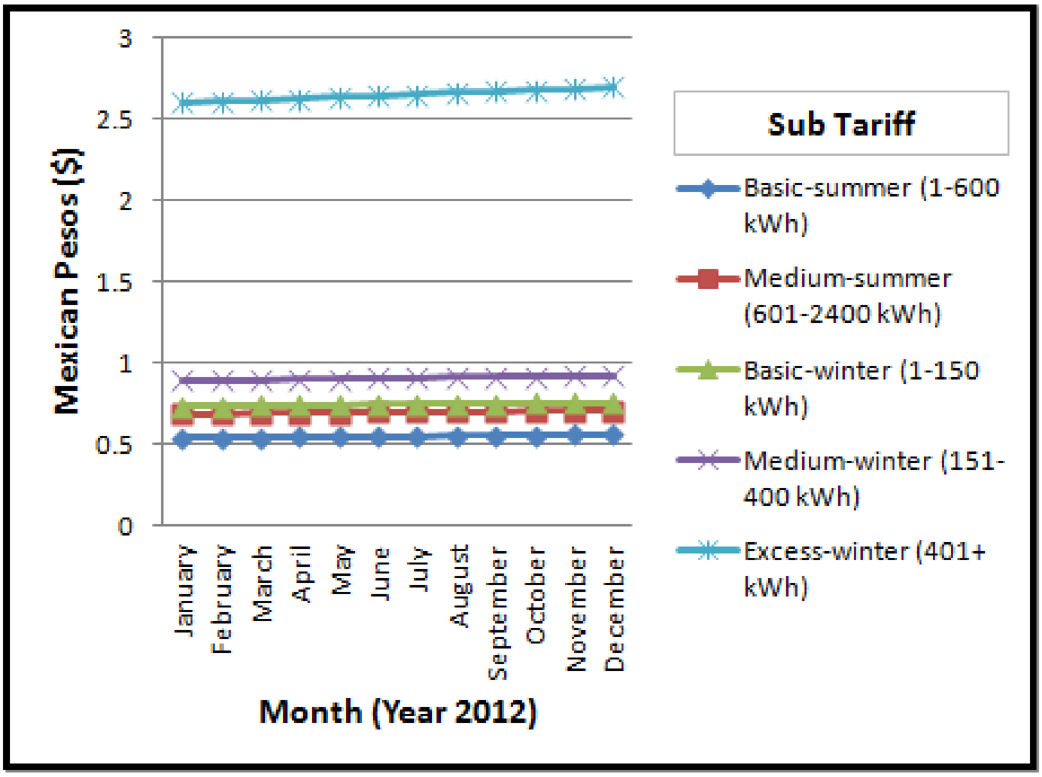

Figure 69. Price of electricity per kWh in tariff 1F for sub classifications 1 and 3

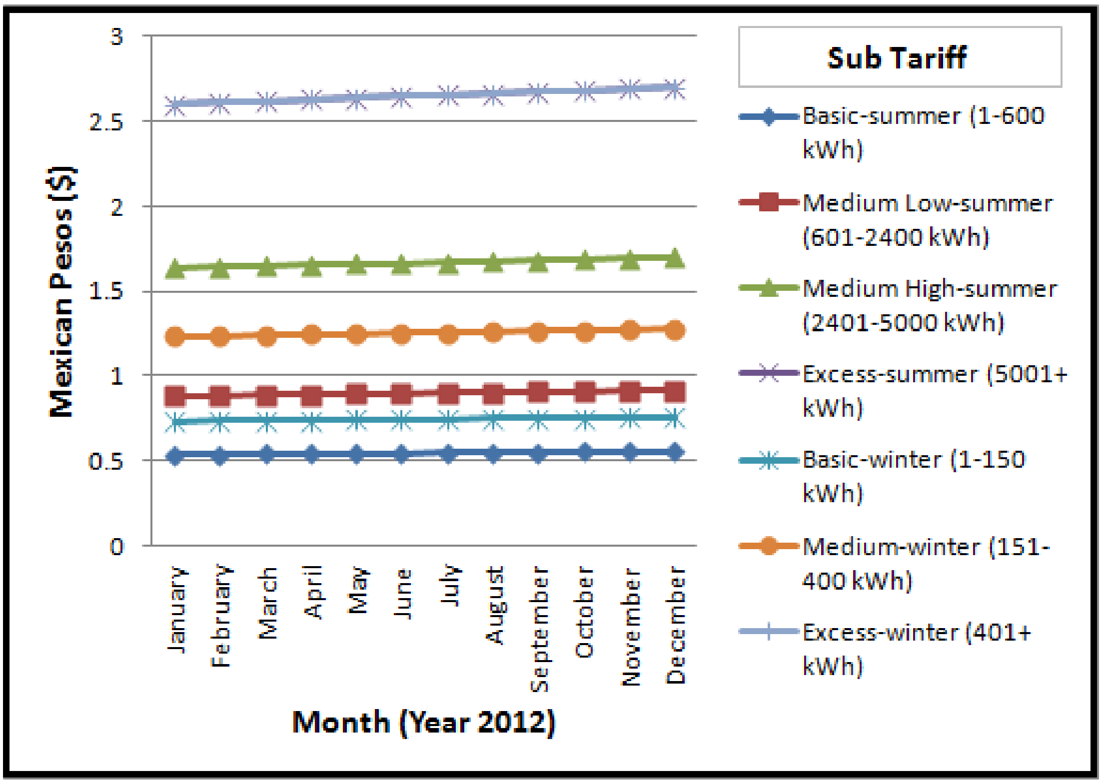

Figure 70. Price of electricity per kWh in tariff 1E for sub classifications 2 and 4

Appendix B: Results of part 1

Table 28. Electricity energy bills breakdown for the different type of households in the community within the hours in a day for the winter season (6 months).

	Single Adult	Over 60s adults	Two Adults	Two adults+ children	One adult + children	Three adults	All households
00:00 - 01:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
01:00 - 02:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
02:00 - 03:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
03:00 - 04:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
04:00 - 05:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
05:00 - 06:00	$4,742.27	$4,299.64	$8,426.06	$19,672.09	$13,298.01	$7,063.62	$57,501.70
06:00 - 07:00	$5,547.24	$4,372.55	$10,425.33	$24,542.61	$13,477.26	$8,601.73	$66,966.72
07:00 - 08:00	$787.57	$1,030.60	$1,698.91	$7,969.38	$2,790.44	$1,363.33	$15,640.22
08:00 - 09:00	$756.79	$3,238.16	$1,698.91	$6,221.98	$8,381.97	$1,392.49	$21,690.30
09:00 - 10:00	$756.79	$950.39	$1,698.91	$3,365.52	$8,585.52	$1,138.34	$16,495.47
10:00 - 11:00	$756.79	$1,430.33	$1,698.91	$3,365.52	$4,013.70	$1,138.34	$12,403.58
11:00 - 12:00	$756.79	$1,077.73	$1,698.91	$3,365.52	$2,944.02	$1,138.34	$10,981.29
12:00 - 13:00	$756.79	$1,219.15	$1,698.91	$3,365.52	$3,480.20	$1,138.34	$11,658.89
13:00 - 14:00	$756.79	$3,723.32	$1,698.91	$10,159.27	$10,420.62	$1,138.34	$27,897.23
14:00 - 15:00	$756.79	$3,805.26	$1,698.91	$10,160.80	$10,255.87	$1,138.34	$27,815.96
15:00 - 16:00	$521.99	$735.39	$1,317.11	$3,268.27	$1,987.58	$969.10	$8,799.44
16:00 - 17:00	$1,697.54	$1,086.47	$3,954.38	$6,042.37	$2,944.02	$3,800.36	$19,525.13
17:00 - 18:00	$1,679.44	$1,189.18	$4,146.48	$5,564.87	$3,484.79	$3,568.84	$19,633.59
18:00 - 19:00	$13,786.84	$17,021.62	$25,853.75	$66,046.26	$50,498.51	$21,883.18	$195,090.16
19:00 - 20:00	$14,035.40	$16,578.13	$26,181.34	$64,557.49	$49,386.20	$22,694.20	$193,432.75
20:00 - 21:00	$14,177.43	$16,671.89	$26,801.92	$63,337.27	$49,434.40	$21,956.00	$192,378.91
21:00 - 22:00	$14,021.72	$16,334.30	$26,651.01	$62,050.38	$48,547.39	$22,137.92	$189,742.72
22:00 - 23:00	$5,679.63	$6,665.18	$10,713.61	$24,114.94	$19,421.21	$8,797.02	$75,391.60
23:00 - 24:00	$4,890.99	$4,299.64	$8,709.72	$19,405.44	$13,298.01	$7,310.31	$57,914.11
TOTAL	$89,475.53	$108,738.37	$172,631.07	$418,182.33	$324,439.66	$142,293.98	$1,255,760.93

Table 29. Electricity consumption breakdown (kWh) for the different type of households in the community within the hours in a day for the winter season (6 months)

	Single Adult	Over 60s adults	Two Adults	Two adults+ children	One adult + children	Three adults	All households
00:00 - 01:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
01:00 - 02:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
02:00 - 03:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
03:00 - 04:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
04:00 - 05:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
05:00 - 06:00	4,378.83	3,970.12	7,780.30	18,164.45	12,278.86	6,522.27	53,094.83
06:00 - 07:00	5,122.11	4,037.44	9,626.35	22,661.69	12,444.37	7,942.50	61,834.46
07:00 - 08:00	727.21	951.62	1,568.70	7,358.61	2,576.58	1,258.84	14,441.57
08:00 - 09:00	698.79	2,989.99	1,568.70	5,745.13	7,739.59	1,285.78	20,027.98
09:00 - 10:00	698.79	877.56	1,568.70	3,107.59	7,927.54	1,051.10	15,231.27
10:00 - 11:00	698.79	1,320.71	1,568.70	3,107.59	3,706.09	1,051.10	11,452.98
11:00 - 12:00	698.79	995.13	1,568.70	3,107.59	2,718.39	1,051.10	10,139.69
12:00 - 13:00	698.79	1,125.71	1,568.70	3,107.59	3,213.48	1,051.10	10,765.36
13:00 - 14:00	698.79	3,437.97	1,568.70	9,380.67	9,622.00	1,051.10	25,759.22
14:00 - 15:00	698.79	3,513.63	1,568.70	9,382.09	9,469.87	1,051.10	25,684.18
15:00 - 16:00	698.79	984.46	1,763.20	4,375.19	2,660.74	1,297.32	11,779.70
16:00 - 17:00	1,567.44	1,003.20	3,651.32	5,579.29	2,718.39	3,509.10	18,028.74
17:00 - 18:00	1,550.73	1,098.04	3,828.70	5,138.38	3,217.72	3,295.33	18,128.90
18:00 - 19:00	5,202.58	6,423.25	9,756.13	24,923.12	19,056.04	8,257.81	73,618.93
19:00 - 20:00	5,296.38	6,255.90	9,879.75	24,361.32	18,636.30	8,563.85	72,993.49
20:00 - 21:00	5,349.97	6,291.28	10,113.93	23,900.86	18,654.49	8,285.28	72,595.81
21:00 - 22:00	5,291.22	6,163.89	10,056.99	23,415.24	18,319.77	8,353.93	71,601.03
22:00 - 23:00	5,244.35	6,154.37	9,892.53	22,266.80	17,932.79	8,122.83	69,613.66
23:00 - 24:00	4,516.15	3,970.12	8,042.22	17,918.22	12,278.86	6,750.06	53,475.63
TOTAL	53,331.19	65,593.10	104,784.55	252,539.35	195,600.20	85,006.95	756,855.34

Table 30. Electricity energy bills breakdown for the different type of households in the community within the hours in a day for the summer season (6 months).

	Single Adult	Over 60s adults	Two Adults	Two adults+ children	One adult + children	Three adults	All households
00:00 - 01:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
01:00 - 02:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
02:00 - 03:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
03:00 - 04:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
04:00 - 05:00	$521.99	$601.89	$1,171.82	$2,321.37	$1,557.99	$785.17	$6,960.23
05:00 - 06:00	$4,743.89	$4,299.64	$8,448.75	$19,628.76	$13,298.01	$7,055.29	$57,474.33
06:00 - 07:00	$5,555.35	$4,389.56	$10,402.65	$24,585.94	$13,504.60	$8,610.06	$67,048.16
07:00 - 08:00	$777.85	$699.12	$1,171.82	$7,956.05	$1,905.85	$966.22	$13,476.91
08:00 - 09:00	$521.99	$3,238.16	$1,698.91	$6,235.31	$8,381.97	$1,355.00	$21,431.34
09:00 - 10:00	$756.79	$945.53	$1,698.91	$2,321.37	$8,594.64	$1,138.34	$15,455.57
10:00 - 11:00	$756.79	$1,411.78	$1,698.91	$3,365.52	$3,751.33	$1,138.34	$12,122.65
11:00 - 12:00	$756.79	$1,028.40	$1,698.91	$3,365.52	$3,063.04	$1,138.34	$11,050.98
12:00 - 13:00	$756.79	$1,223.20	$1,698.91	$3,365.52	$3,564.10	$1,138.34	$11,746.85
13:00 - 14:00	$756.79	$3,759.91	$1,698.91	$10,325.05	$10,352.33	$1,138.34	$28,031.32
14:00 - 15:00	$756.79	$3,760.87	$1,698.91	$10,149.56	$10,168.46	$1,138.34	$27,672.92
15:00 - 16:00	$756.79	$1,189.80	$1,951.67	$4,293.73	$3,032.99	$1,413.33	$12,638.31
16:00 - 17:00	$1,665.24	$1,021.85	$4,067.19	$5,989.45	$2,950.66	$3,431.51	$19,125.89
17:00 - 18:00	$1,784.67	$1,227.89	$4,094.59	$5,773.93	$3,545.27	$3,570.41	$19,996.76
18:00 - 19:00	$1,729.83	$3,507.24	$3,837.48	$10,610.64	$9,584.29	$3,447.95	$32,717.42
19:00 - 20:00	$1,723.74	$3,372.17	$4,020.49	$10,203.11	$9,159.95	$3,114.36	$31,593.82
20:00 - 21:00	$14,077.19	$16,613.05	$26,595.37	$64,289.40	$49,412.88	$22,081.35	$193,069.24
21:00 - 22:00	$14,028.77	$16,336.49	$26,743.59	$62,603.98	$48,533.68	$22,642.76	$190,889.26
22:00 - 23:00	$5,658.49	$6,665.18	$10,629.51	$24,114.94	$19,421.21	$8,900.25	$75,389.59
23:00 - 24:00	$4,868.48	$4,299.64	$8,800.92	$19,405.44	$13,298.01	$7,338.46	$58,010.93
TOTAL	$65,042.95	$81,998.93	$128,515.46	$310,190.06	$243,313.21	$104,682.81	$933,743.42

Table 31. Electricity consumption breakdown (kWh) for the different type of households in the community within the hours in a day for the winter season (6 months)

	Single Adult	Over 60s adults	Two Adults	Two adults+ children	One adult + children	Three adults	All households
00:00 - 01:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
01:00 - 02:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
02:00 - 03:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
03:00 - 04:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
04:00 - 05:00	698.79	805.74	1,568.70	3,107.59	2,085.66	1,051.10	9,317.58
05:00 - 06:00	4,380.33	3,970.12	7,801.24	18,124.43	12,278.86	6,514.58	53,069.56
06:00 - 07:00	5,129.59	4,053.15	9,605.40	22,701.70	12,469.62	7,950.20	61,909.66
07:00 - 08:00	718.24	935.91	1,568.70	7,346.30	2,551.33	1,293.47	14,413.95
08:00 - 09:00	698.79	2,989.99	1,568.70	5,757.44	7,739.59	1,251.15	20,005.66
09:00 - 10:00	698.79	873.07	1,568.70	3,107.59	7,935.95	1,051.10	15,235.20
10:00 - 11:00	698.79	1,303.58	1,568.70	3,107.59	3,463.83	1,051.10	11,193.59
11:00 - 12:00	698.79	949.58	1,568.70	3,107.59	2,828.29	1,051.10	10,204.05
12:00 - 13:00	698.79	1,129.46	1,568.70	3,107.59	3,290.95	1,051.10	10,846.58
13:00 - 14:00	698.79	3,471.75	1,568.70	9,533.75	9,558.94	1,051.10	25,883.02
14:00 - 15:00	698.79	3,472.64	1,568.70	9,371.71	9,389.16	1,051.10	25,552.10
15:00 - 16:00	698.79	1,098.62	1,802.10	3,964.66	2,800.55	1,305.01	11,669.73
16:00 - 17:00	1,537.62	943.53	3,755.48	5,530.43	2,724.52	3,168.52	17,660.10
17:00 - 18:00	1,647.90	1,133.78	3,780.78	5,331.42	3,273.56	3,296.78	18,464.23
18:00 - 19:00	1,597.25	3,238.45	3,543.38	9,797.45	8,849.76	3,183.70	30,209.99
19:00 - 20:00	1,591.63	3,113.73	3,712.36	9,421.15	8,457.94	2,875.68	29,172.50
20:00 - 21:00	5,312.15	6,269.08	10,035.99	24,260.15	18,646.37	8,332.58	72,856.32
21:00 - 22:00	5,293.87	6,164.71	10,091.92	23,624.14	18,314.60	8,544.44	72,033.68
22:00 - 23:00	5,224.83	6,154.37	9,814.87	22,266.80	17,932.79	8,218.15	69,611.81
23:00 - 24:00	4,495.36	3,970.12	8,126.42	17,918.22	12,278.86	6,776.05	53,565.04
TOTAL	46,012.99	59,264.35	92,463.10	222,918.07	175,213.79	74,272.35	670,144.66

Appendix C: Results of part 2

Table 32.Daily average electricity consumption for the six scenarios in a normal day during the winter season

	Single Adult	Over 60s adults	Two Adults	Two adults+ children	One adult + children	Three adults
00:00 - 01:00	0.02	0.04	0.04	0.05	0.05	0.05
01:00 - 02:00	0.02	0.04	0.04	0.05	0.05	0.05
02:00 - 03:00	0.02	0.04	0.04	0.05	0.05	0.05
03:00 - 04:00	0.02	0.04	0.04	0.05	0.05	0.05
04:00 - 05:00	0.02	0.04	0.04	0.05	0.05	0.05
05:00 - 06:00	0.12	0.19	0.19	0.29	0.29	0.31
06:00 - 07:00	0.14	0.20	0.24	0.37	0.29	0.38
07:00 - 08:00	0.02	0.05	0.04	0.12	0.06	0.06
08:00 - 09:00	0.02	0.15	0.04	0.09	0.18	0.06
09:00 - 10:00	0.02	0.04	0.04	0.05	0.19	0.05
10:00 - 11:00	0.02	0.07	0.04	0.05	0.08	0.05
11:00 - 12:00	0.02	0.05	0.04	0.05	0.07	0.05
12:00 - 13:00	0.02	0.06	0.04	0.05	0.08	0.05
13:00 - 14:00	0.02	0.16	0.04	0.16	0.22	0.05
14:00 - 15:00	0.02	0.16	0.04	0.15	0.22	0.05
15:00 - 16:00	0.02	0.05	0.04	0.06	0.06	0.06
16:00 - 17:00	0.04	0.05	0.10	0.09	0.06	0.15
17:00 - 18:00	0.04	0.05	0.10	0.09	0.08	0.16
18:00 - 19:00	0.15	0.31	0.25	0.39	0.45	0.40
19:00 - 20:00	0.15	0.30	0.25	0.40	0.44	0.40
20:00 - 21:00	0.15	0.31	0.25	0.39	0.44	0.40
21:00 - 22:00	0.15	0.30	0.25	0.39	0.43	0.40
22:00 - 23:00	0.15	0.30	0.25	0.36	0.42	0.39
23:00 - 24:00	0.13	0.19	0.20	0.29	0.29	0.33
TOTAL	1.50	3.19	2.62	4.08	4.59	4.06

Table 33.Daily average electricity consumption for the six scenarios in a normal day during the summer season

	Single Adult	Over 60s adults	Two Adults	Two adults+ children	One adult + children	Three adults
00:00 - 01:00	0.02	0.04	0.04	0.05	0.05	0.05
01:00 - 02:00	0.02	0.04	0.04	0.05	0.05	0.05
02:00 - 03:00	0.02	0.04	0.04	0.05	0.05	0.05
03:00 - 04:00	0.02	0.04	0.04	0.05	0.05	0.05
04:00 - 05:00	0.02	0.04	0.04	0.05	0.05	0.05
05:00 - 06:00	0.12	0.19	0.19	0.29	0.29	0.31
06:00 - 07:00	0.14	0.19	0.24	0.36	0.29	0.38
07:00 - 08:00	0.02	0.05	0.04	0.12	0.06	0.06
08:00 - 09:00	0.02	0.14	0.04	0.09	0.18	0.06
09:00 - 10:00	0.02	0.04	0.04	0.05	0.19	0.05
10:00 - 11:00	0.02	0.06	0.04	0.05	0.08	0.05
11:00 - 12:00	0.02	0.05	0.04	0.05	0.07	0.05
12:00 - 13:00	0.02	0.06	0.04	0.05	0.08	0.05
13:00 - 14:00	0.02	0.16	0.04	0.16	0.22	0.05
14:00 - 15:00	0.02	0.16	0.04	0.15	0.22	0.05
15:00 - 16:00	0.02	0.05	0.04	0.06	0.06	0.06
16:00 - 17:00	0.04	0.05	0.10	0.09	0.06	0.15
17:00 - 18:00	0.04	0.05	0.10	0.08	0.08	0.16
18:00 - 19:00	0.04	0.16	0.09	0.15	0.21	0.14
19:00 - 20:00	0.05	0.15	0.09	0.16	0.20	0.15
20:00 - 21:00	0.15	0.30	0.25	0.39	0.44	0.40
21:00 - 22:00	0.15	0.30	0.25	0.38	0.43	0.40
22:00 - 23:00	0.15	0.30	0.25	0.36	0.42	0.39
23:00 - 24:00	0.12	0.19	0.20	0.29	0.29	0.32
TOTAL	1.28	2.87	2.30	3.58	4.09	3.53

Appendix D: Results of part 3

Table 34. Electricity consumption for the all the households within six scenarios in a normal day during the winter season

	Single Adult	Over 60s adults	Two Adults	Two adults+ children	One adult + children	Three adults
00:00 - 01:00	3.84	4.43	8.62	17.07	11.46	5.78
01:00 - 02:00	3.84	4.43	8.62	17.07	11.46	5.78
02:00 - 03:00	3.84	4.43	8.62	17.07	11.46	5.78
03:00 - 04:00	3.84	4.43	8.62	17.07	11.46	5.78
04:00 - 05:00	3.84	4.43	8.62	17.07	11.46	5.78
05:00 - 06:00	24.05	21.81	42.81	99.80	67.47	35.71
06:00 - 07:00	28.23	22.11	52.83	124.51	68.61	43.77
07:00 - 08:00	3.92	5.30	8.62	40.26	13.93	6.85
08:00 - 09:00	3.84	16.43	8.62	31.74	42.53	7.13
09:00 - 10:00	3.84	4.72	8.62	17.07	43.54	5.78
10:00 - 11:00	3.84	7.36	8.62	17.07	19.28	5.78
11:00 - 12:00	3.84	5.55	8.62	17.07	15.71	5.78
12:00 - 13:00	3.84	6.53	8.62	17.07	18.22	5.78
13:00 - 14:00	3.84	18.63	8.62	53.11	52.35	5.78
14:00 - 15:00	3.84	18.32	8.62	51.06	51.97	5.78
15:00 - 16:00	3.84	5.91	9.66	22.09	14.82	7.17
16:00 - 17:00	8.73	5.67	21.03	30.33	14.55	17.19
17:00 - 18:00	8.41	6.01	21.17	28.93	17.77	18.12
18:00 - 19:00	28.55	35.49	53.91	133.76	105.15	46.11
19:00 - 20:00	29.11	34.44	54.02	134.59	102.50	46.31
20:00 - 21:00	29.38	34.48	54.46	131.67	102.40	46.49
21:00 - 22:00	29.15	33.89	54.73	131.24	100.64	46.11
22:00 - 23:00	28.97	33.82	54.26	122.35	98.53	45.13
23:00 - 24:00	24.62	21.81	44.81	98.45	67.47	37.46
TOTAL	293.03	360.40	575.74	1387.58	1074.73	467.07

Table 35. Electricity consumption for the all the households within six scenarios in a normal day during the summer season

	Single Adult	Over 60s adults	Two Adults	Two adults+ children	One adult + children	Three adults
00:00 - 01:00	3.82	4.40	8.57	16.98	11.40	5.74
01:00 - 02:00	3.82	4.40	8.57	16.98	11.40	5.74
02:00 - 03:00	3.82	4.40	8.57	16.98	11.40	5.74
03:00 - 04:00	3.82	4.40	8.57	16.98	11.40	5.74
04:00 - 05:00	3.82	4.40	8.57	16.98	11.40	5.74
05:00 - 06:00	23.92	21.69	42.58	99.26	67.10	35.51
06:00 - 07:00	28.07	21.99	52.54	123.83	68.23	43.53
07:00 - 08:00	3.90	5.27	8.57	40.04	13.85	6.82
08:00 - 09:00	3.82	16.34	8.57	31.56	42.29	7.09
09:00 - 10:00	3.82	4.70	8.57	16.98	43.30	5.74
10:00 - 11:00	3.82	7.32	8.57	16.98	19.17	5.74
11:00 - 12:00	3.82	5.52	8.57	16.98	15.63	5.74
12:00 - 13:00	3.82	6.49	8.57	16.98	18.12	5.74
13:00 - 14:00	3.82	18.53	8.57	52.82	52.06	5.74
14:00 - 15:00	3.82	18.22	8.57	50.79	51.69	5.74
15:00 - 16:00	3.82	5.88	9.60	21.97	14.74	7.13
16:00 - 17:00	8.68	5.64	20.92	30.16	14.47	17.10
17:00 - 18:00	8.36	5.98	21.05	28.77	17.68	18.02
18:00 - 19:00	8.40	18.00	19.95	52.10	48.87	16.53
19:00 - 20:00	8.96	16.96	20.06	52.93	46.24	16.72
20:00 - 21:00	29.21	34.29	54.16	130.96	101.84	46.24
21:00 - 22:00	28.99	33.70	54.43	130.53	100.09	45.86
22:00 - 23:00	28.81	33.63	53.96	121.68	97.99	44.89
23:00 - 24:00	24.49	21.69	44.56	97.91	67.10	37.25
TOTAL	251.44	323.85	505.26	1218.13	957.45	405.86