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Electricity Consumption Characterization of the Different End-use Sectors of Brazil

Justo J. Roberts^{a1}, Agnelo M. Cassula^a, Ines Hauer^b

^aUNESP - Engineering Faculty, UNESP- Univ Estadual Paulista, Campus of Guaratinguetá, Brazil

^bOVGU – Otto-von-Guericke-University, Magdeburg, Germany

Abstract

Information about electrical consumption characteristics of the different economic sectors is crucial for any countries' electricity sector, and Brazil is not an exception. The country has experienced a continuous economic growth during the last years that has influenced the way electric energy is consumed. In this context, the present study aims to present the major findings of a literature review in order to characterize the Brazilian electricity sector. The characteristics of the residential, commercial and industrial subsectors that comprise the electricity sector are presented, as well as further information about their consumption profile. It is observed a higher amount of works devoted to study the residential sector, on the contrary there is a lack of newly researches focusing on the commercial and industrial sectors.

Keywords: brazil; commercial sector; electricity consumption; industrial sector; load profile; residential sector.

1. Introduction

The load to be supplied by a generation system can be represented by a load curve or load profile, which depicts the energy demand as a function of time $D(t)$ for a given time interval T , in kWh [1]. A load profile represents the pattern of electricity usage of a segment of supply market customers. It gives an hourly pattern or 'shape' of usage across a day, and the pattern across the year, for the average customer of each of the profile classes. Typically, a load profile will vary according to customer type, temperature and holiday seasons [2].

The formulation of representative load curves for single consumers and groups of consumers is referred as load profiling. Based on a certain criteria, the consumers can be grouped together in a number of classes like residential, industrial, etc., but also in subcategories within these classes [3]. Load profiling has been identified as one suitable method of dealing with customers without time interval metering equipment [4]. Besides, knowing the characteristics of the loads to be supplied by a distribution system, the knowledge of the load profile of the consumer units entails advantages to the electric utilities [4], [5]. It enables the forecast of contracting power demand, especially at peak hour, thus improving the efficiency of the system and ensuring safe and reliable network supply. The distribution companies can improve their market strategies and offer new services, as well as develop new tariffs with this information. It permits the optimization of resources for planning the expansion of the distribution and transmission systems, as well as the generation plant. Allows a more detailed analysis for better elaborating a tariff framework for the consumers, as well as enables the identification of energy efficiency measures through demand management, thus contributing to energy consumption reduction. Finally, load

¹ Corresponding author: justo@feg.unesp.br

profiling enables the consumers to play an active role in the competitive electricity markets. With accurate information of its demand pattern, the consumer is encouraged to alter its demand in periods where the generation cost is high.

The aforementioned reinforces the importance of knowing the electrical consumption characteristics of the different economic sectors. Since it constitutes strategic information for a good planning of the energy sector, a proper demand forecasting and assists in identifying rationalization measures.

In Brazil, scarce information can be founded in relation to the characterization of consumer load profile. Thus, the objective of this research was to gather the available information in the literature and present in the present article the most important findings derived from it, in order to give an overview of the Brazilian electricity sector in relation to consumer profiling.

The remainder of this work is organized as follows: Section 2 gives a brief description of the electrical system in Brazil, presenting the characteristics of the generation, transmission and distribution sectors in which it is divided. Section 3 introduces further information about the present situation of electricity consumption in Brazil displaying graphics on the historical development of this sector. The characteristics of the residential, commercial and industrial sectors are given in Section 4. Also in this Section the load profile of these sectors is characterized based on information obtained from a literature review. Finally, Section 5 summarizes the main conclusions of the present work.

2. Characteristics of the Brazilian Electrical Sector

The Brazilian electric system, which allows the exchange of energy between the various regions of the country, comprises three segments: generation, transmission and distribution of electricity. The geographical characteristics of Brazil determined the configuration the systems for generation, transmission and distribution have acquired over time and further determine the ease for access the grid for the local population.

With respect to the generation segment, Brazil has in 2014, 3,263 plants in operation, corresponding to an installed capacity of 135,870 MW (excluding the Paraguayan participation in the Itaipu binational hydroelectric power plant) [6]. Historically the country has relied heavily on hydroelectric generation, but the Energy Research Company (EPE), bureau in charge of energy planning in Brazil, intends to diversify the energy mix in order to reduce the dependency relationship between energy generation and hydrological conditions. As observed in Figure 1, two decades ago the hydroelectric generation accounted for nearly 90% of the installed capacity, in 2013 this share fell to 67.85%. Following the hydroelectric generation in order of importance is the thermal generation with 28.82% of the installed capacity, nuclear generation with 1.58% and the renewable sources (excluding hydroelectricity) comprise only 2.34% of the installed capacity. It is worth mentioning that nearly 35% of the electrical energy generated through thermal processes is due to biomass combustion, mainly sugar cane residues [7].

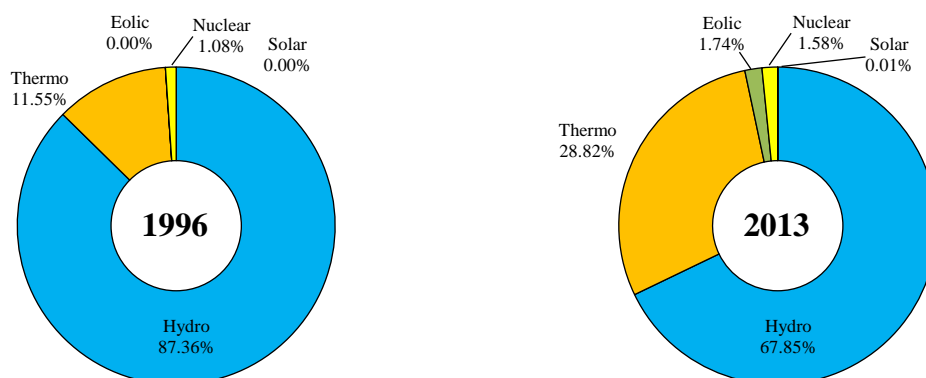


Figure 1. Evolution of the installed capacity for electricity generation from 1996 to 2013 [8].

The transmission sector in Brazil is composed of more than 100,000 km of electric lines and operated by 64 utilities. The vast extent of the transmission network is due to the nature of the generation sector, which is mainly composed by large hydroelectric power plants located distant from the regions where the energy is consumed. The transmission sector is divided into two subsystems: the National Interconnected System (SIN in Portuguese), which covers almost the entire Brazilian territory, and the Isolated Systems. Both systems provide power to more than 99% of the 58 million households in Brazil [9].

The SIN is extended through the South, Southeast, Central-west, Northeast and parts of the North regions. It is composed of approximately 900 transmission lines with voltages of 230, 345, 440, 500 and 750 kV, and is responsible for transporting 96.6% of the country's total electricity production [10] (see Figure 2a).

The Isolated Systems do not exchange energy with the other regions and are predominantly supplied by thermal power plants fueled by diesel and fuel oil, but also small hydro and biomass based power plants can be found (see Figure 2b). In 2008, the Isolated Systems accounted for 3.4% of the electricity produced in the country. However, since the inclusion of Manaus (the capital city of the state of Amazonas in northern Brazil) to the SIN, the share of these systems will be restricted to less than 1%.

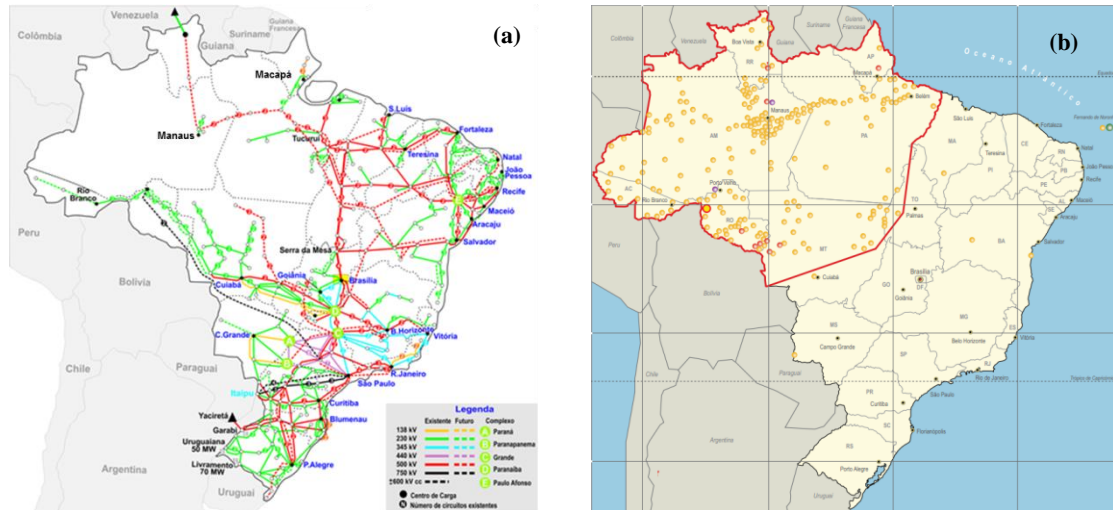


Figure 2. (a) Brazilian Interconnected System (SIN), the dotted lines represent the projected electric lines; (b) isolated systems, the yellow dots are the thermal power plants [10].

The electricity distribution network is a segment comprises the primary electrical networks (medium voltage distribution lines - 15 kV, 23 kV and 34.5 kV), and secondary networks (low voltage distributions lines - 230/115 V, 220/380 and 127V / 220V), whose construction, operation and maintenance is the responsibility of the electricity distribution utilities [10].

The standard voltage for residential consumers is usually 127 V or 220 V, depending on the region, with a frequency of 60 Hz. The common transportation constructions are overhead lines, especially in rural areas and small cities but there are also underground cable systems in big cities [11].

One big problem faced by the Brazilian electrical sector is the unusually high loss of energy. The total energy losses in the transmission and distribution system correspond to 14.4% of the total generated energy. This percentage is twice the world's average, and nearly three times the European average [12].

3. Electricity: Current Demand and Future Projections

In 2013, the electricity consumption in Brazil attained the amount of 516.4 TWh, with a per capita consumption of 2379.9 kWh/year [7]. The country is divided into five geopolitical regions according to geographic, social and economic factors. Each of these regions has a different level of participation in the overall electricity consumption. As it can be seen in Figure 3 the North region encloses 45% of the total land area, accounts for just 8% of the population and is responsible for 6.5% of the electricity consumption. In contrast, the Southeast region corresponds to 11% of the total land area, houses 42% of the population, and is responsible for about 52% of the electricity consumption. In the same Figure 3 the electricity consumption per capita is shown for all the regions. The Southeast and South regions present a per capita electricity consumption above the national average.

In order to monitor the evolution of electricity demand and projecting future scenarios, the EPE has a historical database in which the energy sector is divided into four sub-sectors: residential, commercial, industrial and other². Figure 4 was build based in that information and it depicts the evolution of electricity demand from 1962 to 2008.

²Other = rural + public lighting + public service + public entities + self-consumption.

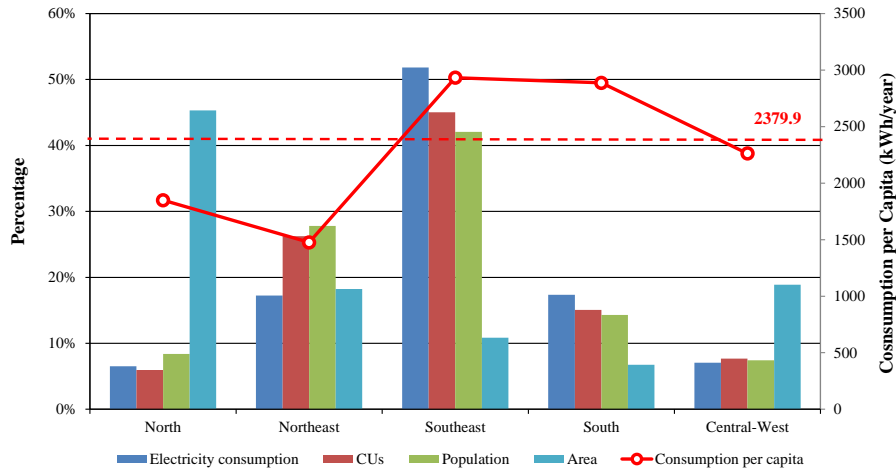


Figure 3. Percentage of electricity consumption, consumer units (CUs), population land area and electricity consumption per capita per geographic region of Brazil for the year 2012 [7], [13].

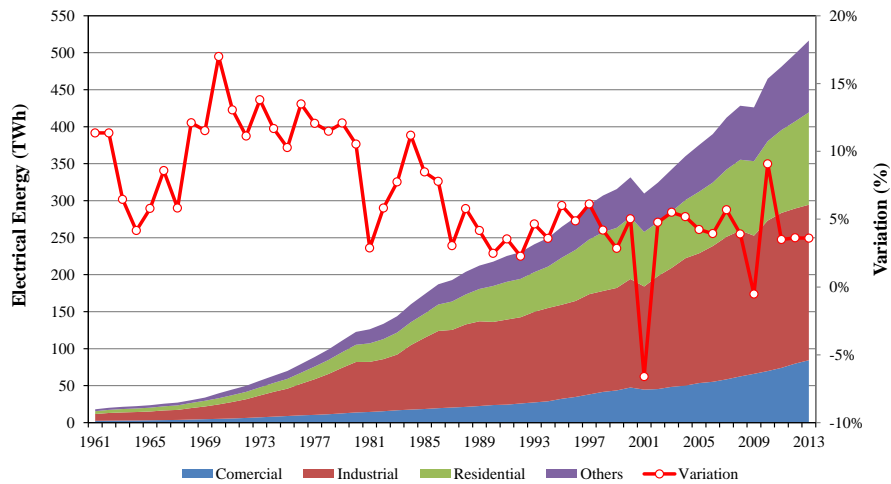


Figure 4. Evolution of the electrical energy consumption in Brazil in the period 1961-2013 [14].

It can be observed that, over the last 51 years, the total electricity consumption in the country has increased almost 30 times, which means an average annual rate of growth of approximately 6.8% year-to-year.

Although it was observed a net positive growth over the last decades, changes in consumption are usually not evenly distributed over time, as they depend on a number of factors such as the average income of the country, the price of energy, the stock of electric appliances, the installed capacity of the industry, the level of industrial activity, the price of substitutes (only in the industry), among others [15]. The aforementioned can be observed in the same Figure 4, which presents the variation in the annual growth rate of electricity consumption in Brazil.

The annual growth rate can be correlated with the economic situation of the country. During the years of the "Brazilian miracle" (70s) the growth rates were higher, exceeding an average of 11% year-to-year and reaching the historical peak of 17% between 1970 and 1971. After the second half of the 1980s decade, the historical averages remained at a much lower level, attaining the lowest value of -6.6% in 2001, year when the crisis that led to rationing in the electricity sector took place.

Historically, the industry represents the highest share due to the volume of energy consumption, but in recent years there has been a slight decrease in its participation. In the 70s its average contribution was 52.6%, however during the last ten years its share fell to 45%. The next sector in importance is the residential, which has increased its share from 19.5% to 22.8%. Likewise, the commercial sector and "others" had increased their share to 20% and 12% respectively, compared to 1970 [7].

Regarding future projections, the Electricity Demand Projection Plan 2014-2023, developed by the EPE, estimates an average growth rate of electricity consumption of 4% per year, reaching almost 689 GWh in 2023. The same study shows that the commercial sector will experiment the greatest expansion in relation to other market segments [16].

4. Load Profile for Commercial, Industrial and Residential Consumers in Brazil

From the literature review performed for the present study, it was evident that there is not much published information related to consumer profiling in Brazil. Some of the most salient works are mentioned following:

- 1) During the 1990s, Prof. Dr. J.A. Jardini and his research group from the São Paulo University performed a series of field measurements to determine consumers' daily load profile behavior, obtaining the representative curves of the most important consumers' classes, *i.e.* residential, commercial and industrial. The measurements were performed: in 1992 and 1993 for residential; in 1993 and 1994 for the commercial; and in 1994 and 1995 for the industrial segment. The results of this research were published in [17].
- 2) More recently, between the years 2005 and 2006, Eletrobras with the support of the United Nations Development Program (UNDP) and with funds donated by the Global Environment Facility (GEF) through the World Bank, conducted the research entitled "Assessment of Energy Efficiency Market in Brazil" [18]. This research project aimed obtaining information to adequately assess the market for energy efficiency in the country and the impact of rationing strategies, in search for a more efficient use of electricity. This study, that covered the commercial, industrial and residential consumption sectors, gathered information from 17 states provided by 21 electric utilities. The results of this research were published in the reports [19]–[21].

Based on the aforementioned references, in the following sections there are described the characteristics of the Brazilian Residential, Industrial and Commercial consumer sectors, providing further information about their electric load profile.

4.1. Commercial Sector

The commercial sector represented in 2013 approximately 16% of total electricity consumption in Brazil. This sector has experienced a continuous growth in the last decades, as seen in Figure 4.

In Figure 5a, the business type of installations with the largest representation in the commercial sector are depicted. It can be observed that hotels, supermarkets and banks together represent a share of over 57%; other salient facilities are hospitals and educational institutions.

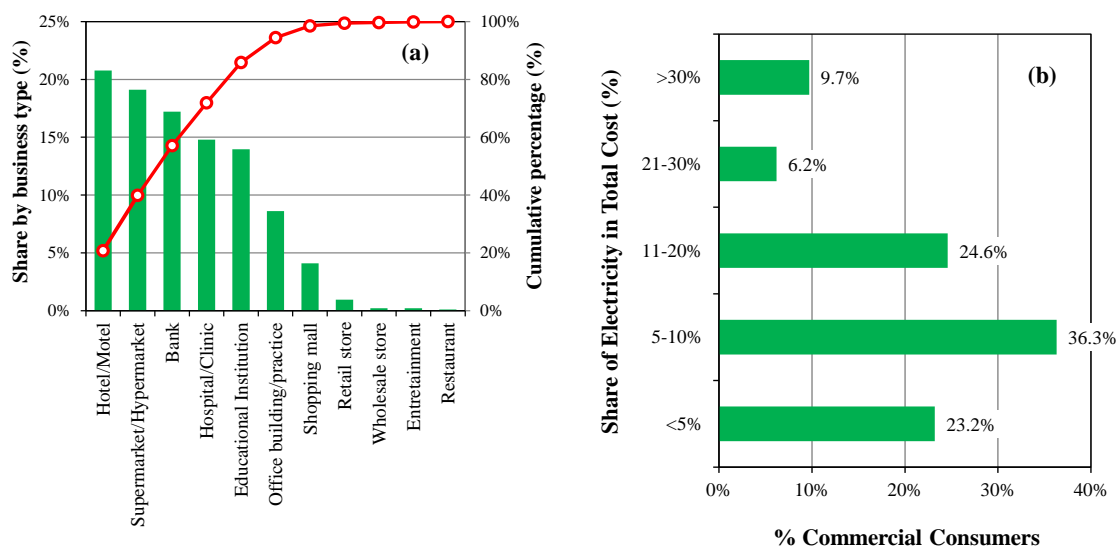


Figure 5. (a) Share of the most representative business types in the commercial sector; (b) relative weight of electricity in the total cost structure for Brazilian commercial sector [21].

The relative importance of the electricity in the cost structure of these consumers can be observed in Figure 5b. In 36.3% of the cases, the share of electricity in total costs lies between 5 and 10%, being the overall industry average 14.1% [21].

Air-conditioning, refrigeration and lighting, are the main electricity end-uses in this sector. The first one is responsible for about 47% share of the energy consumption in the whole commercial sector. But they can account for more than half of total electricity use in large office buildings, hotels, or shopping centers [22]. Refrigeration systems are mainly found in supermarkets and hospitals. On average, the cooling load represents 16% of peak demand in commercial installations [21]. Lighting systems also constitute a significant load in the commercial sector, representing, on average, 22% of peak demand. Entertainment and educational facilities present the highest share of demand due to lighting, with 41% and 34% respectively. Tubular fluorescent type of lamps are widely used in the commercial sector, they are used in 54% of the facilities.

4.1.1. Commercial Load Curves

The characterization of the load profile for the commercial sector is not a simple task given the wide range of activities that comprise it, which present dissimilar behaviors. As an example, Figure 6a and Figure 6b show the load curves for the two different commercial activities, observing how divergent can result the consumption profile depending on the type of commercial activity.

In 2000, Jardini *et al.* [17] presented the results of an extensive study of measurement and characterization of the commercial sector in which over a universe of nearly 200 commercial activities registered in the State of São Paulo.

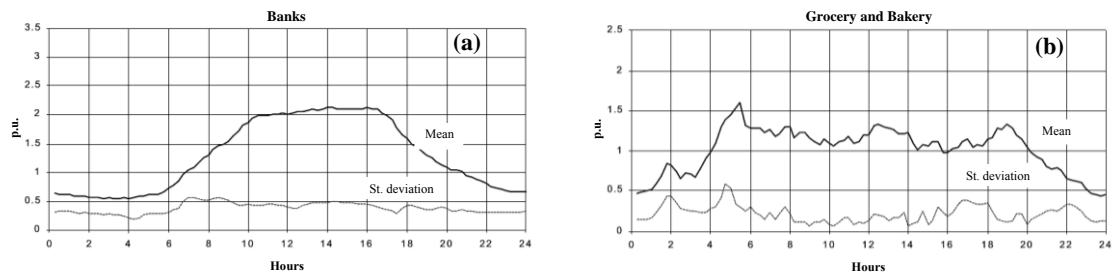


Figure 6. (a) Mean and standard deviation load curve for banks; (b) Mean and standard deviation load curve for grocery stores and bakeries [23].

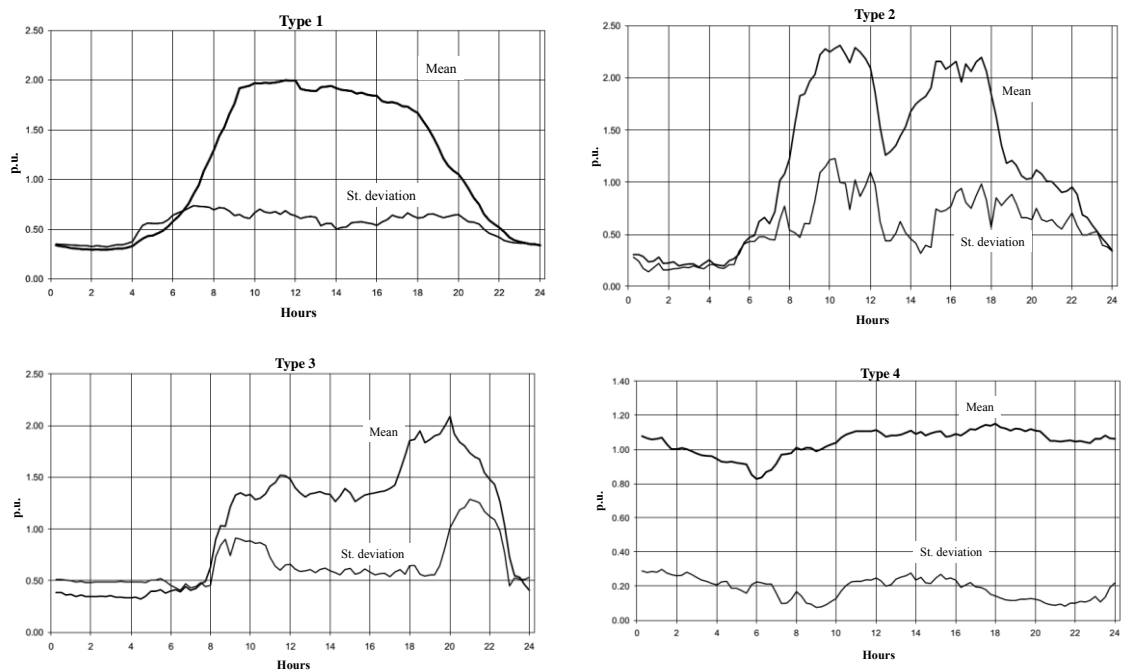


Figure 7. Groups of commercial consumer's curves [23].

In order to characterize the shape (typology) of the commercial load curve, the authors [17] performed a data clustering analysis. Firstly, the data was grouped according to the same activity and similar characteristics. As a result, one model for each activity was established. Afterwards the consumers with similar load curves were grouped independently of the activity they belonged to. This procedure resulted in a group of 4 simple curves shaped as Figure 7 shows. Any commercial activity may be represented by one of these four curves, which in turn can be used to obtain daily load curves in any point of the network by aggregation of the consumers' load, for example [17].

To give some examples, typical activities characterized by Type 1 curve are hotels and motels, banks, management service of real state and newspaper stands. Type 2 curve represents commercial activities like mechanical workshops and car dealers. Type 3 curve can be associated with restaurants, bars, coffee shops and petrol stations. And finally, Type 4 curve may represent radio stations, supermarkets and public transport services.

4.2. Industrial Sector

The industrial sector (excluding energy production) accounted for 40.7% of total electricity use in Brazil in 2013 (Figure 4).

In Figure 8a it can be seen the activities with highest presence in the industrial sector. The activities food and drinks, plastic and rubber and non-metallic minerals, account for almost 60% of the sector, being the former one the most significant industrial activities with a share of 27%.

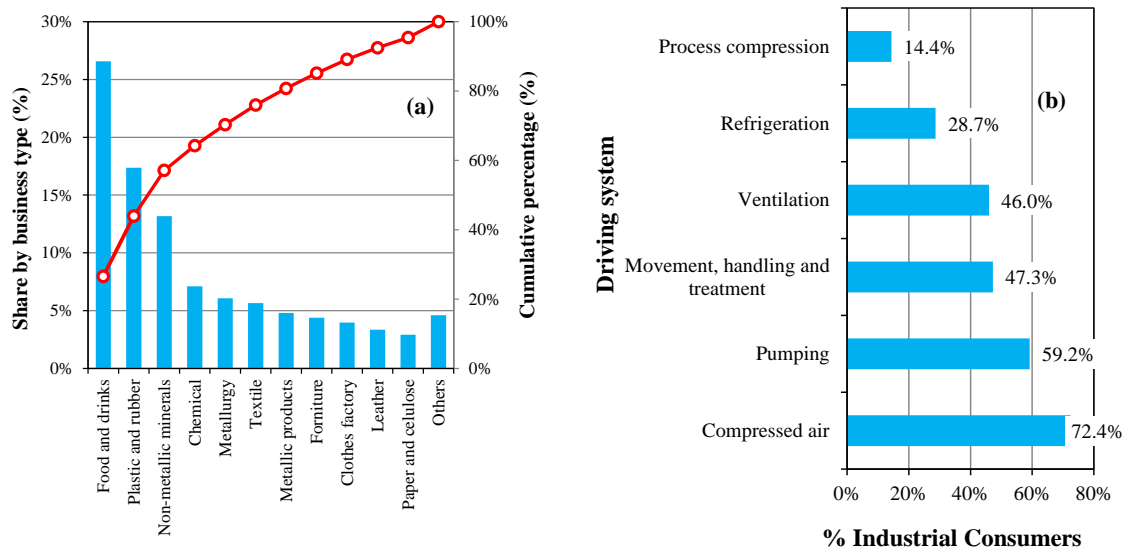


Figure 8. (a) Share of the most representative business types in the industrial sector; (b) Use of drive power in the most relevant industrial processes [20].

From the research conducted by the National Program for Electric Energy Conservation (PROCEL in Portuguese) it is estimated that electricity is used within the industrial sector mainly in motors (63%), electrothermal processes (22%), refrigeration (6%), lighting (6%) and electrolyze (2%) [20].

The main systems where electric motors are used in the Brazilian industrial plants are presented Figure 8b. It is noticed that compressed air systems are the most present in the industries with a share of 72.4%, followed by pumping systems with 59.2%.

About 39% of the industries make use of electricity to produce heat in its facilities using equipment such as ovens, stoves, heaters and boilers. The participation of electrothermal processes on the total maximum load is in average 13.8%, for the whole industrial sector. And the average installed power equals 570 kW.

Lighting represents close to 8% of the total maximum load for industrial facilities, being the assembler and metallurgic industries the ones who present the greatest requirement for illumination. The most common lamps used in the industries' facilities are the tubular fluorescent type, with a share of 51.6%. This model of lamp is mainly used in administrative areas, whereas mix and mercury-vapor type lamps are predominant in exterior areas.

4.2.1. Industrial Load Curve

The industrial load curve characterization was also performed in the work of Jardini *et al.* [17] in a similar way as with the commercial sector. In this case, 218 different types of industries were assessed in the study, and after the characterization and classification according to the quantity of consumers and the level of energy consumption, a final ranking of 26 more representative industrial activities resulted. Thus, 26 representative curves were establishment, one for each activity.

Due to the complexity and diversity in the load profiles that makes difficult to find a common pattern for grouping them, no attempt was made to derive a simple model for the industrial sector [17].

As an example, four load curves from different industrial activities are presented in Figure 9. It is observed that for some of the activities, the standard deviation values resulted high. This can be explained by the fact that in most industrial activities there are small size motors with an intermittent mode of operation during the day. Their loads are sometimes high if compared to industries average power, which may lead to quite high values of standard deviation, as seen in the shoe fabric industry depicted in Figure 9 [17].

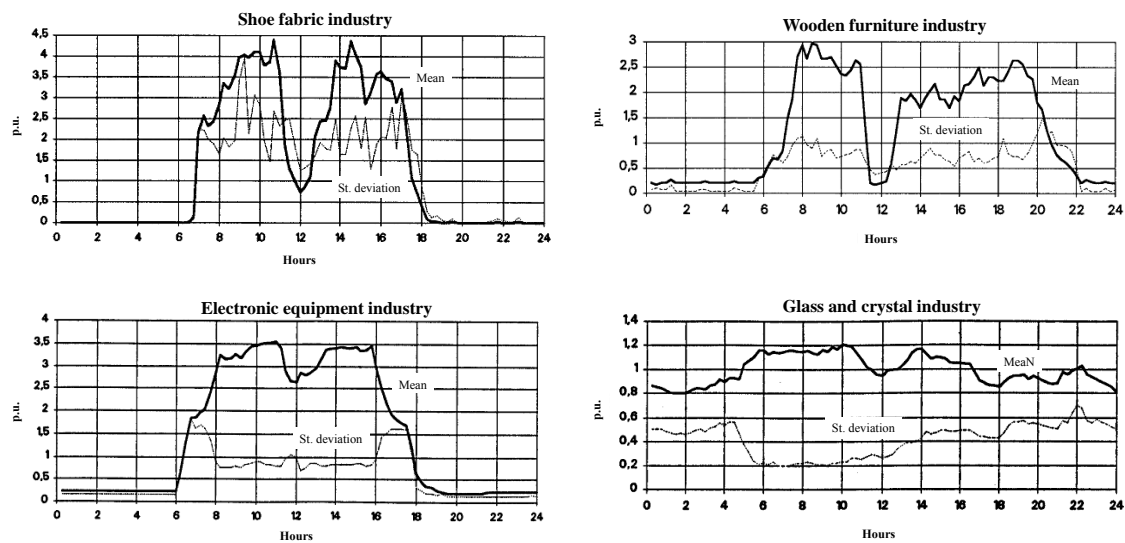


Figure 9. Industrial consumers' curves [23].

4.3. Residential Sector

The residential sector in Brazil represented 24.2% of the total electricity consumption in 2013, being the second sector in importance after the industrial.

This sector has received more attention from the researches as can be seen through the greater amount of publications concerning the residential sector compared with the other electrical sectors in Brazil. To mention some examples, [24]–[26] analyze the structure and evolution of the residential sector; [13], [27] assess the potential implementation of electricity conservation actions and energy-efficient household appliances; and [15] presents an economic approach in which the elasticity income-electricity cost is calculated.

In Figure 10 it can be observed that more than 68% of the households in Brazil consume less than 200 kWh/month, a relatively low level of consumption when compared with some developed countries such as USA (975 kWh/month) or Germany (300 kWh/month) [18]. The Brazilian regions with the highest share of households with consumption level less than 200 kWh/month are the Northeast and Central-west ones. The North region has the highest percentage of households that consume more than 300 kWh/month.

According to the results of the study conducted by [19], the share of household appliances in the Brazilian residential electricity consumption are as depicted in Figure 11. Despite some regional differences, the greater share corresponds to cooling (refrigerator and freezer), representing 27% of the total consumption, followed by water heating for bath (electric shower), with a percentage of 23.5%. Air-

conditioning, that represents 20% of the consumption in this sector, is provided by conventional cooling systems and by reverse cycle systems (cold/hot air).

Refrigeration system, electric showers and air-conditioning systems along with lighting systems account for 84.5% of the electricity consumption in Brazilian households [28].

It is also interesting to analyse the level of ownership of electric appliances in Brazil and over the country's geographical regions, which is depicted in Figure 12. As it can be seen, the refrigerator is present in all Brazilian homes since the national ownership average is 1.0 (Figure 12).

Other appliance that has a major impact in the Brazilian residential sector is the electric shower, which constitutes the most common method for heating water for bathing in the country. As observed in Figure 12 the national ownership level is almost 0.9, but due to different climatic conditions, this appliance is inhomogeneously used along the country.

The level of ownership of air conditioning and freezers is still low in Brazil, but this situation is expected to change in the subsequent years as the Brazilian economy is in continuous expansion, leading the population to acquire more electric appliances for their households. The highest percentages of air conditioning system ownership are in the South and North regions, pointing out that whereas in the North region this appliance is used only for cooling purpose, in the South region the reverse cycle air conditioners are commonly used for heating during the coldest months.

Lighting constitutes a significant share of consumption in the Brazilian residential sector. As the survey conducted by [19] demonstrates, in average, lighting represents 32.5 kWh/month per residence. The most common types of lamps utilized are incandescent and for the fluorescent, though in the latter case, the compact fluorescent lamps are more common than the tubular ones. It is worth noticing that the fluorescent lamp presents a higher level of ownership for regular use (extended periods of time), due to its better consumption/illumination efficiency.

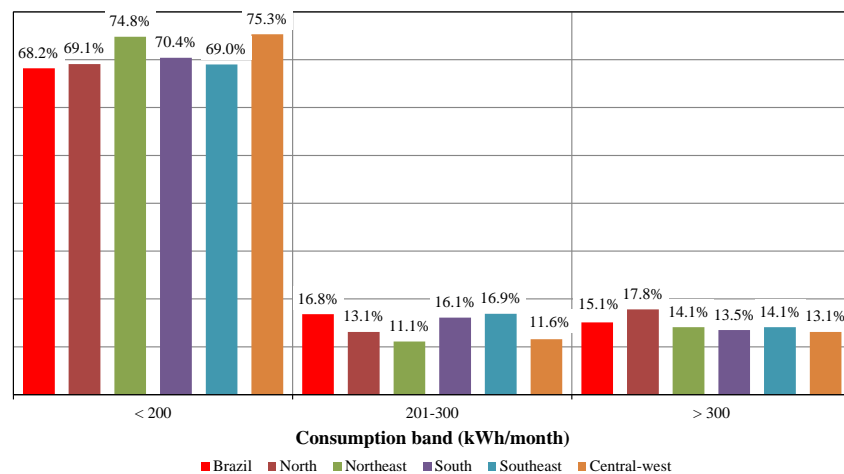


Figure 10. Distribution of residential consumers per consumption band [19].

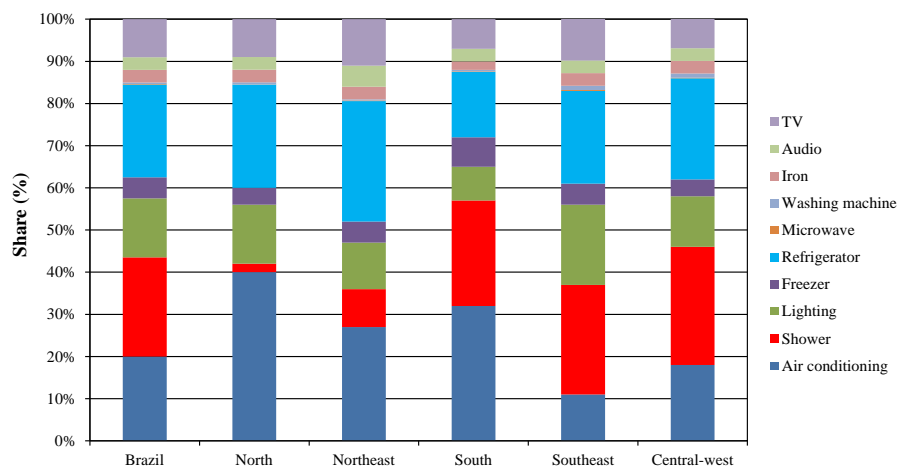


Figure 11. Participation of main household appliances in the electricity consumption of the residential sector [19].

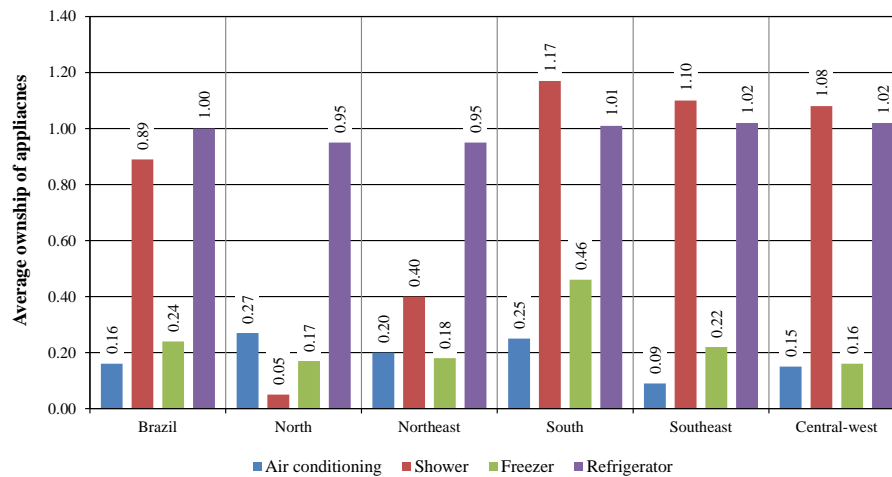


Figure 12. Average electric appliance ownership for Brazil and the different geographical regions [19].

4.3.1. Residential Load Curve

In Brazil, a series of surveys on electric appliance ownership and consumption habits PPHs (*Pesquisas de Posse e Hábitos de Consumo de Energia*) have been conducted in three occasions, 1988, 1997/98 and 2005/06. The results of these surveys give information on the participation of the different electrical appliances in the residential sector, and also after processing the information it is possible to obtain the profile of the consumers' load curve (or group of customers) [29]. This information is available for consultation in the Information System on Electrical Appliance Ownership and Consumer Habits (SINPHA) [30].

The load profiles for Brazil and their geographical regions are depicted in Figure 13. It is observed that the Brazilian load curve for the residential sector is characterized by two periods of peak consumption, one during the morning between 6 a.m. and 8 a.m., and the other during the early evening between 6 p.m. and 9 p.m., the latter contribute significantly to the overall system peak load [28]. These two peaks correspond with the moments when people wake up to go to work and the return to their residences after the working day. During the rest of the day the consumption is fairly constant.

With exception of the North and Northeast regions, the equipment that contributes more heavily to the overall peak load in Brazil is the electric shower. This appliance uses a resistance device that heats the water when coming out of it. Its power is about 3–5 kW, and the average shower period is 8 min [17], [28]. It is estimated that during the evening peak hour (6 p.m. to 9 p.m.), the residential consumption contributes with 22% to the overall consumption, from which 50% corresponds to the electric shower, thus this appliance contributes with roughly 10% of the global peak load [28], [31]–[33].

Other appliance that contributes extensively to the residential consumption is the air conditioning system, especially in the warmer regions such as the North and North-east. As can be seen in Figure 13 this appliance is used out of the working hours, when the people is present at their homes, and its use is extended all through the night. On the contrary, the electric shower is rarely used in the warmer regions of the country.

Lighting contributes clearly to the evening peak load demand all throughout the country and in the same proportion.

For a more detailed analysis of the residential load profile, data from a distribution utility of the State of São Paulo was obtained. This data corresponds to one week (27/03/14 – 03/04/14) of measurements performed in periods of 10 minutes in a 75 kVA transformer that supplies energy to 91 low-voltage residential consumers [34].

It is observed higher values of standard deviation in the early evening period between 5 p.m. to 10 p.m., see Figure 14. This period is characterized by the use of electric shower for bathing. The utilization of this appliance, is characterized by a short period of use (4 to 12 minutes) randomly distributed during the evening peak hour. This makes the loads of showers do not fully coincide at any given time in the distribution transformer. According to [23], [32] the coincidence or simultaneously factor of electric

showers in the transformers is 25%. The peculiar use of electric showers makes de residential load curve more difficult to characterize.

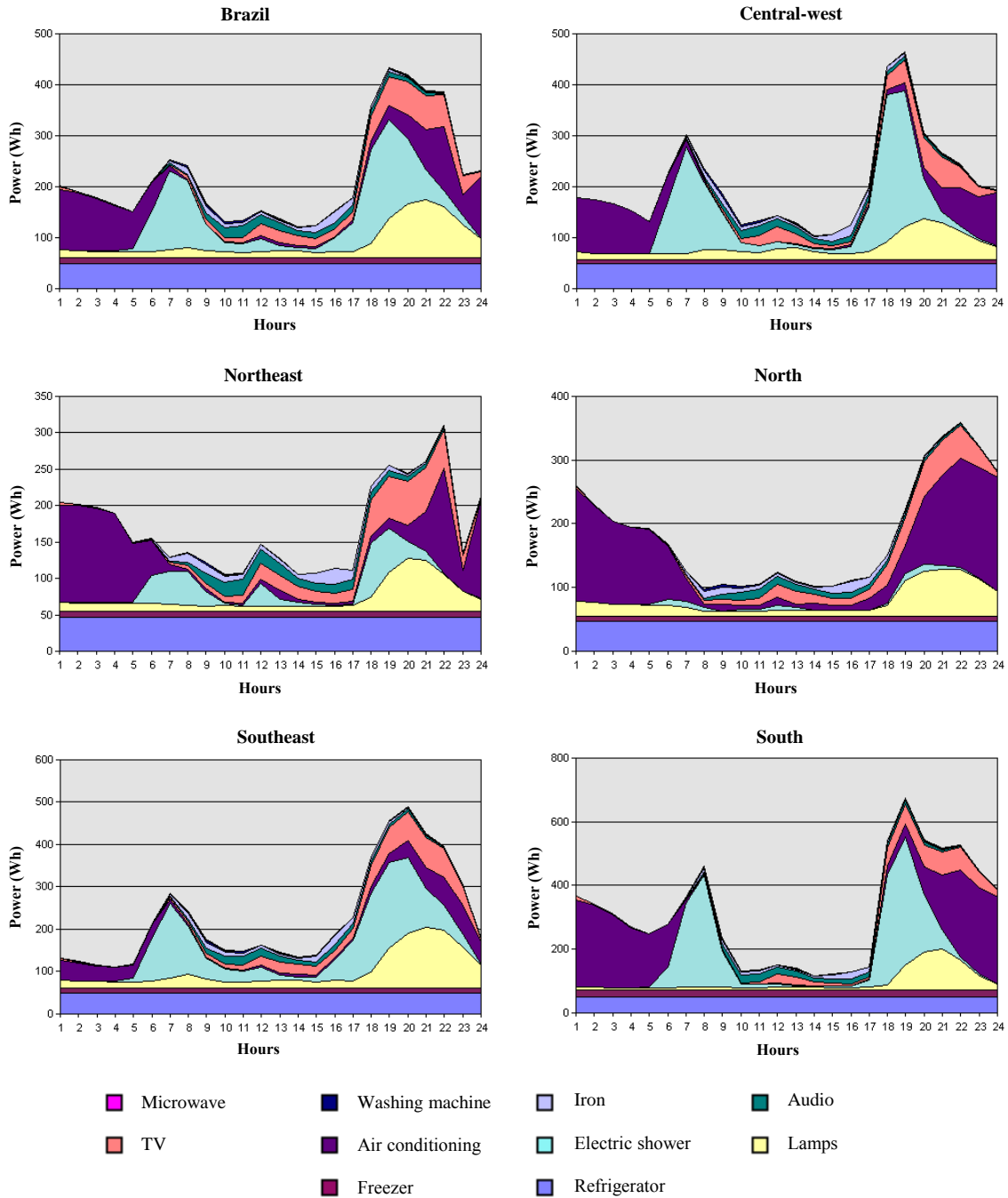


Figure 13. Average daily load curve for Brazil and its different geographical regions [30].

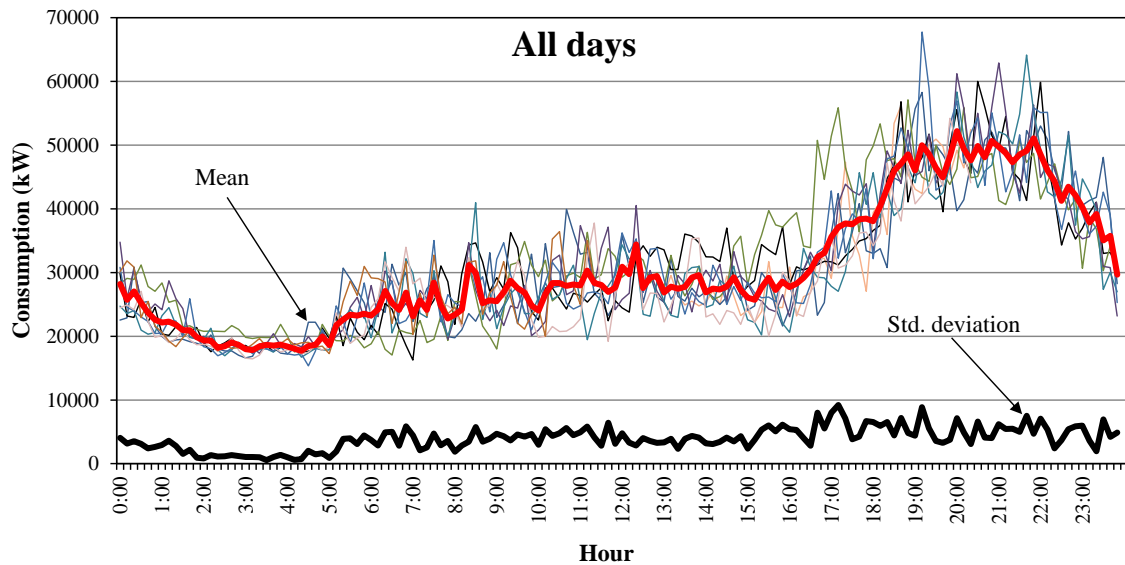


Figure 14. Load curves, mean and standard deviation for a group of residential consumers, considering only weekdays.

5. Conclusions

The present paper sought to present a general overview of the Brazilian electricity sector with focus on the characterization of the consumers' profile. The analysis was based on a literature review from which the available information was excerpted, analyzed and depicted in the form of tables and graphs for better understanding.

As it was perceived from the initial stage of the research, there is not much actual official information related to the electrical consumption of the different economic sectors in Brazil. With respect to the commercial and industrial sectors, the latest salient research was performed during the decade of 1990. On the other hand, more information related to the residential sector was found, where the bulk of the publications are focus on the study of energy efficiency measurements to be implemented in this sector.

The commercial sector accounts for nearly 16% of the total Brazilian electricity consumption and is characterized by a concentration of users in the group of less than 500 kW of peak demand. Air-conditioning, refrigeration and lighting are the main electricity end-uses in this sector, accounting for 85% of the consumption. It was found that any commercial activity may be represented by one of four typical profile curves which can be used to obtain daily load curves in any point of the network by aggregation of the consumers' load.

The industrial sector accounts for 40.7% of total electricity use in Brazil. In this sector, three-fifths of the electrical consumption is due to merely three industrial activities. The electricity is used mainly in motors, electrothermal processes, refrigeration and lighting, being that the motors account for more than 60% of the consumption. Due to the variability introduced by the high participation of small size motors, it results difficult to obtain a simple model to characterize the consumers' consumption profile.

The residential sector is the second in importance after the industrial, it currently accounts for nearly a quarter of the electrical consumption. As a developing country, the Brazilian residential electrical sector still presents a lower level of consumption when compared to developed countries; thereby it is expected a growth in the future as the country is in economic expansion. The appliances that most energy consume are refrigerator and freezer (27%), electric shower (23.5%) and air conditioning system (20%). The Brazilian load curve for the residential sector is characterized by one period of higher peak consumption, during the early evening between 5 p.m. and 10 p.m. It is estimated that the electric shower contributes with roughly 10% of the global evening peak load. Thus, the replacement of a low-efficiency heating system such as the electric shower represents a huge potential for electricity savings, implying the reduction of the investment level needed to meet the full demand during peak hours.

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