Fachhochschule Köln
Cologne University of Applied Sciences

**UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ**

**FACULTADES DE CIENCIAS QUÍMICAS,**
**INGENIERÍA Y MEDICINA**

PROGRAMA MULTIDISCIPLINARIO DE POSGRADO
EN CIENCIAS AMBIENTALES

AND

**COLOGNE UNIVERSITY OF APPLIED SCIENCES**

INSTITUTE FOR TECHNOLOGY AND RESOURCES
MANAGEMENT IN THE TROPICS AND SUBTROPICS

# POTENTIAL OF ENERGY EFFICIENCY IN THE RESIDENTIAL SECTOR IN BRAZIL

**THESIS TO OBTAIN THE DEGREE OF**

**MAESTRÍA EN CIENCIAS AMBIENTALES**
**DEGREE AWARDED BY UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ**
**Y**
**MASTER OF SCIENCE**
**"TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS**
**FOCUS AREA "ENVIRONMENTAL AND RESOURCES MANAGEMENT"**
**DEGREE AWARDED BY COLOGNE UNIVERSITY OF APPLIED SCIENCES**

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## **Erklärung / *Declaración***

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# Abstract

The main contribution of this master thesis is to characterize the residential end use energy consumption in Brazilian households and to provide a methodological framework that permits energy forecasts for different building types in Brazil on a national level. The research looked at the evolution of energy use and developed a business-as-usual (BAU) and an efficiency scenario (ES) to 2020. The ES considered a) the replacement of electricity water heaters by solar water heaters, b) the improvement of energy efficiency of electric appliances and c) the improvement in cooking energy efficiency.

To develop the scenarios there have been realized various steps that already delivered interesting results. In a first step there have been developed four different building types of the Brazilian residential sector. In a next step energy patterns of the buildings were determined, by disaggregating the energy use by end use technologies and building types. The third step identified the key drivers for energy consumption in the residential sector in Brazil that is the number of dwellings, the ownership rate and the unit energy consumption of appliances. The forecast of their development until 2020 constitutes the base for the scenario development.

In the efficiency scenario, the total consumption of the residential sector in relation to the BAU scenario is reduced from 385 TWh to 311 TWh that is by 69 TWh (18%). In relation to the reference year 2005 this is an increase of about 121%, instead of 151% in the BAU scenario. The thesis permits to disaggregate the contribution to the saving potential by building type and end uses. The main drivers for electricity consumption are the shower and the air condition that together are responsible for about 50% of the electricity consumption in both scenarios by 2020. Special interest was given to the air conditioning because of its enormous growth potential according to global air condition ownership forecast models.

# Resumen

El mayor aporte de esta tesis es caracterizar el uso final del consumo energético en el sector residencial brasileño y proveer una metodología que permita pronósticos energéticos para diferentes tipos de edificaciones a nivel nacional en Brasil. El estudio contempló la evolución del uso energético y desarrolló un escenario de situación actual (*Business-as-usual*-BAU) y un escenario de eficiencia para el 2020. El escenario de eficiencia consideró a) el reemplazo de calentadores de agua eléctricos por calentadores de agua solares, b) el mejoramiento de la eficiencia energética en electrodomésticos y c) el mejoramiento de la eficiencia energética para cocinar.

Para desarrollar los escenarios se realizó diferentes pasos que arrojaron resultados interesantes. En el primer paso se desarrolló cuatro tipos de edificaciones del sector residencial brasileño. En el siguiente paso los patrones energéticos de dichos edificios fueron determinados por desagregación del uso energético y por los tipos de edificios En el tercer paso se identificó los principales impulsores del consumo energético en el sector residencial brasileño los cuales son; el número de edificios, la tasa de propiedad y el consumo unitario por electrodoméstico. El pronóstico del desarrollo de estos tres impulsores constituye la base para el desarrollo de los escenarios.

En el escenario de eficiencia, el consumo total en relación con el escenario de situación actual (BAU) se redujo de 385 TWh a 311 TWh. En relación con el año de referencia 2005 esto representa un incremento de alrededor 121%, en vez de 151% en el escenario de situación actual (BAU). La tesis permite desagregar la contribución al ahorro de energía por edificio y uso final. Los principales impulsores del consumo eléctrica son las duchas eléctricas y los aires acondicionados que juntos son responsables de aproximadamente 50% del consumo eléctrico en las dos escenarios en 2020. Interés especial tuvo el uso de aire acondicionado debido a su enorme potencial de crecimiento respecto un modelo global de pronóstico de propiedad de aire acondicionado.

**TABLE OF CONTENTS**

# List of Figures

# List of tables

# List of Equations

## List of abbreviations

| Abbreviation | Significance |
|---|---|
| BAU | Business-as-usual |
| CDD | Cooling degree days |
| CDM | Clean Development Mechanism |
| CFLs | Compact fluorescent light bulbs |
| COP | Coefficient of performance |
| EER | Energy efficiency ratio |
| ES | Energy efficiency scenario |
| GDP | Gross Domestic Product |
| GHG | Greenhouse gas |
| Gini | Gini coefficient |
| HDI | Human development index |
| HVAC | Heating ventilation and air conditioning |
| IAQ | Internal air quality |
| LMFH | Large multifamily house |
| LPG | Liquefied petroleum gas |
| MASP | Metropolitan Region of São Paulo |
| MI | Minimum income |
| PoA | Program of Activities |
| PBE | Brazilian Labeling Program (Programa Brasileiro de Etiquetagem) |
| PPP | Purchasing power parity |
| R&D | Research and Development |
| RSFH | Rural single family house |
| SMFH | Small multifamily house |
| SWH | Solar water heater |
| USFH | Urban single family house |
| UEC | Unit energy consumption |
| WEO | World Energy Outlook |

## List of institutions

| Acronym | English | Portuguese |
|---|---|---|
| ABESCO | Brazilian Association of Companies of Energy Conservation Service | Associação Brasileira das Empresas de Serviços de Conservação de Energia |
| ABRAVA | Association of Refrigeration, Air Conditioning, Ventilation and Heating | Associação Brasileira de Refrigeração, Ar condicionado, Ventilação e Aquecimento |
| ANBT | Brazilian Association for Technical Norms | Associação Brasileira de Normas Técnicas |
| ANEEL | National Electricity Agency | Agencia Nacional de Energia Elétrica |
| ANVISA | National Sanitary Surveillance Agency | Agencia Nacional de Vigilância Sanitária |
| ASHRAE | American Society of Heating, Refrigerating and Air conditioning Engineers | |
| BEN | National Energy Balance | Balanço Energético Nacional |
| BNDES | National Development Bank | O Banco Nacional do Desenvolvimento |
| CONPET | National Program for Rational Use of Derivates of Petrol and Natural Gas | Programa Nacional da Racionalização do Uso dos Derivados do Petróleo e do Gás Natural |
| EMBRAESP | Brazilian Corporation for Property Studies | Empresa Brasileira de Estudos de Patrimônio |
| EPE | Power Research Company | Empresa de Pesquisa Energética |
| GTZ | German Development Cooperation | |
| IBGE | National Institute for Geographic and Statistics | Instituto Brasileiro de Geografia e Estatística |
| IEA | International Energy Agency | |
| INMETRO | National Institute of Metrology, Standardization and Industrial Quality | Instituto Nacional de Metrologia, Normalização e Qualidade Industrial |
| IPCC | International Panel on Climate Change | |
| LabEEE | Laboratory for Energy Efficiency in Buildings | Laboratório de Eficiência Energética em Edificações |
| MME | Ministry of Mines and Energy | Ministério das Minas e Energia |
| PNAD | National Household Survey | Pesquisa Nacional por Amostra de Domicílios |
| PROESCO | Support of Energy Efficiency Program | Programa para eficiência energética |
| PROCEL | The National Program for Electricity Conservation | Programa Nacional de Conservação de Energia Elétrica |

| | | |
|---|---|---|
| Qualisol | Program for Qualification of Suppliers of Solar Heating | Programa de Qualificação de Fornecedores de Sistemas de Aquecimento Solar |
| RGR | Global Reversion Reserve | Reserva Global de Reversão |
| SINPHA | Information system of ownership of electrical household appliances and habits of consumption | Sistema de Informações de Posses de Eletrodomésticos e Hábitos de Consumo |
| SIDRA | Automatic recuperation system of IBGE | Sistema IBGE de Recuperação Automática |
| WWF | World Wide Fund For Nature | |

## Units and conversion factors

| Abbreviation | Unit | Conversion factor (to GWh) |
|---|---|---|
| **Energy** | | |
| J | Joule (Watt second) | $3\ 641\ 868 * 10^6$ |
| PJ | Peta joule | 0,004 |
| TJ | Tera joule | 3,642 |
| GJ | Giga joule | 3 641,868 |
| MJ | Mega joule | 3 641 868,000 |
| Wh | Watt hour | 1 000 000 000 |
| kWh | Kilowatt hour | 1 000 000 |
| MWh | Megawatt hour | 1 000 |
| GWh | Gigawatt hour | 1 |
| TWh | Terawatt hour | 0,001 |
| toe | Tons of oil equivalent | 11,6 |
| BTUh | British thermal unit | $0{,}2929 \times 10^{-9}$ |
| **Power** | | |
| W | Watt | - |
| kW | Kilowatt | - |
| Etc. | | |
| **Other** | | |
| t | Time | |

# 1. Background of research

## 1.1. Introduction

30%– 40% of all primary energy is used in residential and public buildings worldwide. Energy efficiency in buildings has become an important issue due to high energy costs, increased environmental awareness and advances in the energy management sector. The energy consumption in Brazil is mainly composed of firewood, gas and electricity to almost equal shares. 80% of the electricity consumption is used by only four appliances, the electrical shower, the refrigerator, lighting and air condition. In the last years electricity consumption has been growing steadily and in the future it is expected to grow with about five percent each year. To analyze future saving potentials in the residential sector, scenarios of energy demand are necessary.

Existing studies that develop future scenarios of energy demand mainly use integrated economic models to project baseline scenarios, both at the country and at the global level. The results of these scenarios are typically presented at the sectoral level disaggregated by industry, transport, and buildings without further disaggregation (IEA, 2006; MME, 2007b). These studies cannot deliver explanations for the development due to missing disaggregation of the end uses. Recent publications present bottom up scenarios and technical energy saving potentials are displayed in detail, however not disaggregated by building types (Bozon, 2007; Graus and Blomen, 2008; IEA, 2006; IPCC, 2007). A limiting factor of the quality of forecast is the availability of information required.

Considering different usage patterns of different building types, the thesis research first analyzed the actual building stock in Brazil developing the characteristics of four different building types. In a second step the energy consumption of the Brazilian residential sector was calculated in function of income, number of inhabitants and constructed area. To permit the disaggregation of end use energy, the forecast of energy demand and saving potential disaggregated by building type and end use technology by 2020 there were developed reference buildings in a third step. For the determination of these reference buildings there had to be forecasted the main drivers of energy consumption, especially the development of a) the ownership rate of electrical appliances, b) the building stock and c) the *unit energy consumption* (UEC) of the appliances. The results of this forecast provided valuable inputs for the elaboration of the scenarios. The development of a business-as-usual (BAU) and an efficiency scenario (ES) enabled the calculation of the saving potential. The energy efficiency scenario considered a) the replacement of electricity water heaters by solar water heaters, b) the improvement of energy efficiency of electric appliances and c) the improvement in cooking energy efficiency.

The field research was conducted within the framework of the GTZ program *Renewable Energy and Energy Efficiency* in Brazil with the support from the GTZ office in Rio de Janeiro.

## 1.2. Definitions

*National Household Survey* (PNAD) of Brazil defines some buildings according to typology and situation of it. To better understand the categories of PNAD there will be given their definitions (IBGE, 2009).

<u>Situation of the building:</u>

- Urban or rural
  - The classification of the situation of the home can be urban or rural, according to the location area of the household. The base of this classification is the existing legislation for the realization of the demographic census in the year 2000.
  - Urban are considered the areas corresponding to the cities (municipal headquarters), towns (district headquarters) or isolated urban areas.
  - Rural is considered the entire area outside those limits.
  - This criterion is also used for the classification of the population

<u>Building type: House, apartment or room:</u>

- House:
  - Located in a building with one or more floors, which are entirely occupied by a single household
  - With direct access to a street (streets, town, street, road, etc..) legalized or not, regardless of the material used in its construction;
  - A home does not contain any common spaces (such as vestibule, stairway, corridor, entrance and other dependencies) to serve the permanent private housing units that exist there.
  - This definition also includes a home located in a building with at most three floors
- Apartment/Flat
  - Is considered a home located in the building of one or more floors with more than a particular permanent home
  - Is served by public spaces (lobby, staircase, corridor, entrance and other dependencies)
  - Has two or more floors, with more than one permanent homes
  - Has independent entrances to the floors, or more than three floors, where the other units are not residential
- Room/Quarter:
  - Is considered a home that occupies one or more rooms within a house

According to common building typologies, small multifamily houses (SMFH) are considered buildings with an area up to 1000 $m^2$ and up to four stocks (Hessische Energiespar-Aktion, 2009). Multi family houses that are not small multi family houses fall in the category large multi family houses.

In this thesis the denomination of household and dwelling is used synonym, although according to literature, a household normally refers to a group of persons and the dwelling to the living space (UN-Habitat, 2001). However the data from PNAD is not disaggregated at this level (IBGE, 2009).

<u>Potential</u>

For this thesis there is adapted the technical potential definition as applied by the fourth *International Panel of Climate Change* (IPCC) assessment report on climate change (IPCC). The technical potential is defined as the amount by which it is possible to reduce GHG emissions by implementing already demonstrated technologies and practices without specific reference to costs although economic considerations might be applied (IPCC, 2007).

The following table gives a short overview of energy related definitions applied in this report.

**Table 1:** Energy related definitions

| Dimension | Unit | Definition |
|---|---|---|
| Energy efficiency | | It is the ratio of the energy input and output in general. A higher efficiency results in lower energy consumption. |
| Coefficient of Performance (COP) | [W/W] | It is the basic parameter used to report efficiency of refrigerant based systems. It is the ratio between useful energy (Eu) acquired and energy applied (Ea) and can be expressed as:<br>COP = Eu / Ea |
| British thermal unit (BTU) | BTU/h | It is used to describe the power of heating and cooling systems and in this case the correct unit is BTU per hour (BTU/h). |
| Energy Efficiency Ratio (EER) | BTU/ Wh | It is a term generally used to define cooling efficiencies of unitary air-conditioning and heat pump systems. It is defined as the ratio of net cooling capacity (Ec in BTU/h) to the total input rate of electric energy applied (Pa in Watt) and can be expressed as:<br>EER = Ec / Pa |

Source: Elaboration of author on base (Engineering-ToolBox, 2010)

## 1.3. Research region

The urbanization process in Brazil started since the end of the 19th century, with cities acquiring increasing importance in the territorial organization of the country. The industrialization process strongly linked with the urbanization process, started in the first half of the 20th century and had a strong influence on the structure and development of the urban network (Xavier and Magalhães, 2003).

The high urbanization rates of Brazil, despite an actual decrease in migration to cities, originate in the process of economic development, when the concentration of efforts and investments to support industrialization in the urban centers, particularly in Rio de Janeiro and São Paulo, resulted in an intense migration process (Xavier and Magalhães, 2003).

Brazil is geographically divided into five large regions – North, Northeast, Central-East, South and Southeast, with a total of 27 states and 5 551 municipalities (IBGE, Census 2000). Although the small municipalities with urban populations under 20 000 inhabitants represent 75 per cent of the total, they concentrate only 19,5 per cent of the country's population. This means that around 80 per cent of the population lives in 25 per cent of the municipalities, revealing the existence of a strong spatial concentration in the country (IBGE, 2003; Xavier and Magalhães, 2003).


**Figure 1:** Map of Brazil

Source: (CIA, 2009)

**Table 2:** Principal socio-economic indicators of Brazil

| **Data of Brazil** | |
|---|---|
| Population[1] | 192 272 890 |
| Area[1] | 8 514 877 $km^2$ |
| Density[1] | 22/$km^2$ |
| GDP (PPP)[2] | Total $2,0 billion |
| Minimum income (MI)[*] | 510 R$ (2010); in 2005 it was 260 |
| Average income/ household | 4,2 x MI |
| Gini[3] | 55 |
| HDI[3] | 0,813 |
| HDI Rank[3] | 75 |

1 (IBGE, 2003)
2 (IMF, 2010)
3 (UNDP, 2009)
4 (Hirsch, 2006)

## 1.4. Problem statement

Brazil is the largest country and leading energy consumer in South America. Hydroelectricity accounts for more than 80% of Brazil's installed generating capacity in the nation's 450 dams. This not only makes the country vulnerable to energy shortages from droughts, but also has negative impact on Brazil's rivers and river-based communities (WWF - Brasil, 2007). The total electricity consumption in the residential sector in Brazil has risen in the last years about three to six percent every year. Under a Business-As-Usual scenario (BAU), Brazil's electricity demand is expected to grow by about five percent until 2020 according to official estimates (EPE, 2009a). Brazil already started to increase its consumption of fossil fuels in 2005 (WWF - Brasil, 2007).

The country needs to manage an energy infrastructure that responds to the growing electricity demand. The share of the total building sector in the overall energy consumption is 15%, whereupon 10% are of the residential sector. The share of electricity consumption is higher. In 2008, the residential sector accounted for 22 % of the total Brazilian electricity consumption (EPE, 2009a). The main energy end users in Brazilian households are electric showers, illumination devices, air conditioning systems and refrigerators that together are responsible for 80% of the electricity consumption in the residential sector (PROCEL/Eletrobrás, 2007).

The electric shower alone is responsible for 18% of the peak demand (PROCEL/Eletrobrás, 2007). Both, because of its high energy consumption and its disproportionate impact on peak load the electrical shower is of particular interest for this research. Due to the high contribution to peak demand, the electric showerhead has an approximate investment cost between US$ 800 - 1 000 during their lifetime. If other technologies were used instead, the utilities would benefit from avoiding these substantial investments (Geller et al., 1997). Lighting and air condition are also contributing to high peak demands in the morning and in the night. In contrast the refrigerator is supposed to be running all the time (PROCEL/Eletrobrás, 2007). Figure 2 represents an the average load profile of Brazil.

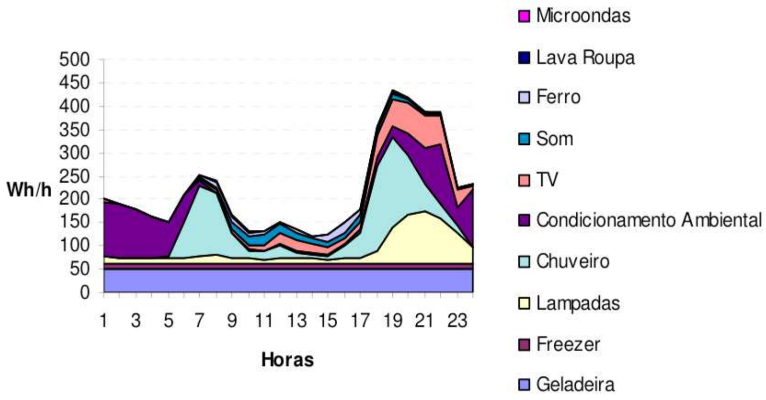


**Figure 2:** Average daily load curve of Brazil

* Translation of author: *chuveiro* means electric shower, *geladeira* is refrigerator, *lampadas* are light bulbs and *condicionamento ambiental* means air condition.
Source: (PROCEL/Eletrobrás, 2007)

Not only for its contribution to peak demand, but also for its already high share of electricity consumption (20%) combined with a low ownership rate of only 16% in 2005 this end use consumer is also of high interest, especially regarding future energy demand. The actual ownership rate has still a big potential to grow. Development of air condition ownership rate in some countries has shown that it can grow faster than economic growth in climate, especially in warm countries. This happened in China, where from 1993 until 2003 the ownership rate grew from less than one percent to 62%. A similar rapid growth could happen in Brazil (and in every other country with similar circumstances). A rapid increasing of ownership rate of air conditioners can be a challenge to secure energy supply.

## 1.5. Justification

When negative environmental impacts of energy consumption become more urgent, there is a need to evaluate current and future sources of energy-related effects at a greater level of accuracy and detail. Quantifying how much energy could be saved on a nationwide level is of increasing interest especially as the environmental consequences of energy consumption come to be seen as global issue. Developing models of energy demand for different end uses on national scale is far from easy. Statistics of energy use, such as those collected by the IEA, or in the case of Brazil by the EPE typically provide energy consumption disaggregated only by sector.

Apart from the top down studies there many are case studies that analyze end uses consumption in specific buildings located in specific climate zones in Brazil, in many cases produced in the environment of the *Laboratory for Energy Efficiency in Buildings* (LabEEE). However studies on national scale are not known. A disaggregated analysis of energy consumption of the residential sector is highly desirable in order to better understand the energy demand of the end uses and to be able to guide policies towards increased efficiency.

## 1.6. Objective and research questions

The purpose of this thesis research is to estimate the potential of energy efficiency in the residential sector in Brazil.

To achieve this objective the following research leading questions will be answered:

1. What does the building stock lock like?
2. What is the energy demand of the building stock?
3. What is the energy consumption disaggregated by end use and building type?
4. What are the main drivers for energy consumption in the residential building stock?
5. What is the future development of these main drivers …
    a. … under a reference scenario?
    b. … under an efficient scenario?

## 1.7. Methodology

The methodology was determined by the objectives of the thesis and the data available. It combines a bottom-up with a top-down approach. The top-down data (e.g. fuel consumption statistics from national and international sources, permits to calibrate data and validate results. In the case of missing data top down data also supports assumptions. The bottom-up data provides information of detailed level on drivers of energy consumption. In this research the two methods have been combined. Top down data is used at the end of each step to calibrate the data.

According to van Vuuren energy demand can be described as a function of three basic elements (Morna and vanVuuren, 2009).

**Equation 1:** Energy demand in the residential sector

$$E_{bs} = A \times S \times I$$

Where:
$E_{bs}$ = total energy consumption in residential sector
A = activity
S = structure
I = intensity
Source: (Morna and vanVuuren, 2009)

The activity parameter describes the underlying force of energy demand, such as population, GDP or number of dwellings. In the case of this research the activity parameter is expressed as the number of dwellings. The corresponding intensity parameters are the specific energy consumptions per unit. Structural parameters are elements that determine energy demand. A structural parameter is the ownership rate, in the case of energy demand for air conditioning a structural parameter can also be *Cooling Degree Days* (CDD)[1].

In the case of the air condition, the climate factor as limiting factor for cooling demand will be excluded. It is considered insignificant for the cooling energy demand in Brazil at the moment. Due to a still relatively low ownership rate and the objective of this thesis to forecast energy demand for the near future, the determining factor for energy

[1] A cooling degree day is given for each degree that the daily mean temperature departs above the baseline of 75 degrees Fahrenheit. It is used to estimate the energy requirements, and is an indication of fuel consumption for air conditioning or refrigeration (Morna and vanVurren, 2009).

demand caused by the air conditioning is the ownership rate that in turn is determined very strong by affordability (McNeil and Letschert, 2008).

For Brazil the main drivers for the energy consumption identified are ownership rate, unit energy consumption and number of dwellings. Equation 1 can be rewritten for this research:

**Equation 2:** Energy demand in the residential sector (adapted formula)

$$E_{res} = A \times O \times UEC$$

Where:
A = number of dwellings
O = ownership rate
UEC = unit energy consumption
Source: Elaboration of author

Figure 3 illustrates the methodology developed determining the various steps to be realized to determine the saving potential of energy efficiency measures in the residential sector in Brazil. There can be distinguished four main steps:

1. Development of the building typology
2. Determination of energy consumption disaggregated by building type and end use
3. Determination of reference buildings
4. Development of the BAU and efficiency scenario (ES)

Every step requires a different method to process the data and produce results. These results (output) are required in the next step as input. To secure the quality of data and results, they are calibrated at the end of each step.

Normally one chapter presents the method first, then the data and then the results. Step 2, 3 and 4 required a discussion and calibration of data, realized within the chapter. In step 2 (general) data is presented at the beginning of the chapter before the method. Step two is somehow special because it needs the input of the building typology developed in step 1 and data on energy consumption given by what is marked yellow and called PROCEL study.

The step-by-step approach was chosen because of the necessity of each step for the output data of the previous step to produce output itself. The final step, the development of the two scenarios, is discussed together at the end of the thesis.

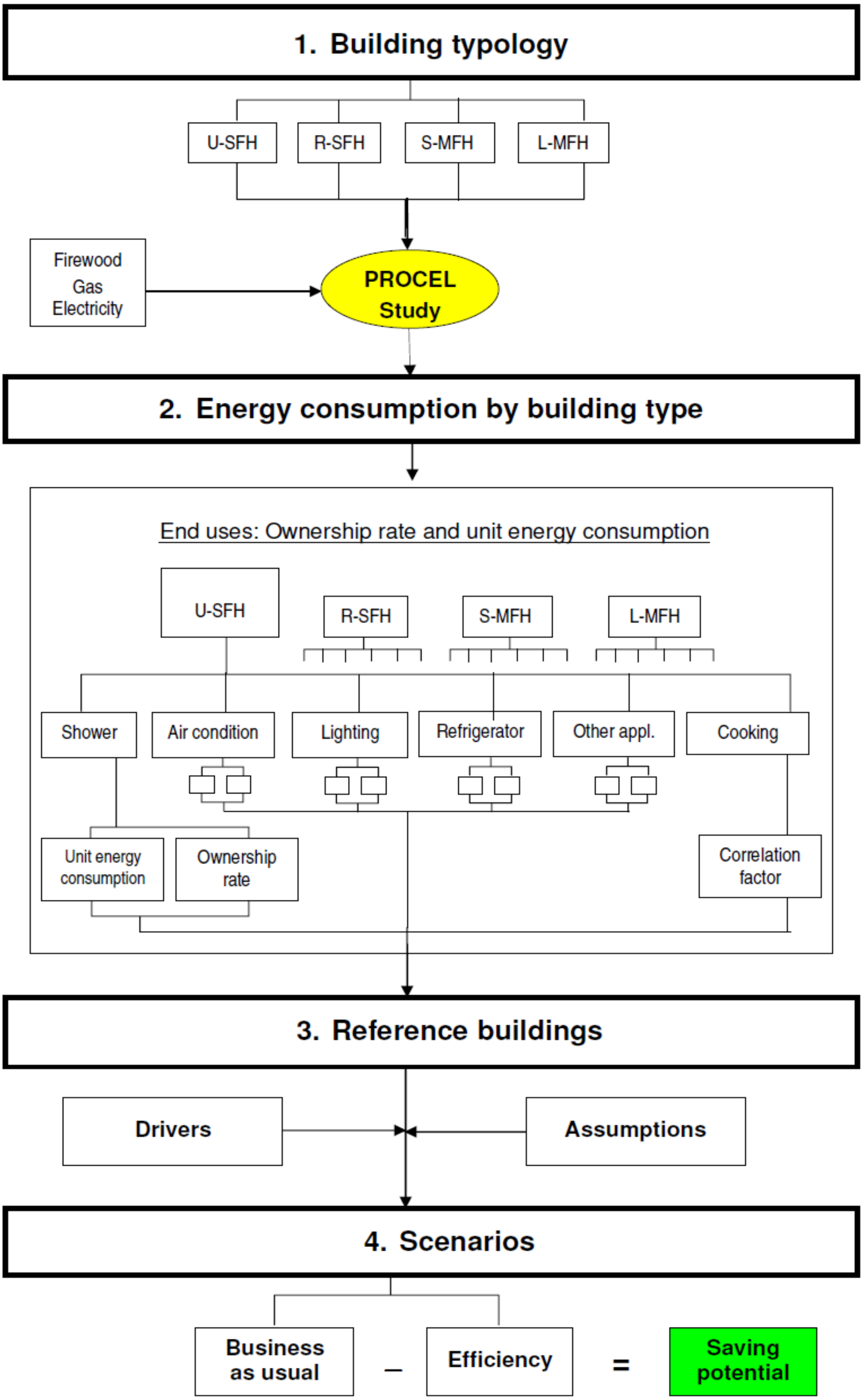


**Figure 3:** Research methodology

Source: Elaboration of author

## 1.8. Structure of the report

In general the structure of the report is determined by the methodology and follows the individual steps. The second chapter introduces the energy efficiency related political framework, laws, norms and support schemes for energy efficiency in Brazil. In chapter three the building typology is developed, in chapter four, the energy consumption is disaggregated by building type and end uses and in chapter five the reference buildings are developed. In the last two chapters (six and seven), there are developed the scenarios, and there are presented and discussed the results. The final discussion (chapter eight) compares the outcomes of the scenarios to similar studies and reflects on the methodology and the produced results. Last chapter concludes about the findings and names desiderata for future research in this field.

## 1.9. Delimitation and expected results

The thesis research is embedded in a PHD project that investigates the energy efficiency potential in several countries. Within this context this thesis report investigates the efficiency potential of Brazil on nationwide level. Due to this scope there are not taken into account regional differences. Input and output data are always weighted averages on country level. The building typology was limited to four different building types. The four suggested categories of building types planned to investigate were attached and detached single family houses and small and large multifamily houses. Due to lack of data on the parameter detached or attached of single family houses this parameter was quit. Instead of this the fourth building type to be investigated was decided to be the rural single family house due to its high occurrence in the building stock.

It was decided not to analyze slum dwellings separately. They are accounted in national statistics separately (IBGE, 2009), but not in the national energy balance (EPE, 2009a). According to data from the *Brazilian Institute for Statistic and Geographic* (IBGE), slum dwellings account for about 3,5% of the dwellings (IBGE, 2009). Based on that data the number of slum dwellings seems to be small. Data from UN however indicates that in Brazil about 25% of the population live in slum dwellings (UN-Habitat, 2010). The difference may arise from different definitions and accounting. For this research the crucial question was the number of slum dwellings that are connected to the official electricity network. In 1996 already 92,5% of the slum dwellings were connected to the official network (Xavier and Magalhães, 2003). It is assumed that more than ten years later the percentage is higher and that only a small number of slum dwellings are not connected to the official network. Therefore the research will not differentiate between slum dwellings and other dwellings.

The situation of data and the chosen methodology affects the results. For the estimation of future potential of energy saving it was planned to calculate the cooling demand for the residential sector in Brazil in order to develop the efficiency scenario taking into account buildings with better thermal performance and therefore less cooling demand. In order to do so there had to be developed reference buildings, defining the characteristics of the buildings for the calculation. In the course of the investigation there was realized that the lack of data on the present building situation is immense. Data on building types, construction materials, construction-, demolition- and refurbishment rates, dimension of buildings, insulation and u-values, shadowing, orientation, ventilation and internal loads are almost not existent. The only exception is a norm developed for social housing projects that specifies amongst other characteristics u-values (ABNT, 2005). But this is relatively new and not representative for the whole residential building stock.

Apart from the fact that there are many unknown parameters, about 60-70% of the construction market is informal, what makes it even more difficult to estimate the unknown parameters. There were interviewed several experts from the field of energy efficiency and buildings (Barbieri, 2010; Emerson, 2010; Lamberts, 2010; Leduc, 2010; Nieters, 2010) but the data base could not be completed well. Due to this immense lack of data it was decided not to calculate the cooling demand of the stock because results were expected to have the character of random numbers. Cooling demand refers to a theoretical demand that would exist if all buildings were cooled according to the national Cooling Degree Days (CDD) (McNeil and Letschert, 2008).

Instead of the cooling demand there was calculated the energy demand for cooling. That means the energy for cooling was calculated on the base of the development of the ownership rate of air conditioners according to a global forecast model developed by Mc Neil and Letschert (McNeil and Letschert, 2008). This approach does not permit to develop an efficiency scenario taking into account thermal performance improvements in buildings. Instead it develops a forecast on expected ownership rate and unit energy consumption and saving potential related to that parameters and not to thermal performance and CDD

A crucial point in the research has been the estimation of drivers for future energy consumption. It should be considered that the most important driver for the development of the scenario in this research is, apart from the unit energy consumption and the increasing number of dwellings, the ownership rate forecast. Due to lack of detailed data, the ownership forecast had to be based on only two surveys. Statistically it is not possible to determine future curve developments on base of two surveys. There had to be made assumptions of the future trend of the curve.

# 2. Energy efficiency in Brazil

## 2.1. Political framework

In 1984 the *National Institute of Metrology, Standardization and Industrial Quality* (INMETRO) started the debate on energy efficiency, informing consumers of energy efficiency products, and encouraging consumers to purchase such products. At the beginning INMETRO acted in the automotive sector. Today INMETRO is working mainly in the area of consumer products and is responsible for the *Brazilian Labeling Program* (PBE) (INMETRO, 2010b).

In 1985 the *National Program for Electricity Conservation* (PROCEL) was created by the *Ministries of Mines and Energy* (MME), and managed by an Executive Secretariat subject to Eletrobrás, a Brazilian utility. In 1991, PROCEL was transformed into a government program. The mission of PROCEL is "to promote energy efficiency, helping to improve the quality of life and efficiency of goods and services and to reduce environmental impacts." (PROCEL, 2010b)

To fulfill its mission, it uses resources from Eletrobrás and of the *Global Reversion Reserve* (RGR), a federal fund established with funds from the utilities. Also it uses funds from national and international agencies whose purposes are congruent with its objectives.

In 1991 there was established the *National Program for Petroleum Rational Use* (CONPET), located within Petrobrás. Its objective is to encourage the efficient use of oil and natural gas derivatives in transportation, the residential and commercial sector, agriculture and industry (CONPET, 2010; PROCEL, 2010a).

In 1996 the *National Electric Energy Agency* (ANEEL) was established by Law 9427 of 26 December 1996. Its mission is to regulate and supervise the generation, transmission, distribution and marketing of electricity, given claims by agents and consumers with balance between the parties and the benefit of society; mediate conflicts of interests between players in the electricity sector and between them and consumers, grant, allow and permit facilities and services of energy, ensure fair rates, ensuring the quality of service, require investment, stimulate competition among operators and to ensure universal service. ANEEL Is responsible for the selection and evaluation of projects designed to combat the waste of electricity (ANEEL, 2010a).

In 2004 the *Power Research Company* (EPE) was created. Its mission is to develop an integrated long-term planning for the power sector in Brazil. It carries out studies and research services in the planning of the energy sector in areas of energy resources and energy efficiency. EPE serves as input for the planning and implementation of actions by the MME in the formulation of the national energy policy (ANEEL, 2010a; EPE, 2009b).

## 2.2. Laws, norms and labeling schemes related to energy efficiency

In 2001 Brazil has suffered an energy crisis due to lack of rain, investments in transmission lines and backup generation plants. This imposed the country to reduce 20% of its electricity consumption. The management of the crisis and the cooperation of the population led to high reductions in the country energy consumption and some of this reduction became permanent. The important output of this crisis was the signature by the government of the energy efficiency law that has been on the senate for 10 years, the *Energy Conservation Act*, law N° 10,295 (INMETRO, 2010c; Lamberts and Ghisi, 2008).

### 2.2.1. Laws

Law no 10,295 – energy efficiency for buildings and apparatus

The law orients the national policy for conservation and rational use of energy and is regulated by Decree 4059 of December 19, 2001, which was published at the end of 2001 (INMETRO, 2010a; INMETRO, 2010c). It announced the elaboration of maximum levels of energy consumption, or minimum energy efficiency of machines and apparatus produced or commercialized in Brazil as well as of buildings based on technical indicators and specific regulations. The decree creates a "Technical Group for Energy Efficiency in Buildings in the Country", a group that will propose a way to regulate the buildings in Brazil to encourage rational use of electricity (LabEEE, 2007; Lamberts and Ghisi, 2008). In the first step a labeling scheme for commercial buildings was developed and is now in its voluntary phase, foreseen to be obligatory from 2011 onward (INMETRO, 2003). A labeling scheme for residential buildings is still under development and as stated by PROCEL *Edifica* (Buildings) is ready for public consultation.

Until now there have not been established any minimum efficiency requirements for buildings.

Law No 9,991 - investments in energy efficiency

The state law Nº 9,991 came in force in 2001 (ANEEL, 2010b). The purpose of this law is to obligate the concessionaires and utilities of the public electricity service to invest in research and development and in energy efficiency programs. One of these obligations is to invest annually at least 1,0 % of its net operating revenue in (electric) energy efficiency projects, whereas 0,25% have to be projects with a social background. ANNEL is responsible for the selection and evaluation of these projects that can be conducted in the following areas (ANEEL, 2010b):

– Education
– Energy management,
– Commerce and services,
– Communities with low purchasing power,
– Public bodies,
– Residential sector,
– Rural areas,
– Public services.

The main focus group of these projects are communities with low purchasing power and the projects aim a) at the replacement of inefficient equipment, e.g. refrigerators, light bulbs, electric showers, b) at educational activities, such as lectures for promoting energy conservation in households and c) the regularization of illegal consumers through connection to the supply grid (ANEEL, 2010b). One focus of ANEEL are solat thermal projects with a social background (Epp, 2008).

### 2.2.2. Norms

Norms and programs related to solar water heating

Related to solar water heating, which can reduce considerably the energy consumption in buildings, the following technical norms characterize the performance of system components, project and installation:

- ABNT NBR-7,198: Planning and implementation of hot water installation in buildings
- ABNT NB-128: Hot water installation in buildings
- ABNT NBR-10,185: Heat tank of fluids for solar water heating systems
- ABNT NBR-12,269: Installation of solar water systems with planar collectors
- ABNT NBR-10,184: Planar solar collectors – Determination of efficiency

(ABNT, 2006)

These norms however do not really support the use of solar water heaters; they rarely aim at the preparation of the installations and verification of a solar water system and planar solar collector in the case it will be installed. The building code of Sao Paulo includes a relatively new law referring to the use of solar water heater in buildings São Paulo (see item 2.3).

There exists a *Program for Qualification of Suppliers of Solar Heating* (Qualisol) that is the result of a protocol signed between INMETRO, PROCEL and the Brazilian Association of Refrigeration, Air Conditioning, Ventilation and Heating (Abrava). It aims at increasing the knowledge of suppliers in the area of solar water heating, quality of installation and satisfaction of the consumer. Under the Brazilian Labeling Program (PBE), Qualisol adds even more security on the premises of solar water heating systems (ABNT, 2006; INMETRO, 2010e).

Norms on thermal performance and minimum thermal standard of buildings

There are some Brazilian voluntary standards related to thermal performance of buildings published by the *Brazilian Association for Technical Norms* (ABNT). NBR 15,220, published in 2005, is the first standard that established the bioclimatic zoning of Brazil and defined for the first time thermal performance standards for single family houses of social housing programs (ABNT, 2005)[2]. Another norm with relation to energy efficiency in buildings is the NBR-15575, published in June 2010. This norm

[2] The bioclimatic zoning of Brazil, the recommended strategies and U-values for each building component are found in the annex 1.

has the intention to normalize social housing projects of one to five stores (ABNT, 2006).

Apart from that there are no energy efficiency related norms on a nationwide level for buildings in Brazil.

Norm for air conditioning systems

The official reference for air condition design is the Brazilian standard NBR- 6401 from 1980. It is based on air renovation established in the *American Society of Heating, Refrigeration and Air Conditioning Engineers* (ASHRAE) handbook of 1972 and establishes the fundamental base for the elaboration for the design and installation of air condition (ASHRAE, 1989). According to Lamberts, although these values set out in this norm are the minimum values required many designers tend to use more recent ASHRAE standards and handbooks and do not follow NBR 6401 (Lamberts, 2007b).

The Ministry of Mines and Energy (MME), on 26$^{th}$ of December in 2007, published the Interministerial Enactment approving specific rules that define maximum rates of energy consumption of window and split air conditioners. The regulation states that equipment that does not meet the requirements set by the Ordinance may not be manufactured or imported within 90 days after publication (MME, 2007b; MME, 2007e).

**Table 3:** Minimum requirements for air conditioner type window

| **Cooling capacity (Cc)** | | **Minimum energy efficiency** |
|---|---|---|
| BTU/h | kW | W/W [COP] |
| ≤ 9.000 | Cc ≤ 2,6 | 2,08 |
| 9.000 < CR < 14.000 | 2,6 < Cc < 4,1 | 2,16 |
| 14.000 ≤ CR < 20.000 | 4,1 < Cc < 5,9 | 2,24 |
| 20.000 ≤ CR | 5,9 ≤ Cc | 2,11 |

Source: (MME, 2007e)

It should be noted that this minimum requirement is very low. According to Lamberts, Brazil runs the risk to buy inefficient appliances imported from China that are no longer sold there). In comparison to the INMETRO labeling this requirement is more or less equal to the worst category E (that begins with a minimum larger than 2,08 COP in the case of window air conditioners up to 9000 BTU/h).

Maximum energy consumption for refrigerators and freezers

The MME on 26$^{th}$ of December in 2007, published the Interministerial Enactment approving specific rules that define maximum rates of energy consumption for refrigerators and freezers. The maximum consumption for every refrigerator is calculated according to a formula given in the ministerial ordenance and expressed in kWh per month and proportional to volume (MME, 2007c).

Minimum efficiency quota for stoves

The MME on 26$^{th}$ of December in 2007, published also the Interministerial Enactment approving specific rules that define minimum rates for energy efficiency of stoves and furnaces with natural gas according to table 4 (MME, 2007d).

**Table 4:** Minimum efficiencies for natural gas stoves and ovens

| Component | Minimum efficiency of component [%] |
|---|---|
| Stove | 56% |
| Oven | 33% |

Source: (MME, 2007d)

### 2.2.3. Labeling schemes

Apart from norms there exist voluntary labeling schemes.

<u>Buildings</u>

In 2007, the voluntary energy efficiency labelling for commercial, service and public buildings *(Regulamentação para etiquetagem voluntária de nível de eficiência energética de edifícios comerciais, de serviços e públicos*) became legally effective (LabEEE, 2010b). This label will assess buildings according to their thermal performance of the building envelope and energy efficiency of the air conditioning and the lighting system. The labeling classifies the buildings in ranges A, B, C, D and E according to their energy consumption (figure 4). The still to be implemented voluntary labeling for residential buildings asses apart from the building envelope, air conditioning and lighting system also the water heating system. The implementation of water saving measures and in social housing the provision of energy-efficient refrigerators or ceiling fans gives extra points (INMETRO, 2009a).

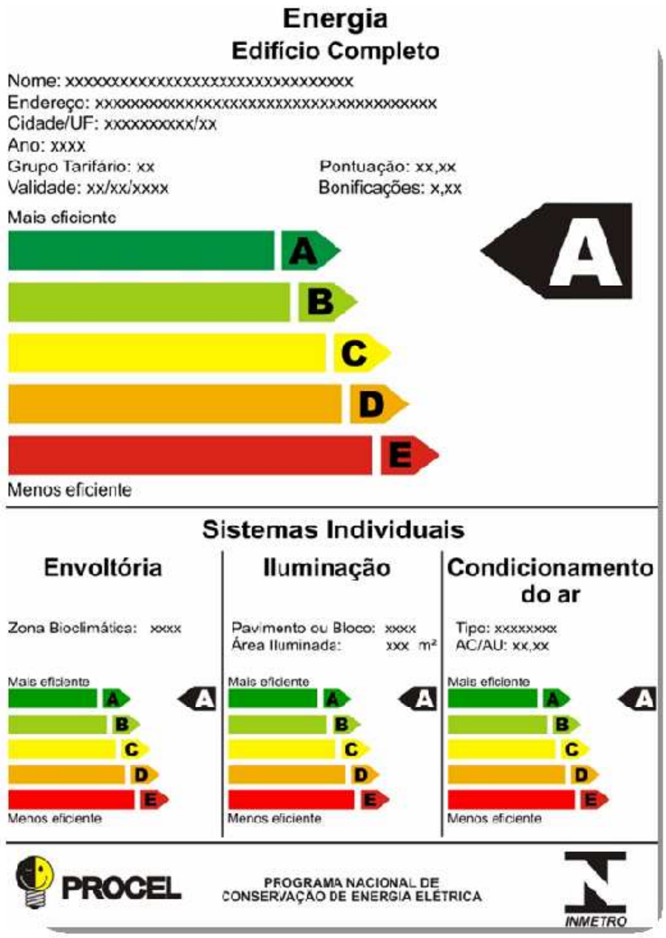


**Figure 4:** Model of the national energy conservation labeling, in this case representing level A

Source: (INMETRO, 2009a)

Appliances

Based on decree 4059, INMETRO established a voluntary *Brazilian Labeling Program* (PBE) that actually labels about 38 product categories, e.g. refrigerators, electric showers and freezers, which are annually updated and listed (INMETRO, 2009a). Every year, PROCEL honors the most energy-efficient appliances of the market with its seal of quality (INMETRO, 2009a). The following is an example of a labeling template for a refrigerator (figure 5).

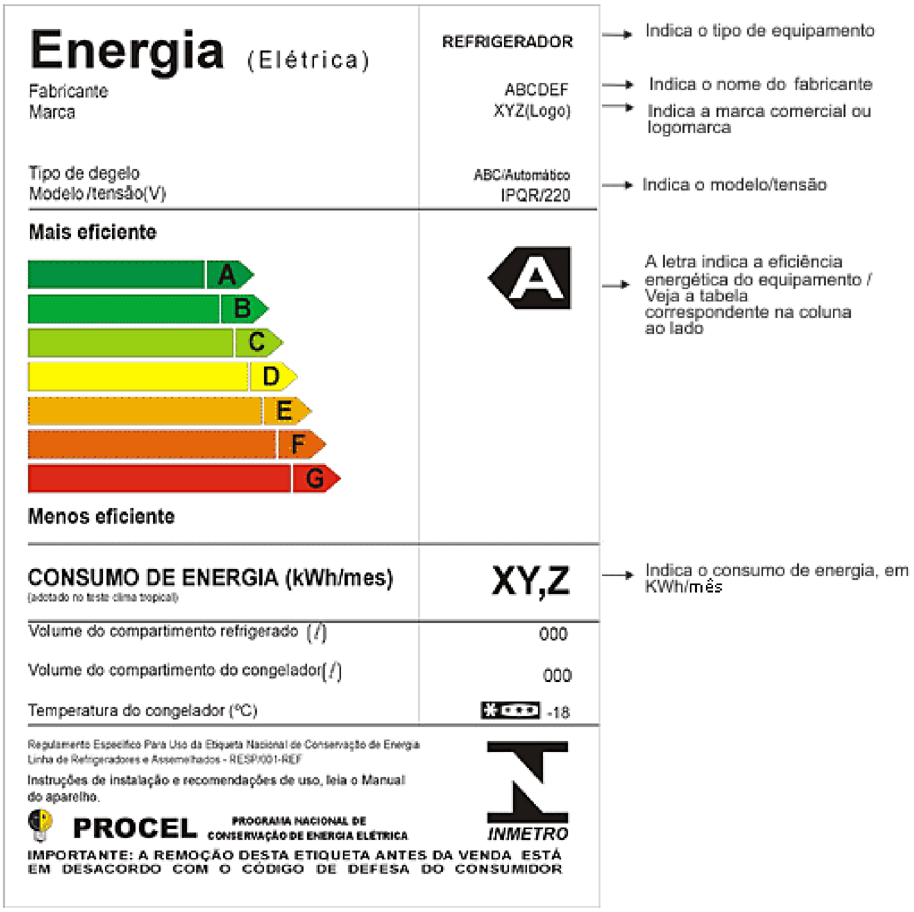


**Figure 5:** Model of the national energy conservation labeling, in this case for a refrigerator

Source: (INMETRO, 2010d)

INMETRO provides a list of the different label categories and their specific ranges (figure 6) and also a detailed list of all labeled apparatus (figure 7). The two figures show the lists in the case of window air condition products.

CONDICIONADOR DE AR JANELA — Data atualização: 16/3/2010

| Classes | Coeficiente de eficiência energética (W/W) (*) | | | | | | | | | | | | Total de modelos por classe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Categoria 1 ≤9.495 kJ/h ≤9.000 BTU/h | | | Categoria 2 9.496 a 14.769 9.001 a 13.999 | | | Categoria 3 14.770 a 21.099 14.000 a 19.999 | | | Categoria 4 ≥ 21.100 ≥ 20.000 | | | |
| A | ≥ 2,91 | 45 | 62,5% | ≥ 3,02 | 30 | 55,6% | ≥ 2,87 | 9 | 50,0% | ≥ 2,82 | 6 | 33,3% | 90 |
| B | ≥ 2,68 | 19 | 26,4% | ≥ 2,78 | 16 | 29,6% | ≥ 2,70 | 5 | 27,8% | ≥ 2,62 | 6 | 33,3% | 46 |
| C | ≥ 2,47 | 8 | 11,1% | ≥ 2,56 | 8 | 14,8% | ≥ 2,54 | 2 | 11,1% | ≥ 2,44 | 1 | 5,6% | 19 |
| D | ≥ 2,27 | 0 | 0,0% | ≥ 2,35 | 0 | 0,0% | ≥ 2,39 | 2 | 11,1% | ≥ 2,27 | 2 | 11,1% | 4 |
| E | ≥ 2,08 | 0 | 0,0% | ≥ 2,16 | 0 | 0,0% | ≥ 2,24 | 0 | 0,0% | ≥ 2,11 | 3 | 16,7% | 3 |
| | | 72 un | | | 54 un | | | 18 un | | | 18 un | | 162 un |

**Figure 6:** Updated list of efficiency categories of labeled window air conditioners

Source: (INMETRO, 2010e)

| FABRICANTE | MARCA | MODELO | VERSÃO | CAPACIDADE DE REFRIGERAÇÃO | | | | POTÊNCIA NOMINAL W | | EFICIÊNCIA ENERGÉTICA W/W | | FAIXA DE CLASSIFICAÇÃO | | CONSUMO DE ENERGIA (*) kWh/mês | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | BTU/h | kJ/h | W | kW | 127V | 220V | 127V | 220V | 127V | 220V | 127V | 220V |
| ELECTROLUX | ELECTROLUX | EAM07F EC07F EAE07F | FRIO | 7.500 | 7.913 | 2.198 | 2,20 | 754 | 754 | 2,92 | 2,92 | A | A | 15,8 | 15,8 |
| ELECTROLUX | ELECTROLUX | EAM07R EC07R | REVERSO | 7.500 | 7.913 | 2.198 | 2,20 | | 754 | | 2,92 | | A | | 15,8 |
| ELGIN | ELGIN | EGF-5000-2 | FRIO | 5.000 | 5.275 | 1.465 | 1,47 | | 530 | | 2,76 | | B | | 11,1 |
| ELGIN | ELGIN | EGF-5000-1 | FRIO | 5.000 | 5.275 | 1.465 | 1,47 | 545 | | 2,69 | | B | | 11,4 | |

**Figure 7:** Extraction from the list of labeled air conditioners

Source: (INMETRO, 2010e)

In 2009 Brazil adopted a new set of rules for conformity assessment and energy efficiency labeling for air conditioners.Amongst other things, INMETRO extended the rules and compulsory labeling requirement to multi-split ceiling-and-floor air conditioners (previously only window and high-wall type splits were covered).INMETRO chose to adopt European criteria for this type of air conditioner and to extend the rules for all air conditioning units up to 60 000 BTUs (previously rules only covered up to 36 000 BTUs). Also it tightened the efficiency classification, to reflect the fact that air conditioning models on the market have improved efficiency by an average of 8% since the 2006 regulation (Keith, 2009). However these air conditioners with such big cooling capacities are not common in the residential market (PROCEL/Eletrobrás, 2007).

The following table gives an overview of the minimum efficiency rate for each category established by INMETRO for stoves and ovens. The maximum consumption or minimum efficiency respectively of refrigeration, light bulbs and electric showers depend from the various factors and are not given in categories but is labeled by appliance (INMETRO, 2010d).

**Table 5:** Efficiency ranges for ovens and cook stoves according to INMETRO

| Category | Cook stove efficiency [%] | Oven consumption [%] |
|---|---|---|
| A | ≥ 62,0 | ≤ 51 |
| B | ≥ 60,0 | ≤ 55 |
| C | ≥ 58,0 | ≤ 59 |
| D | ≥ 56,0 | ≤ 63 |
| E | ≥ 52,0 | ≤ 67 |

Source: (INMETRO, 2009a)

Comparing the norm with the labeling in the case of the air conditioning and the cook stove it can be noticed that the minimum requirement of the norm is equal to the worst labeling that correspondent to category E.

## 2.3. Building codes related to energy efficiency

In general with a few exceptions energy efficiency does not play any role in Brazilian building codes yet. In Brazil, decisions on building laws are mostly made at the municipality level (Epp, 2008; Lamberts, 2007b) and there is no unique building code in Brazil. Therefore the inclusion of energy efficiency for buildings is also responsibility of the municipalities.

In 2007 São Paulo Paulo has approved a law to obligate the installation of solar thermal heating in all new buildings in all single or multifamily houses with four or more bathrooms (Diario de São Paulo, 2008; Epp, 2008). All single or multifamily houses with up to three bathrooms per living unit have only to install the infrastructure that permits the installation of solar collectors afterwards (Diario de São Paulo, 2008)**.** However other municipalities are beginning to include this law in their building codes (Cidades Solares, 2010; Lamberts, 2007b).

## 2.4. Financing schemes to support for energy efficiency

In recent years, Brazil has created mechanisms to finance public interest activities as part of the restructuring of its power sector (Jannuzzi, 2000a; Jannuzzi, 2000b; Wiser, 2003). These mechanisms provide funds to invest in Research and Development (R&D) of new technologies and in energy efficiency programs. Under the regulator's supervision electricity distribution companies are required to invest part of their annual net revenue in energy efficiency programs (table 6). 0,5% of their annual net sales revenue has to be invested in efficiency programs and 0,5% in R&D. Public interest energy efficiency programs can be funded by the CTEnerg fund. The total annual investment in energy efficiency programs is about R$ 300 million (Vidinich, 2006). CTEnerg is the public interest fund created to invest in energy efficiency and energy R&D administered by a board with representatives from government, academia and private sector (ANEEL, 2008; Jannuzzi, 2000b).

**Table 6:** Investment requirements (Law 9.991/00)

| | % of the annual net sales revenue (Minimum) | | | |
|---|---|---|---|---|
| | **Energy Efficiency** | **CTEnerg** | **ANNEL** | **MME** |
| **Distribution** | 0.50% | 0.20% | 0.20% | 0.10% |
| **Generation and Transmission** | 0% | 0.40% | 0.40% | 0.20% |

Source: (USAID, 2007)

Other sources for funding energy efficiency measures in Brazil are the *Global Reverse Reserve Fund* (RGR) and the *Support of Energy Efficiency Program* (PRESCO). The RGR fund is administrated by Eletrobrás and is used for the electricity for all *(Luz para todos)* and PROCEL (Eletrobrás, 2009). PRESCO is used to support and foment the energy efficiency in the energy sector of Brazil (Lamberts and Ghisi, 2008). This fund was created in 2006 by the National Development Bank (ABESCO, 2010; BNDES, 2008).

## 2.5. Conclusions

In Brazil energy efficiency is not included building codes yet. That may be due to the decentralized regulation on municipality level. It seems that the building codes are advancing in the sense of the inclusion of solar thermal heating, although there are too much looping holes. However it can be evaluated positively that are quite a few projects on the way in some big cities (e.g. Salvador de Bahia) that are planning to include solar thermal heating in their building code. Due to lack of data and the decentralized regulation a forecast of the development is difficult.

The voluntary labeling scheme for residential buildings is still not implemented and until its impact there will be pass quite some time. The norms set for social housing are only supposed do have little impact due to fact that it is only obligatory for social housing projects.

The labeling schemes of appliances have already established and therefore are supposed to have more influence on the energy consumption in residential buildings in the short to middle term. The requirements for electrical appliances are still very low and have a big potential to bring down the unit energy consumption of appliances.

# 3. Characterization of the residential building stock in Brazil

Principal information for the development of energy efficiency scenarios of the residential sector apart from the energy consumption is the actual situation and development of the population and households. The *National Household Survey* (PNAD), realized through the *National Institute for Geographic and Statistics* (IBGE) informs amongst other things about the residential building stock in Brazil, e.g. about the number of residential buildings, habitants per dwelling, number of rooms and main equipment found inside the buildings.

Since 2004, the results add the information from urban and rural areas for all units of the federal states, the major regions and total Brazil and achieved complete coverage of the national territory. Before 2004 some rural areas where not included in the statistic. That inclusion had some influences in the statistics regarding the percentage of urban and rural households and should be considered when interpreting the data. In the PNAD 2008, 391.868 people and 150 591 households were surveyed, distributed in all units of Brazil (IBGE, 2009).

## 3.1. Method

The following steps have been realized in the given order to develop the building typology and characterize the building stock of Brazil:

1. Identification of the building stock disaggregated by types and building situation
2. Determination of number of inhabitants
3. Development of the building stock (construction and demolition rates)
4. Determination of the constructed area of buildings
5. Determination of building typology
6. Determination of the occurrence of each building type in Brazil

**Table 7:** Parameter required for the characterization of the building stock

| Development of a building typology | |
|---|---|
| **Input parameter needed** | **Data generation** |
| Construction, demolition and refurbishment rate | • Interviews<br>• Literature<br>• Statistics |
| Number of inhabitants per dwelling | |
| Situation of building (rural or urban) | |
| Type of building (flat or house) | |
| Constructed area of building | PROCEL |

Source: Elaboration of author

Following flow chart gives an overview of the process of the development of the building typology:

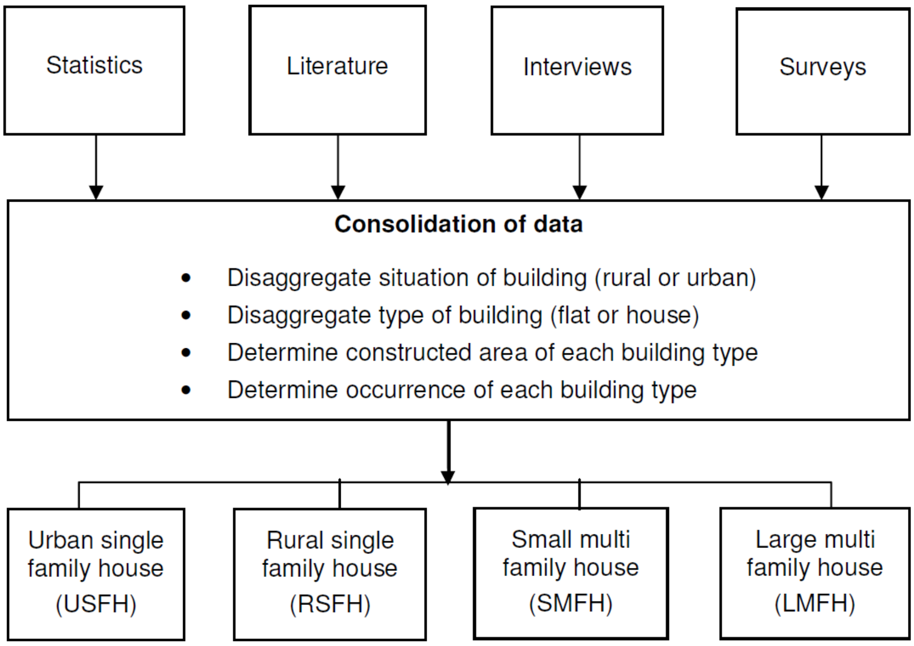


**Figure 8:** Flow chart of the development of the building typology
Source: Elaboration of author

**Table 8:** Required information at end of chapter

<table>
<tr><th>Building type</th><th></th><th>USFH</th><th>RSFH</th><th>SMFH</th><th>LMFH</th></tr>
<tr><td>Occurrence</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Dwellings</td><td>Mio</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Floor area</td><td>Mio m²</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Average floor area per dwelling</td><td>m² per dw.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Average floor area per building</td><td>m² per building</td><td colspan="4" rowspan="3">These parameters are not needed for the scenarios because floor area rather an indicator for space heating that is not existent in Brazil. IN the base of the thesis it serves as validation check</td></tr>
<tr><td>Average floor area per capita</td><td>m² per capita</td></tr>
<tr><td>Average person per dwelling</td><td>person per dw.</td></tr>
<tr><td>Construction rate</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Demolition rate</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Growth rate[1]</td><td>%</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Refurbishment rate</td><td>%</td><td></td><td></td><td></td><td></td></tr>
</table>

Source: Elaboration of author

## 3.2. Data

### 3.2.1. Situation and type of building in Brazil

The PNAD delivers useful data of the evolution and actual situation of the population, the number of dwellings and its distribution in urban and rural area and number of habitants. In 2008 the number of Brazilian population was about 190 Mio, from which

83,8% of the population lived in urban and 16,2% in rural areas and the total number of residential buildings was 58 Mio, from which 85% are located in urban and 15% in rural areas. The number of households is increasing with an annually average growth rate of 3,23% since 1997 till 2008. These figures indicate only a slightly lower average number of persons are living in urban than in rural areas or in other words that 83,8% of the urban population has to share 85% of the buildings situated in urban area and the 16,2% living in rural areas has to share 15% of the buildings situated in rural area (figure 9). The total average number of persons, obtained by dividing the number of people by the number of dwellings, is 3,3 with 3,6 average inhabitants in the rural and 3,3 in the urban area.

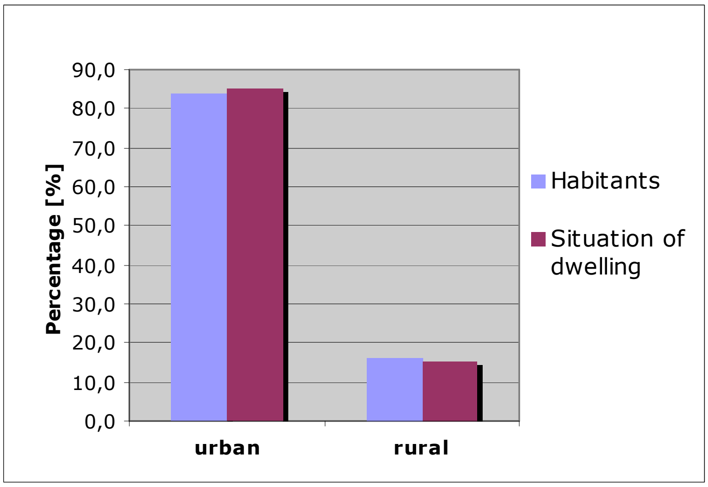


**Figure 9:** Percentage of inhabitants according to living situation

Source: Elaboration of author based on (IBGE, 2009)

The predominant type of building is the house with a occurrence of 89,1%. The apartment has a share of 10,6% and the room, even in urban centres has a share of only 0,3%. Figure 10 illustrates that the fraction of people living in houses (91,3%) corresponds to 89,1% of the fraction that houses share in the building stock, and 8,5% of the population live in apartments that have an percentage of 10,6% in the building stock. That means that the average number with 3,4 inhabitants is higher in houses than in apartments with 2,6.

There is no information found if the houses are detached or not.

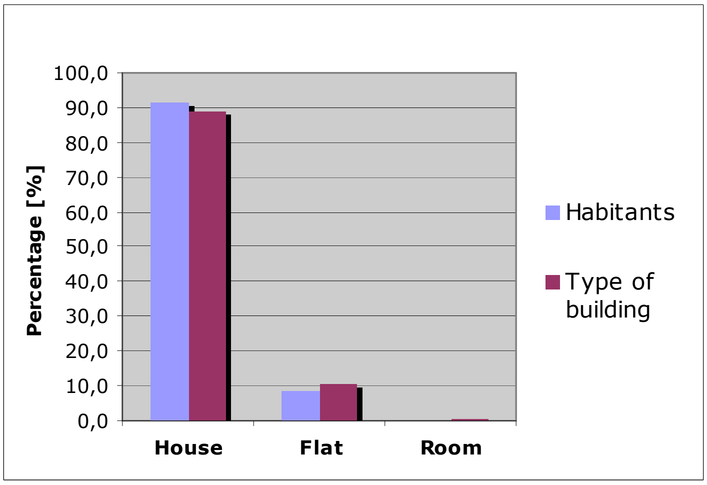


**Figure 10:** Fraction of habitants according to living situation

Source: Elaboration of author based on (IBGE, 2009)

The statistics provide data along the five main geographic divisions of Brazil. The first regional division in Brazil was established in 1942 and it was adopted in 1969 to political and administrative changes. This division defined five major regions that exist until today. These regions are shown in figure 10: North (3), Northeast (2), Southeast (4), South (5) and Midwest (1), subdivided into 86 meso- and 360 micro regions.

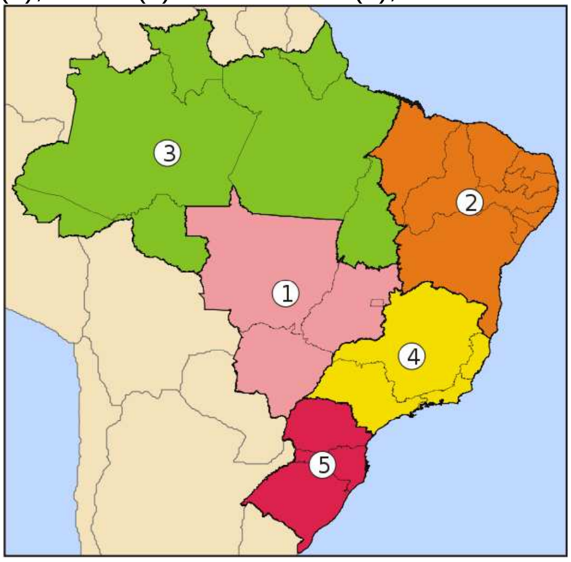


**Figure 11:** Map of Brazil with a division by the major geographic regions

Source: (Wikipedia, 2006).

In general the north of Brazil is more rural and much less dense settled. The following figure (11) illustrates the distribution of the population in the major regions in Brazil and figure 12 of the distribution of the number of dwellings in these regions.

Almost half of the population is living in the southeast region and together with the south and the northeast the population has a share of 85% of the overall population (figure 12). Apart the distribution of dwellings in relation to the population neither per regions (figure 9) nor per situation (urban and rural) differ that much (figure 13). In other words the number of average inhabitants differs only slightly from urban to rural and from region to region (IBGE, 2009).

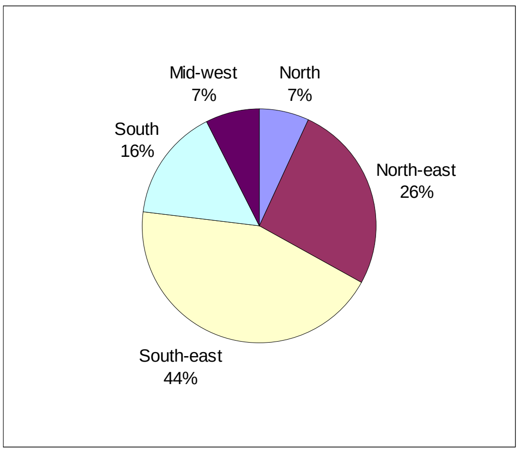


**Figure 12:** Distribution of dwellings by major regions in Brazil

Source: Elaboration of author on base of (IBGE, 2009)

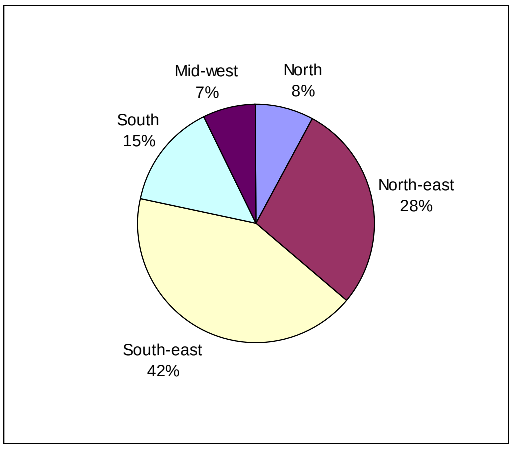


**Figure 13:** Distribution of dwellings by major regions in Brazil

Source: Elaboration of author on base of (IBGE, 2009)

PNAD provides information about the share of houses and flats in the Brazilian residential stock. Table 9 gives an overview of the distribution of houses and flats in the major regions of Brazil and the average number of inhabitants. Compare to the two biggest (in number of population) metropolitan[3] regions of Brazil it can be noticed that the share of the building type apartment with about 24,5% is much higher in Rio then the average. Rio has the most apartments in relation to houses compared to other cities.

**Table 9:** Distribution of the type of building in the major regions and two main metropolitan areas of Brazil and average number of habitants

| | **Brazil** | **North** | **North-east** | **South-east** | **South** | **Mid-west** | **Rio de Janeiro** | **Sao Paolo** |
|---|---|---|---|---|---|---|---|---|
| House [%] | 89,1 | 95,7 | 93,3 | 85,8 | 87,6 | 91,2 | 75,0 | 81,1 |
| Apartment [%] | 10,6 | 3,3 | 6,3 | 14,0 | 12,3 | 8,2 | 24,5 | 18,7 |
| Room [%] | 0,3 | 1,0 | 0,4 | 0,2 | 0,1 | 0,6 | 0,5 | 0,2 |
| Average habitant [number] | 3,3 | 3,8 | 3,6 | 3,1 | 3,1 | 3,2 | 3,0 | 3,1 |

Sources: (Abreu de Queiroz and Tramontano, 2009; EMBRAESP, 2008; IBGE, 2009)

First it can be recognized that the southeast has a much higher rate of apartments than the rest of Brazil. Considering the two biggest metropolitan areas São Paulo and Rio de Janeiro they even has a higher share of apartments and fewer houses in the area. Other metropolitan areas have also a share of apartments above the average, such as Porto Alegre (21,6%), Salvador de Bahia (20,2%) e.g. But it is important to recognize that the overall share of apartments in the building stock is in average low, also in the metropolitan areas.

Almost 18% of all dwellings of Brazil are found in the metropolitan area of Rio de Janeiro and São Paulo (IBGE, 2009). It can be concluded that any trends found in this dense region is an indicator due to its weight in the building stock. Another conclusion that can be derived from that figures is that with rising urbanization rate and increasing apartments rate the average number of habitants is decreasing and vice versa.

Due to lack of cross relation of data between building type and situation of building, that is, a lack of information if a multi family house is situated in urban or rural area, it was assumed that multifamily houses are mainly found in urban areas and in rural areas there are found only single family houses. The only data found from the IBGE was from 1989 and constituted that only 0,8% of the apartments have been situated in rural areas (IBGE, 2010).

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[3]The identification of metropolitan regions in Brazil was initiated in the decade of 1960 and institutionalized by the Congress in 1973/1974. There have been established nine metropolitan areas: Belém, Fortaleza, Recife, Salvador, Belo Horizonte, Rio de Janeiro, Sao Paolo, Curitiba and Porto Alegre. Since 1988, the Federal Constitution of Brazil provided the institution of metropolitan areas to the states, "formed by grouping adjacent municipalities together with the objective to integrate the organization, planning and implementation of public functions of common interest " (Article 25, Paragraph 3). Since 1998, the units of the federation, seeking to solve administration problems of state territory, defined a total of 22 metropolitan areas (IBGE 2003, 22f).

### 3.2.2. Development of the building stock

There is no official data available on construction, demolition and refurbishment rate (Barbieri, 2010; Emerson, 2010; Lamberts, 2010; Leduc, 2010; Nieters, 2010). To understand the development of the building sector the historical development of the building stock will be analyzed. Since 1940 the building stock is steadily increasing (figure 14). The annually growth is relatively stable since 1997, whereas the annual average growth rate of the last 10 years has been 3,23% (figure 15) (IBGE, 2009).

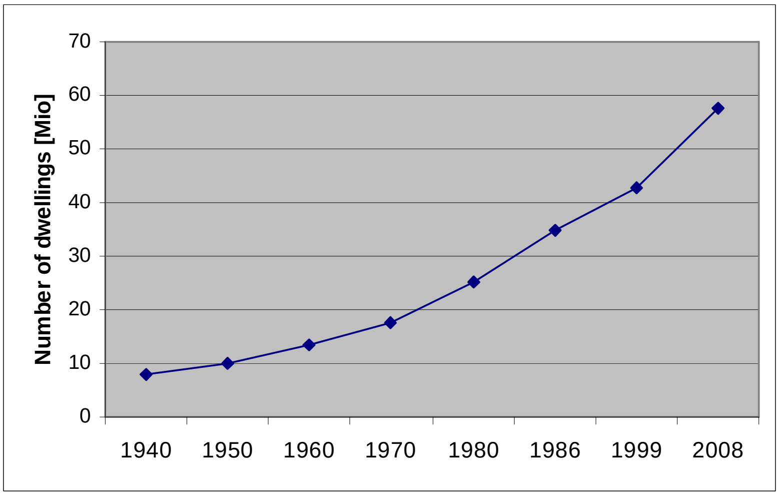


**Figure 14: Grow of the Brazilian building stock since 1940 until 2008**

Source: Elaboration of author on base of (IBGE, 2003; IBGE, 2009)

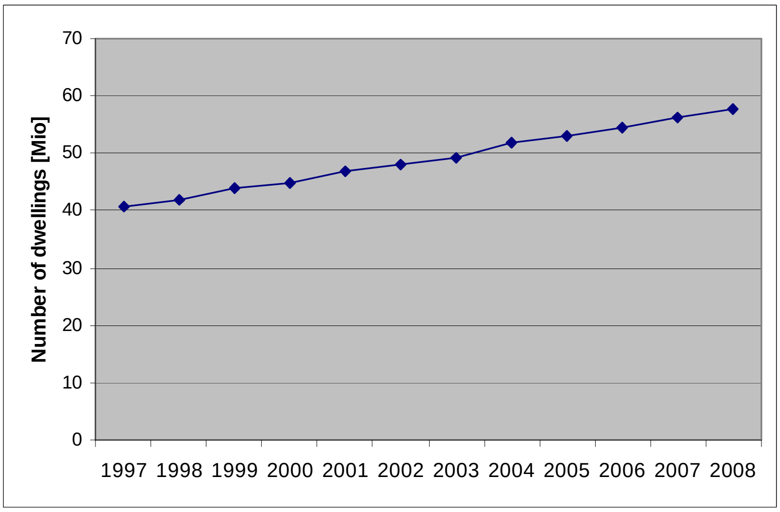


**Figure 15: Growth of the building stock in Brazil from 1997 till 2008**

Source: Elaboration of author on base of (IBGE, 2003; IBGE, 2009; SIDRA, 2008)

To understand better the development within the building stock, that is the urbanization and the development of different building types it is necessary to analyze the development more detailed and the reciprocal effects of that developments. It should be considered that in 2004 there were included for the first time the rural areas Rondonia, Acre, Amazonas, Roraima, Para and Amapa. Therefore in the statistic, a slight increase of the number of houses combined with a slight decrease of the urban buildings from 2003 to 2004 should be interpreted as result of this inclusion and not be seen as a trend (IBGE, 2009).

Since 1997 the urbanization growth is in average 0,45% every year although since 2001 there has been almost increase in the urbanization rate. The rate of the different types of buildings is almost the same since 1989 with the share of the house between 88,4% and 90,3%. The linear regression indicates that the share of houses is slightly decreasing with 0,025% and the share of the flat stock is slightly increasing with 0,08% per year (figure 16) (IBGE, 2009).

But taken into account the data discussed in 3.2.1., especially the weight of the two metropolitan regions Sao Paulo and Rio de Janeiro in the building stock it can be assumed that there is a trend to a higher share of apartments in the building stock. Also this trend should not be overestimated because on the other hand the ratio of the share between houses and flats of the building stock is relatively stable in the last 14 years and that despite of an increased urbanization rate (from 81,1% in 1997 to 85% in 2008). From this point of view it seems that the urbanization trend did not have an effect in the favor of apartments (IBGE, 2009).

Figure 16 visualizes the trends discussed above since 1996. It illustrates the evolution of the situation and typology of the buildings.

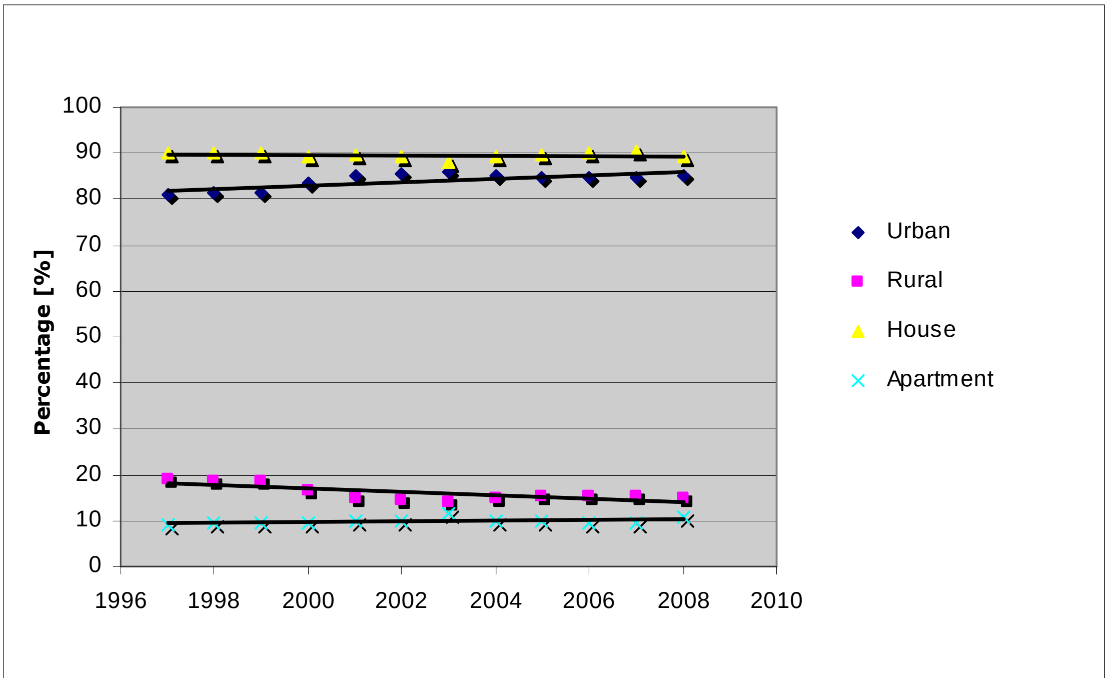


**Figure 16:** Linear regression of historic development of situation and type of building. The equations of the simple linear regression can be found in the annex 2.

Source: Elaboration of author on base of (IBGE, 2003; IBGE, 2004; IBGE, 2005; IBGE, 2009; IBGE, 2010)

### 3.2.3. Constructed area of buildings

The survey realized by PROCEL in 2005 collected data on the constructed area of the households. The data available is divided in six categories illustrated in table 10. In Brazil 20% of the buildings are smaller than 50 $m^2$, 65% of the buildings have a constructed area up to 75 $m^2$ and 87% have a constructed area not larger than 100 $m^2$. The overall average constructed area per building in Brazil in 2005 was calculated to be 74 $m^2$ and per capita 22 $m^2$.

**Table 10:** Share of the different sizes of dwellings in Brazil

| **Constructed area [m²]** | <50 m² | 51-75 m² | 76-100 m² | 101-150 m² | 151-200 m² | >200 m² |
|---|---|---|---|---|---|---|
| **Mean values** | 40 | 62 | 85 | 120 | 170 | 210 |
| **Occurrence [%]** | 20,4 | 43,7 | 22,3 | 8,4 | 2,7 | 2,5 |

Source: (PROCEL/Eletrobrás, 2007)

A recent case study by (Abreu de Queiroz and Tramontano, 2009) of São Paulo reveals some figures about the apartment market in São Paulo. These data is available from the *Brazilian Corporation for Property Studies* (EMBRAESP, 2008), but due high costs there will only be related to the data citied by Queiroz. He relates to the annual EMBRAESP report from 2007 that comprises figures from 2000 till 2007. The original publication provides the data base for an analysis of the behaviour of the real estate market in the Metropolitan Region of São Paulo (MASP) for the last 31 years (1985-2007) and also the prognosis for the current year. Figure 17 illustrates the development of the apartment market in the MASP. It can be noticed that the apartments with less sleeping rooms (0-2) have decreased in favour of the flats with more sleeping rooms (3-4) whereas the flat with four rooms has the highest share and the fastest increasing in the past. The apartment few sleeping rooms (0 or 1) had decreased very much and has at the moment as also the apartment with 5 and more sleeping rooms almost no significance in the market. The market is more or less shared equally between apartments with 2 to 4 sleeping rooms, with a little higher share with the apartment with four sleeping rooms.

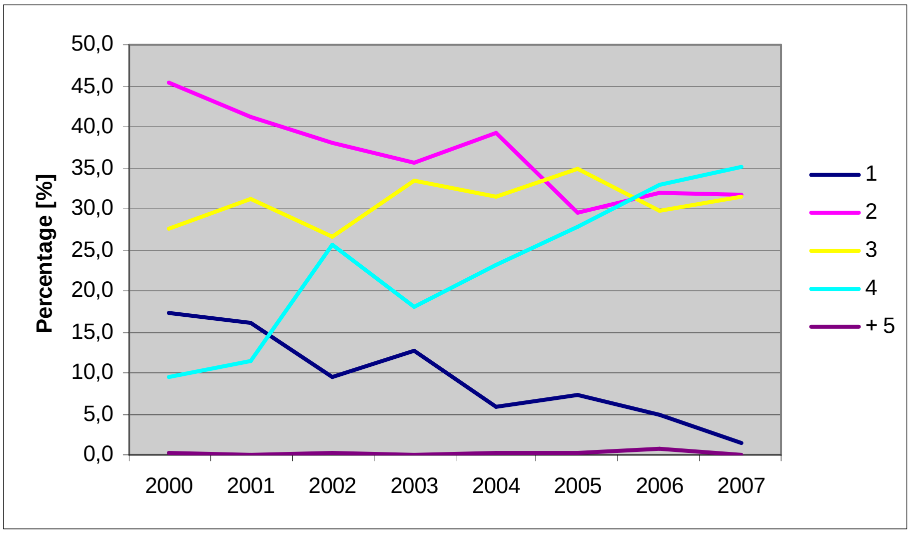


**Figure 17:** Distribution of apartment by number of sleeping rooms from 2000-2007

Source: Elaboration of author on base of (Abreu de Queiroz and Tramontano, 2009).

The constructed area of the apartments did not change much in time. Each type of apartment (1,2,3 or 4 sleeping room) has more or less a relative stable size of area (figure 18). The important fact is that together with figure 17 it can be assumed that the overall constructed area is increasing because of the increasing of the 3 and 4 sleeping room apartments.

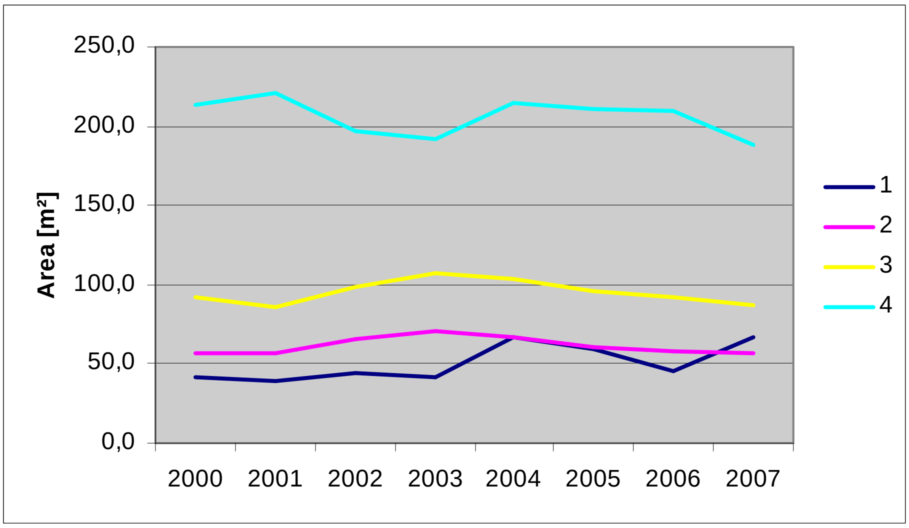


**Figure 18:** Constructed area by number of sleeping rooms from 2000-2007

Source: Elaboration of author on base of (Abreu de Queiroz and Tramontano, 2009)

The conclusion drawn from this study was that in São Paulo the number of big apartments is growing whereas number of small apartments is decreasing. Due to missing data it cannot be concluded if this was representative for all metropolitan areas. But due to the fact that São Paulo is the biggest metropolitan area it was assumed that this is more or less reflected in other metropolitan areas in Brazil. This development was taken into account on a qualitative assumption at the moment of the determination of the building typology and the projection of the future building stock. The table with the real number of constructed apartments can be seen in the annex 2.

### 3.2.4. Results

<u>Building types</u>

The building types recorded in the citied studies are houses, apartments and quarters. The quarter with its occurrence of 0,3% is not considered significant and will not be analysed separately but added to the share of apartments. The following table explains the calculations made to define average sizes of the dwellings on base of the divisions given by PROCEL.

**Table 10:** Explanation of the determination of the building typology

| Building type | Area [$m^2$] | Explanation |
|---|---|---|
| **Urban SFH** | 74 | Calculated as weighted average of all buildings.[1] It represents the average income, floor area and number of inhabitants building |
| **Rural SFH** | 56 | Due to the low income situation in the rural area it was assumed that most of the rural houses are found in the first two categories defined by PROCEL (< $50m^2$ and $51\text{-}75m^2$). The value is therefore the weighted average of these two categories.[2] |
| **Small MFH** | 56 | This is the typical old multi family house for the low income class. The study of PROCEL does not distinguish between |

| | | |
|---|---|---|
| | | house and apartment sizes. The case study from São Paulo permits to calculate average values of the SMFH and the LMFH based on data from 2000-2007. The SMFH comprises 0-2 bedroom apartments. The constructed area is the mean value of these apartments.[3] This building type is assumed to have four floors. It is assumed that this building type in the past was built very often because of the law that MFH with more than four floors have to integrate an elevator in the building. Also this is a typical building type of social housing[4]. |
| **Large MFH** | 137 | This represents the typical new large multi family house for the middle to high income class. Based on the case study of São Paulo the LMFH comprises the 3-5 bedroom apartments. The constructed area is the mean value of these apartments.5 The number of floors is set to 16, although there is no data available. This was based on observation of the author in Rio de Janeiro and estimated to be reflecting the trend of newer apartments built. The construction of larger multi family houses is originated in the fact of the higher profitability of the large multifamily houses because of a lower price of the terrain per apartment and due to the fact of scarce of terrain. |

[1] Source: Elaboration of author on base of (PROCEL/Eletrobrás, 2007)
[2] Source: Elaboration of author on base of (PROCEL/Eletrobrás, 2007)
[3] Source: Elaboration of author on base of (EMBRAESP, 2008)
[4] Source: Elaboration of author on base of (Nieters, 2010)
[5] Source: Elaboration of author on base of (EMBRAESP, 2008)

Occurrence of building types

To be able to make energetic calculations it was very important to determine the occurrence of each building type in Brazil. There was found no data that directly crosses the building type with the situation of the building. The following steps explain the calculation of the occurrence of building by type and situation, (for an overview of the steps see figure 19):

1. The share of 15% of the rural SFH has to be subtracted from the overall building stock. There was almost no data available on the occurrence of apartments in rural areas, only one data from 1989 has been found the share of apartments in rural areas has been 0,8% (IBGE, 2010). Due missing data and to facilitate the calculation it was assumed that there are almost no apartments in the rural area and the value was set to 0%.

2. The total share of apartments in the Brazilian building stock is 10,9%. Due to the assumption that there are no apartments in the rural area the share of 10,9% has to be subtracted from the share of the urban SFH.

3. The share within the apartment stock is set to SMFH as 80% and LMFH to 20%. That has two reasons:

    a. The constructed area of every apartment type (small and large) does not change significant, see (item 3.2.3.).
    b. The assumed share of 20% of the LMFH implies a total number of about 1,12 million large apartments in MFH in the actual building stock. In the period from 2000-2007 there has been built about 105.000 apartments, about 24.000 of them only in 2007 and only in the city of São Paulo. Considering the metropolitan area of São Paulo and the other metropolitan areas in Brazil this assumption seems reasonable.

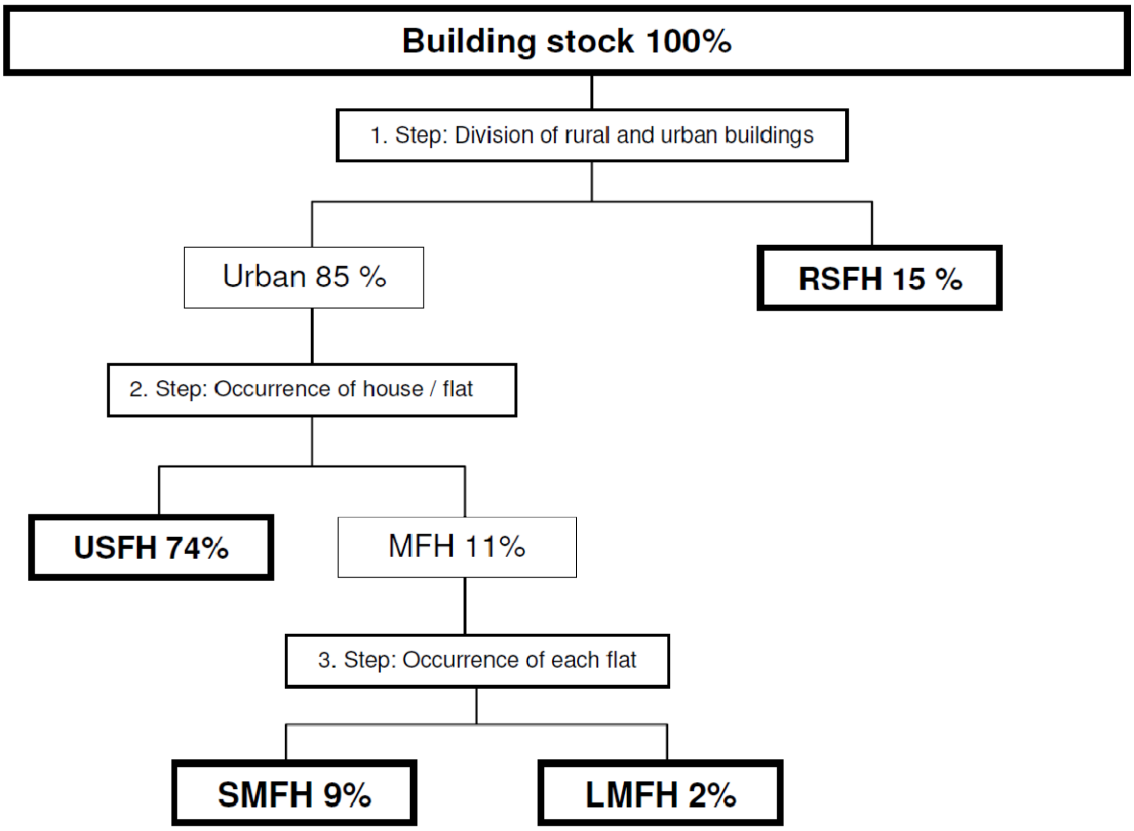


**Figure 19:** Steps of the determination of the occurrence of each building type in Brazil
Source: Elaboration of author on base of (EMBRAESP, 2008; IBGE, 2009),

The following table summarizes the data obtained in this chapter and gives an overview of the structure of the actual building stock disaggregated by type of building.

**Table 11:** Structure of the building stock according to typology in Brazil in 2008

| | Unit | SFH Urban | Rural | Small MFH | Large MFH | Total residential |
|---|---|---|---|---|---|---|
| Occurrence | % | 74,1 | 15,0 | 8,7 | 2,2 | 100 |
| Dwellings | Mio | 42,61 | 8,67 | 5,02 | 1,25 | 57,56 |
| Floor area | Mio m² | 3.187 | 486 | 281 | 172 | 4.125 |
| Average floor area per dwelling | m² per dw. | 74,8 | 56,0 | 56,0 | 137,0 | 71,7 |
| Average floor area per building | m² per building | - | - | 896 | 4384 | - |
| Average person per dwelling | person per dw. | 3,29 | 3,56 | 2,60 | 2,60 | 3,27 |
| Construction rate | % | Data on construction, demolition and refurbishment rate is not | | | | |

| | | |
|---|---|---|
| Demolition rate | % | available. Instead for further calculations there was adapted the average historic growth rate of the building stock from 1997 until 2008. |
| Refurbishment rate | % | |
| Growth rate[1] | % | 3,23 (calculated) |

[1] average growth rate (1997-2008), on base of (EMBRAESP, 2008; IBGE, 2004; IBGE, 2005; IBGE, 2009; PROCEL/Eletrobrás, 2007),

## 3.3. Examples of real buildings in Brazil

The following examples of different housing types taken from a case study of the residential sector in Porto Alegre serve as illustration of the prototypes defined.
Examples for single family houses in urban or rural area are:

- Type 1 includes one-storey masonry houses, having simple finishing, being part of low income housing schemes;
- Types 2 and 3 include small one-storey buildings, having a rectangular plan, being quite old and having a front balcony, with wood or mixed finishing, for type 2, and masonry finishing, for type 3;
- Type 4 households have one-storey, masonry finishing, occupying the whole land plot frontal area; their ground plans being rectangular or "L" shaped;
- Types 5 and 6 have good quality masonry finishing, two floors, compact shape, for type 5, and irregular shape, for type 6;
- Type 7 includes one or two floors detached houses, settled on large land plots (nearly 1,000 m2, on average);

Examples for small multifamily houses are:

- Type 8 includes four storey housing blocks, having plain external finishing and rectangular shape, gathered in housing complexes;
- Type 9 include 3-5 storey buildings, including penthouse, and follow good quality standards;
- Type 10 includes tall (12 to 20 storey) buildings, with penthouse, built on piles.

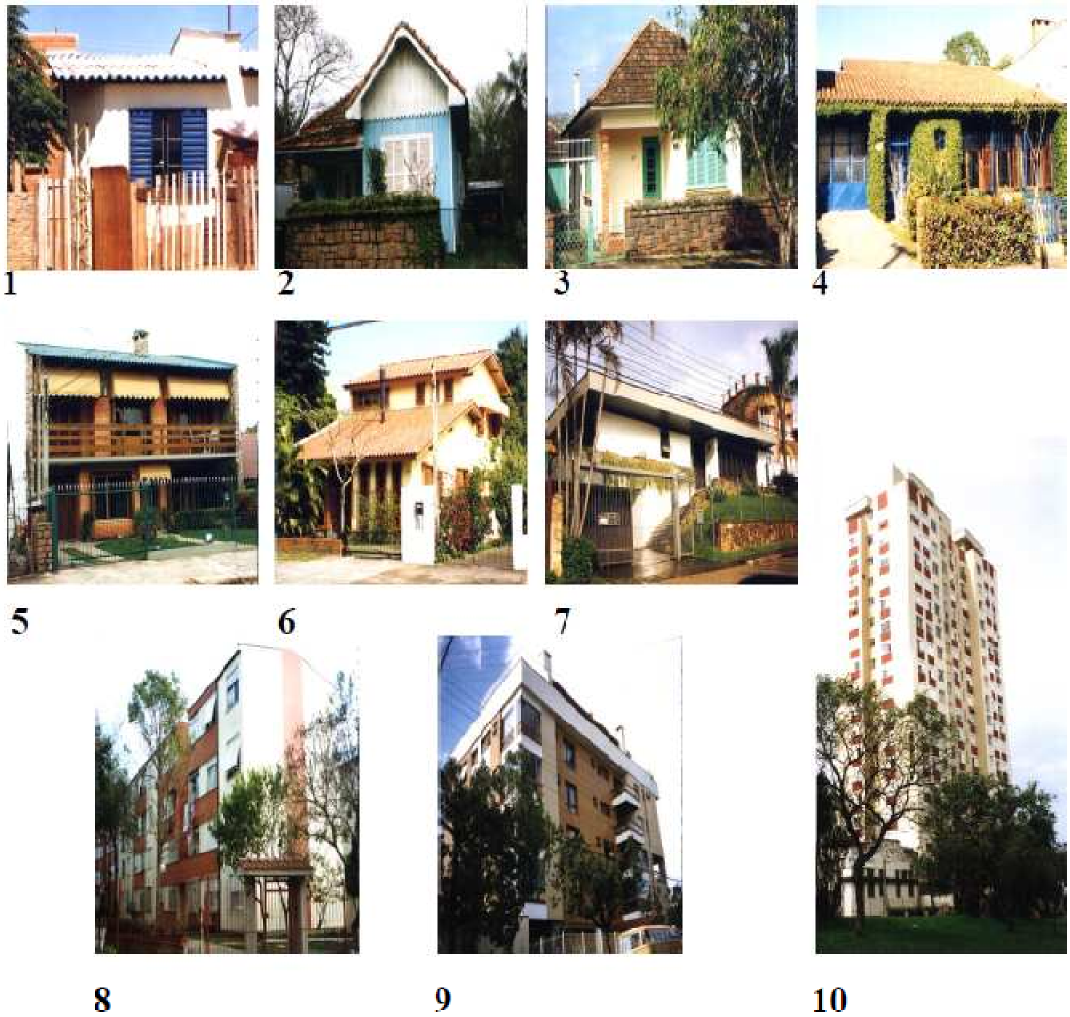


**Figure 20:** Photos of the different types of houses
Source: (Sattler and Hansen, 2001)

## 3.4. Conclusions on the building stock in Brazil

The actual building stock in Brazil is increasing with a growth rate of about 3,2% in the last years. Also from the data it is not possible to determine a construction, demolition and refurbishment rate. The building stock was disaggregated due to situation and type of the building. On base of the data four building types has been defined and weighted by their share in the total building stock. It was found that the urbanization rate is slowly increasing and also that due to historic data the ratio of the two building types house and apartment stay relatively unchanged. However figures from big metropolitan areas indicate that there is a trend to a higher share of apartments in the stock. The stock of multi family houses itself shift from the smaller ones to the larger ones indicating a slow shift of weight from the small to the large multi family houses. From the data it could be calculated an average constructed area of 74 m² per building, an average of 3,3 inhabitants in buildings and an average area of 22m² per inhabitant.

This value permits to validate the data at least from data available from the municipality of Rio de Janeiro where the average constructed are per capita is 21 $m^2$ (SMF, 2000). Taking this into account it seems that the input values from PROCEL are valid and the outputs of good quality.

# 4. Energy consumption by building type

Data for the energy consumption in Brazil is obtained from the *National Energy Balance* (BEN). The BEN (MME, 2010) is published by the *Power Research Company* (EPE) on the behalf of the Ministry of Mines and Energy (MME) that counts the energy consumption of the main sectors of economic activities as also its energy production by primary and secondary energy sources. The database goes back to 1970 and counts the annual physical flows of 49 energy forms and groups in the production activities, stocks, commerce, transformation, distribution and consumption in different economic sectors (EPE, 2009a).

Technically the BEN defines cooking energy as all energy sources that is LPG, canalized gas, firewood and charcoal, except electricity (BEN 2009: 123). The residential electricity consumption is understood as all electrical appliances, water heating and lighting (EPE, 2009a). Although this is not 100% correct this assumption is adapted due to lack of more detailed data.[4]

## 4.1. Energy consumption in the residential sector by source

In 2008 the final energy consumption in Brazil was $226*10^6$ toe that corresponds to 89 % of the national energy supply. The sectors with the highest consumption were the industry with 36%, the transport with 28%, the energy sector with 11% and the residential with 10% share (figure 21).

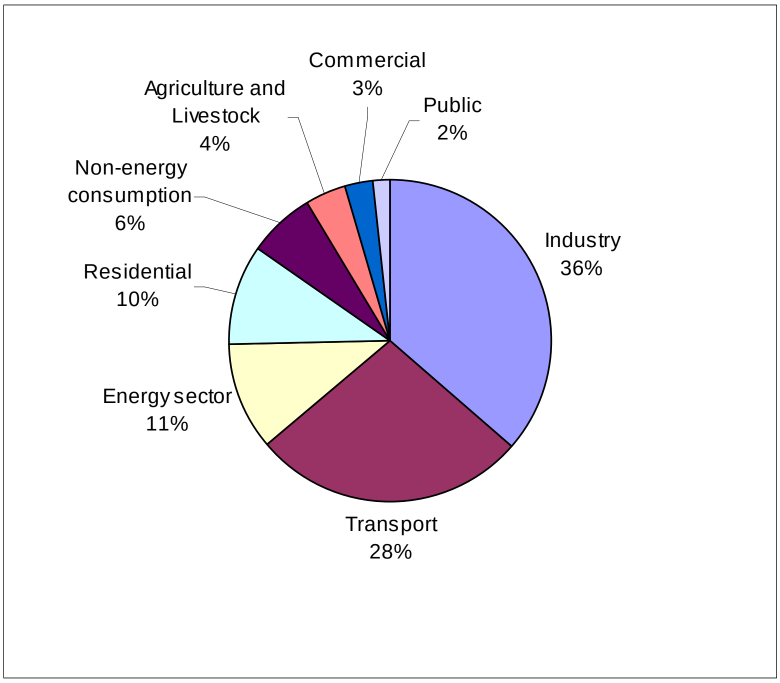


**Figure 21:** Final energy consumption by sector

Source: (EPE, 2009a)

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[4] Kerosene is mainly used for lighting and also functions for refrigerators in far away communities and not for cooking purposes. Firewood is also used for heating purposes. Due to BEN kerosene consumption is very small and about the consumption of firewood as heating source there are no data available although it is assumed to be not significant (Tavares, 2006). Also there are end uses of gas others than for cooking, such as heating water and other hygiene activities. The only data available on that is the percentage of households that heat water not with electricity but with gas (PROCEL, 2007). On the other hand there are electric appliances that are used for cooking and are not taken into account for the cooking energy consumption. These are relatively new appliances with low penetration and purchase still limited to those with a high familiar income (Tavares 2006).

The energy matrix in the Brazilian residential sector is dominated by the three main sources electricity, firewood and liquefied petroleum gas (LPG). In 2008 the energy consumed in the residential sector was 22 738*$10^3$ toe. Electricity consumption was 8 220*$10^3$ toe, gas (natural and LPG) was 6 272*$10^3$ toe and firewood was 7 706*$10^3$ toe (EPE, 2009a). The distribution of the consumption by source is illustrated in figure 22.

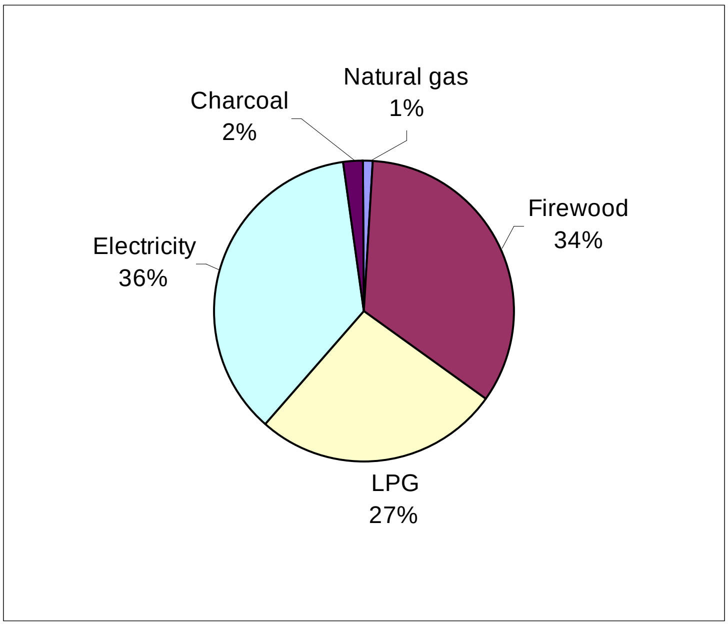


**Figure 22:** Distribution of the energy consumption in the residential sector

Source: (EPE, 2009a)

Firewood

Amongst the main sources that are used in the residential sector, firewood was predominant until 2007. Its low cost and good availability are responsible for its consumption mainly for cooking activities, but also for water heating and finally for heating purposes in rural communities and urban periphery. Its predominance is justified because of its low energy yield in relation to LPG that increases its quantitative consumption (item 4.3.). Vegetal coal is similar to firewood in terms of its consumption. Its participation also had a small increase after the energy crisis in 2000.

Electricity

In 2008 electricity has become the main source in the residential sector. The increase in the consumption is directly associated with the indices of the ownership of household appliances that in turn is strongly related with the GDP. The electricity consumption almost doubled between 1990 and today (increase of 96%). Only in the last three years, from 2005 to 2008, the electricity consumption increased with 15%, from 83.193 GWh to 95.585 GWh corresponding to a share of 22,3 % of the overall electricity consumption in Brazil (EPE, 2009a).

Liquefied petroleum gas (LPG) and natural gas

The LPG completes the group of the energetic sources of major use in residential sector. As principal concurrent to firewood for cooking and mainly in urban centres its consumption has decreased after 2001 due to increasing prices and natural gas entering the market. Only in 2008 the consumption of LPG increased in comparison to 2007 with 2,6%. Natural gas has perspectives of increasing because of increasing market penetration due to higher disposition due to growing national production and access to the Bolivian market (EPE, 2009a). Nevertheless in absolute figures the through main sources are firewood, LPG and electricity.

## 4.2. Evolution of the consumption of LPG, firewood and electricity

The final consumption of the residential sector fell from 1970 to 1994, see figure 23 in function of the substitution of the use of firewood through LPG that is 7 to 10 times more efficient (EPE, 2009a; MME, 2006; Tavares, 2006). Since the 1960s, there has been an effort to create a market for liquefied petroleum gas (LPG) in order to replace firewood as the main cooking fuel in Brazilian households (Jannuzzi, 1989). Subsidies were one of the main elements used to promote LPG as a substitute for fuel wood and support a transformation of the cooking fuel mark (Jannuzzi, 2004; Lucon, 2004).

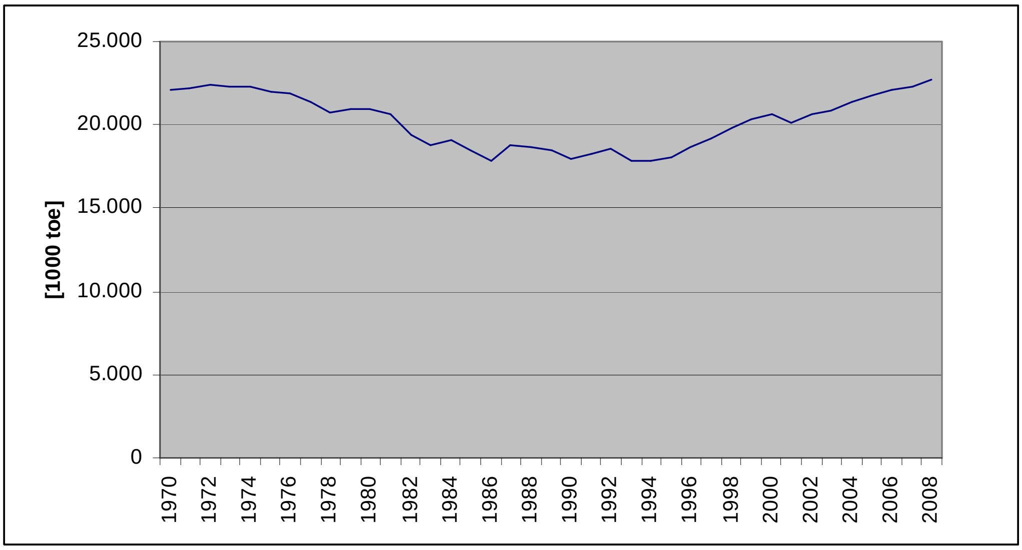


**Figure 23:** Evolution of the energy consumption in the residential sector

Source: Elaboration of author on base of (EPE, 2009a)

Due to the energy crisis of 2001 the consumption of firewood increased whereas at the same time the consumption of LPG decreased. According to Tolmasquim and Szklo the reasons why the LPG did not fully substituted the use of firewood are a) the preference of the users for meals made by in the stoves of firewood, b) the reduces costs of firewood and c) the difficulty of the reposition of the LPG connection valves of the gas bottles and the access to the dwellings together with the distribution that often was not confident in rural zones and slum communities (Tolmasquim and Szklo, 2000).

The increase of the consumption was also an effect of the lower electricity consumption that did not retake its old growth until 2007, when consumption of firewood and electricity was almost equal. The evolution of the consumption in the residential sector from 1973 till 2008 illustrates the steady decrease of the firewood and steady increase of electricity and gas consumption until 1997 (figure 24). It can be noted that in 2008 electricity had the highest share in the matrix.

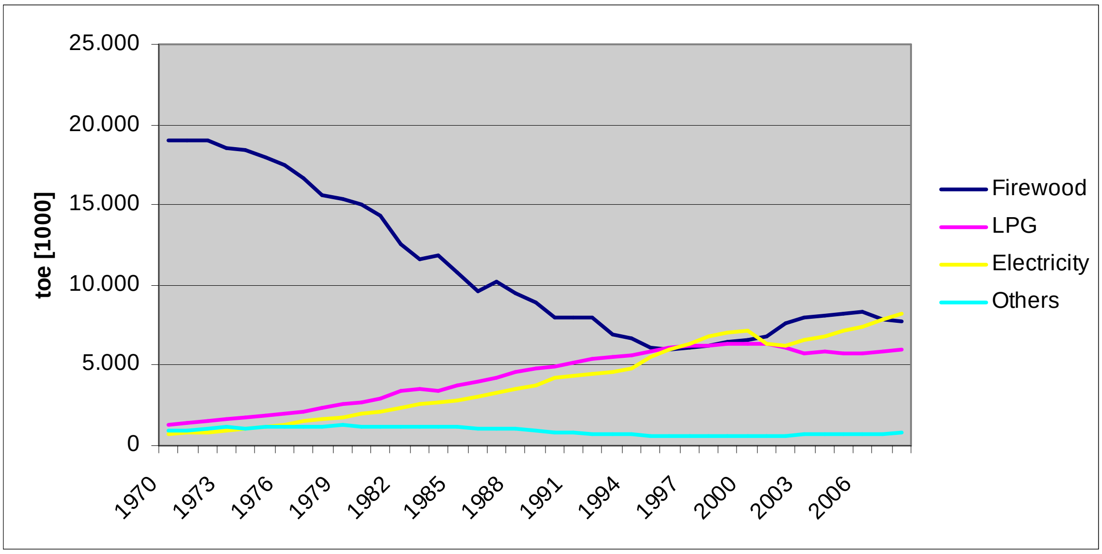


**Figure 24:** Consumption by source in the residential sector (1970-2008) [$10^6$ toe]

Source: Elaboration of author on base of (EPE, 2009a)

Since the 70ties the ratio energy for cooking to electricity decreased until 1995 and has remained more stable since then with the exception due to the energy crisis, when the electricity dropped down in ratio to the cooking energy (figure 25). In 2008 cooking energy accounted for 64% of the total energy consumption in the residential sector and electricity for 36% (EPE, 2009a).

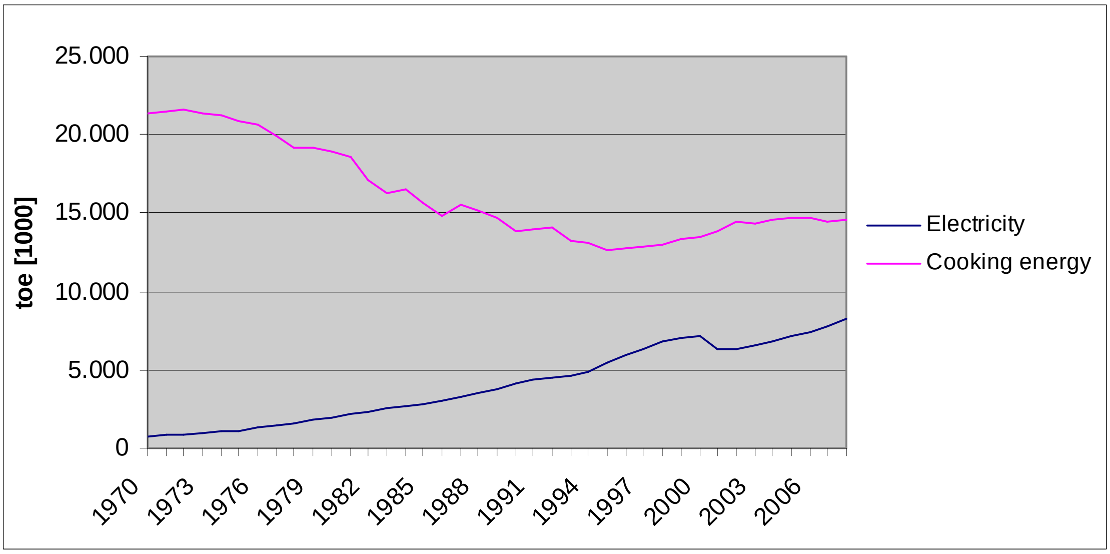


**Figure 25:** Cooking energy and electricity in the Brazilian residential sector

Source: Elaboration of author on base of (EPE, 2009a)

## 4.3. Method and data

A very important research on national level that investigates questions of the electricity consumption in the residential sector is the *Research of possess and habits of the use of electrical* realized by PROCEL / ELETROBRÁS in 2005 (PROCEL/Eletrobrás, 2007). With specific focus on residential electricity consumption, the study contains data that correlates electricity consumption with number of habitants per dwelling, family income and constructed area. The study claims to be representative for Brazil and to have a maxim error of 1,5%, considering the worst case for the confidence interval of 95% (PROCEL 2007).

For the development of energy efficiency scenarios it was important to break down the energy consumption by building types. The energy consumption of each building type has been determined with linear regression as function of income, inhabitants and constructed area of the dwelling.

The consumption by equipment was divided in energy for cooking (mainly LPG and wood) and electricity. Electricity consumption is calculated by equations obtained from simple linear regressions, based on (SINPHA, 2006). According to the definition of BEN and due to the lack of detailed data the cooking energy consumption was calculated on the base of the electricity consumption following the historical series of BEN that relates these two consumptions of the residential sector. There was established a ratio of these two consumptions for the different building types based on the reference year 2005 because the electricity consumption calculated on base of the PROCEL study realized its survey in this year.

The energy consumption of the building stock is in year n is given by the sum of all cooking energy (Ec) and all electricity (El) of the building stock:

**Equation 3:** Energy consumption of the building stock in year n

$$E_{bs,n} = El_{bs,n} + Ec_{bs,n}$$

Where:
n = year (for the reference year: 2005)
$E_{bs,\,n}$ = Total energy consumption of building stock in year n
$El_{bs,\,n}$ = Electricity consumption of building stock in year n
$Ec_{bs,\,n}$ = Cooking energy consumption in building stock in year n
Source: Elaboration of author

The energy consumption of a specific building k therefore can be calculated by the following equation:

**Equation 4:** Energy consumption of building k in year n

$$E_{k,n} = El_{k,n} + Ec_{k,n}$$

Where:
k = building type
Source: Elaboration of author

The parameters needed for the calculation are summarized in the following table (12)

**Table 12:** Parameter needed for the calculation of the energy consumption disaggregated by building types

| Disaggregation of energy consumption by building type | |
|---|---|
| **Input parameter needed** | **Data generation** |
| Energy consumption in the residential sector | National energy balance (statistic) |
| Average income per building | Based on average values for Brazil, disaggregation on estimations regarding |

| | |
|---|---|
| Average inhabitants per building | income class of building (validated by weighted average value) |
| Electricity consumption in function of income | Linear regression |
| Electricity consumption in function of inhabitants | |
| Electricity consumption in function constructed area | |
| Correlation electricity to gas and firewood consumption | National energy balance (statistic) and estimations on different energy uses due to building type |
| Ratio of firewood to gas stove efficiency | Literature |

Source: Elaboration of author

For the third step in this thesis research, the output data needed is illustrated in the following table (13).

**Table 13:** Output data expected

| | Unit | Urban SFH | Rural SFH | Small MFH | Large MFH | weighted average | statistic value | deviation |
|---|---|---|---|---|---|---|---|---|
| Income per household | [x MI][1] | | | | | | 4,9[2] | |
| Number of inhabitants | [number] | | | | | | 3,3[2] | |
| Calculated electricity consumption per household | [kWh/ month] | | | | | | 131[3] | |
| Correlation factor | Cf | | | | | | | |
| Calculated cooking energy consumption per household | [kWh/ month] | | | | | | | |
| Calculated electricity consumption of building stock | [GWh/a] | | | | | | 83 198 738[3] | |

[1] Note of author: household income is given as a multiply of minimum income in statistics from IBGE
[2] (IBGE, 2009)
[3] (EPE, 2009a; IBGE, 2009)
Source: Elaboration of author

### 4.3.1. Cooking energy consumption by building type

The cooking energy consumption was calculated on base of the electricity consumption due to the weight of the energy consumption of firewood or gas or both in the households.

The cooking energy consumption was calculated in correlation to the electricity consumption of a specific building:

**Equation 5:** Consumption of firewood and gas in building k in a specific year

$$Ec_{k,n} = El_{k_n} \times cf_{k_n}$$

Where:
k = type of building
$cf_{k,n}$ = correlation factor for building type k in year n
Source: Elaboration of author

The different factors for the calculation of the cooking energy consumption were determined by developing different cooking scenarios.

The sum of the cooking energy consumption of the four building types in a specific year can be expressed as follows,

**Equation 6:** Cooking energy consumption of the building stock, disaggregated by building type

$$Ec_{bs} = \sum(El_{k1} \times cf_{k1}) + \sum(El_{k2} \times cf_{k2}) + \sum(El_{k3} \times cf_{k3}) + \sum(El_{k4} \times cf_{k4})$$

Where:
k1 = Urban single family house
k2 = Rural single family house
k3 = Small multi family house
k4 = Large multi family house
Source: Elaboration of author

For simplifying the analysis natural gas and liquid petroleum gas (LPG) will no be differentiated, but referred to as gas, implying that almost all of it (exactly 97%) was LPG in 2005. Energetically, the consumption of firewood is the main source, due to its low energy yield. Looking at the historic development from 1995 -2008 (figure 24 and 25) the energy for cooking and electricity have been in a relatively stable ratio of almost 2:1. In the reference year 2005 the exact ratio was 2:1.

That occurs because of the low energy yield of firewood in comparison to gas. Gas stoves in comparison to cook stoves for fuel wood have a higher efficiency. The thermal efficiency of the stoves for wood lies in the range from 6-10%, in more modern cook stoves reaching about 22% (Anoziea, 2004; Geller, 1982; Gupta. D., 1998; van Ruijven, 2010; Vanin, 1983; Yuanbo, 1989) needing about 7-8 times more firewood as gas for realizing the same cooking services (Tavares, 2006). The exact factor is very difficult to determine due to few data available and the big differences in the cook stove stock and the different moisture content of wood (Anoziea, 2004; van Ruijven, 2010; Vanin, 1983). According to the study of Tavares it will be assumed that 7 units of firewood are equal to 1 unit of gas.

In the case, that consumption of cooking energy and electricity was compared; the values would have only small differences, as shown in the simulation in the table, adopting the suggested conversion factor of 1/7 for charcoal and firewood. Following the definition of BEN (EPE, 2009a), all energy that is not electricity was included in the cooking energy.

**Table 14:** Residential consumption of electricity and cooking energy (conservation factor for firewood and charcoal into gas is assumed 1/7) in reference year 2005

| **Source** | **Energy consumption [toe]** | |
|---|---|---|
| Firewood | 8.235 (equiv. to 1176 of gas) | total cooking energy: 7.154 (50%) |
| Natural gas and LPG | 5.904 | |
| Charcoal | 517 (equiv. to 74 of gas) | |
| Electricity | 7.155 | total electricity: 7.155 (50%) |

Source: Elaboration of author on base of (EPE, 2009a)

This thought is important to understand for the development of the correlation factor, because it indicates that if converting the firewood to gas units the cooking energy would be half of the energy consumption in the residential sector and therefore in average in every building. In other words, if all households used gas for cooking, the correlation factor would be 1 because the energy share per household would be 50% gas and 50% electricity. However this ratio is only given when no firewood is used for cooking. The more firewood is used for cooking, the more increases the correlation factor because of the increasing share of cooking energy in relation to electricity.

In order to determine estimations of the different energy consumptions due to building type and situation there were considered the different types of cook stoves in the buildings. The Brazilian Census, realized in 2000 provides the following data: 15% of the buildings possessed woodstoves and 65% gas stoves and the resting 20% possessed both types of stoves. The geographic distribution indicates that the buildings possessing gas stoves are found mainly in urban areas and the ones possessing woodstoves mainly in rural areas. The buildings that possess the two types of stoves are distributed in rural and urban regions in the function of family income (IBGE, 2003). The possible scenarios ranges from one with 100% firewood to one with 100% gas as cooking energy.

In the first scenario of 100% firewood the ratio of cooking energy to electricity consumption was assumed to be 4:1 reflecting the low income dwellings located in rural areas with difficult access and low ownership of electrical appliances and therefore a relatively high cooking energy consumption in relation to electricity consumption.

In the second scenario the buildings possess two cook stoves, using 65% of their cooking energy of firewood and 35% of gas, reflecting the situation that part of urban dwellings located in the periphery, have two options to cook. Here the gas cooker normally is used for short heating services like e.g. water boiling. For the daily cooking of food, such as beans e.g., the wood cooker is used (Ghisi, 2007; Shell, 2007a). Also it reflects the reality that some of the dwellings do not use the gas stove for weeks due to lack of purchase power of LPG (Shell, 2007a). The cooking energy consumption is much lower due to higher energy yield of the gas used for cooking. That combined with a higher ownership of electricity appliances indicates that in this scenario is used more electricity than in the first scenario. The energy consumption was assumed to be composed of 66% cooking and 33% electricity that is the ratio of cooking energy to electricity 2,5:1.

The third scenario is the most common one with only one gas stove in the household and no firewood cook stove, the relation is 50% electricity and 50% cooking energy (table 15). The ratio of cooking energy to electricity was therefore set to 1:1.

The consumption scenarios for the ratio of gas to firewood cook stoves and electricity to cooking energy based on the given estimations as also the factors for the calculation of the cooking energy as a multiple of electricity consumption are given in table 15

**Table 15:** Scenarios for the relation gas and firewood stoves and the factor for the calculation of cooking energy consumption on base of the electricity consumption

| | **Consumption 100% firewood** | **Consumption 65% firewood, 35% gas** | **Consumption 100% gas** |
|---|---|---|---|
| Occurrence | 15% | 20% | 65% |
| Characteristics | Rural dwellings, low income and difficult access | Urban periphery, low to middle class income | Urban dwellings, all income ranges |
| Division of energetic | 20% electricity, 80% cooking energy | 40% electricity, 60% cooking energy | 50% electricity, 50% cooking energy |
| Correlation factor (cf) | 4,0 | 2,5 | 1 |

Source: Elaboration of author on base of (EPE, 2009a; IBGE, 2003; IBGE, 2009; PROCEL, 2007)

### 4.3.2. Electricity consumption by building type

The sum of the electricity consumption of the four building types developed can be expressed as follows,

**Equation 7:** Electricity consumption of the building stock, disaggregated by building type

$$El_{bs,n} = \sum El_{k1} + \sum El_{k2} + \sum El_{k3} + \sum El_{k4}$$

Source: Elaboration of author

In order to calculate the specific electricity consumption per building type there was established the relation of the electricity consumption with income level, dwelling size and number of habitants. The electricity consumption was calculated as average of the three values obtained by linear regression:

**Equation 8:** Electricity consumption of building k

$$El_k = \frac{(h + a + i)}{3}$$

Where:
h = electricity consumption in function of number of inhabitants of the building type
a = electricity consumption in function of area of the building
i = electricity consumption in function of income of household
Source: Elaboration of author

The PROCEL study distinguishes six electricity consumption classes (table 16). For the purpose of the determination of the linear regressions of the electricity consumption as function of income, constructed area and habitants there had to be determined average consumption values for each energy range. For the first consumption range it was assumed that the mean value is 40 kWh per month. There were no exact data available, but due to older studies (SINPHA, 1999) the main consumption in this range is found between 30 and 50 kWh per month. In the consumption range two till five there has been taken the mean value of the limits of this range (e.g. 75 for the range 51-100). For the sixth consumption range there was assumed a mean value of 550 kWh per month.

**Table 16:** Number of dwellings per consumption range

| Consumption range # | Consumption class [kWh/month] | Mean values of the consumption class [kWh/month] | Number of dwellings [unit] | Occurrence [%] |
|---|---|---|---|---|
| 1 | 0-50 | 40 | 656 | 15,2 |
| 2 | 51-100 | 75 | 952 | 22,1 |
| 3 | 101-200 | 150 | 1 331 | 30,9 |
| 4 | 201-300 | 250 | 722 | 16,8 |
| 5 | 301-500 | 400 | 402 | 9,3 |
| 6 | >500 | 550 | 247 | 5,7 |
| | total | | 4 310 | 100,0 |

Source: (PROCEL, 2007)

The parameters have been obtained through simple linear regression calculated with mean values of the energy classes.

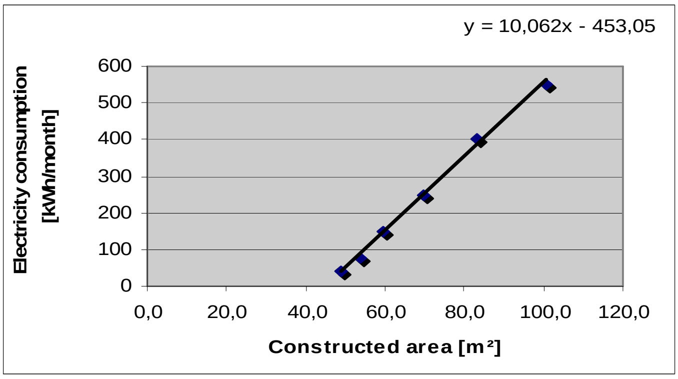


**Figure 26:** Linear regression of constructed area vs. electricity consumption

Source: Elaboration of author on base of (PROCEL, 2007)

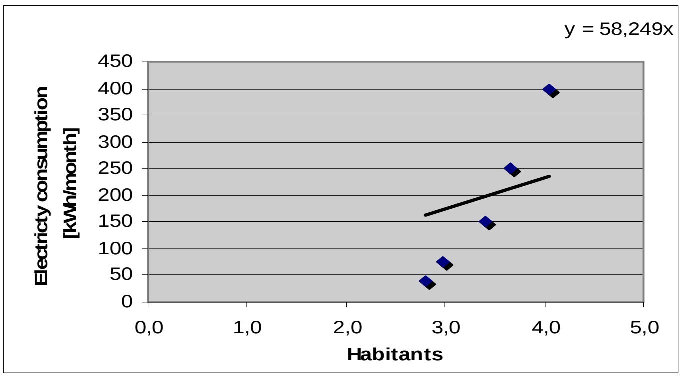


**Figure 27:** Linear regression of electricity consumption vs. number of inhabitants

Source: Elaboration of author on base of (PROCEL, 2007)

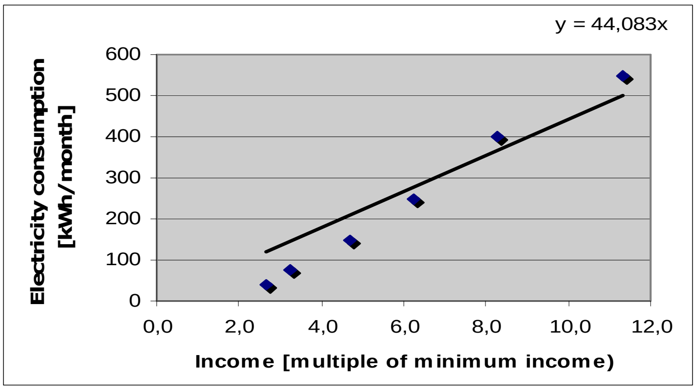


**Figure 28:** Linear regression of electricity consumption vs. family income

Source: Elaboration of author on base of (PROCEL, 2007)

The three equations provide a base to calculate the electricity consumption in the households for different income levels, dwelling size and number of habitants. The three equations are given in the following table (17):

**Table 17:** Linear regressions variables

| Variable | F(x) |
|---|---|
| Area (a) | 10,062 x – 453,05 |
| Number of habitants (h) | 58,249 x |
| Family income (i) | 44,083 x |

Source: Elaboration of author on base of (PROCEL/Eletrobrás, 2007)

## 4.4. Results and calibration of data

Before calculating energy consumption by building type, the data from the PROCEL study has been compared to top down data from the BEN for the reference year of 2005. BEN gives the data of the overall electricity consumption of the residential sector. This divided by the number of households gives the average annual electricity consumption. On that base the average consumption per month per dwelling is 131 kWh that is only 73% of the average consumption calculated on base of the data from PROCEL, which is 180 kWh (EPE, 2006; PROCEL/Eletrobrás, 2007).

There are two possible interpretations for this big difference:

1. PROCEL overestimates the electricity consumption; its methodology is different and based of a smaller sample and of information given them by the utilities and the costumers. Also it is possible that the percentage of the population that belongs to specific category consumption is not correct and overestimated. So in this scenario BEN should be the correct data and the electricity consumption should be adapted using a correction factor *cof* = 131/180=**0,73**.
2. BEN underestimates the electricity consumption because of rigid defined categories. This would also lead to an over- not underestimation of the electricity consumption. Because cooking with electricity, which should correctly accounted fall in the cooking energy section falls in the electricity consumption that excludes cooking energy. Therefore it can be concluded that BEN is not underestimating the electricity consumption.

Considering this two points it is decided that the electricity consumption shall be corrected with the suggested correction factor *cof* of 0,73. The correction factor guarantees equal weighted correction in all ranges of electricity consumption.
Therefore the equation for the calculation of the energy consumption of households is:

**Equation 9:** Energy consumption of a specific building k in year n (calibrated formula)

$$E_{k,n} = (El_k \times cof) + (Ec_k \times cf_k)$$

Where:
cof = correction factor
(cf = correlation factor!)
Source: Elaboration of author

On base of the developed buildings with the parameters required, the energy consumption of each building type was calculated on base of the linear regressions developed. In order to enable the calibration of the data there has been calculated the average values (called "weighted average" in table 19) and then compared with the average values obtained from statistics from PROCEL, IBGE and EPE (EPE, 2009a; IBGE, 2009; PROCEL/Eletrobrás, 2007). The most important indicator is the projected electricity consumption for 2005 compared to the real consumption counted by *National Energy Balance* (BEN) (EPE, 2006). After the first calculation the there have been some high deviations (table 18) and therefore there have been made some adaptations. The calibration process of the three important parameters income, inhabitants and constructed area is described in table 19. The calibrated table gives an overview of the results.

The yellow marked values have been considered critical due to high deviation and further calibrated.

**Table 18:** Results of the projected energy consumption for the building stock before calibration

| | Unit | Urban SFH | Rural SFH | Small MFH | Large MFH | weighted average | statistic value | deviation |
|---|---|---|---|---|---|---|---|---|
| Family income[1] | [x Ml] | 4,9 | 2 | 3 | 12 | 4,5 | 4,9 | -7% |
| Number of inhabitants[2] | [number] | 3,3 | 4 | 3 | 4 | 3,15 | 3,3 | -3% |
| Calculated electricity consumption per household | [kWh/ month] | 120 | 93 | 93 | 192 | 115 | 131 | -12% |
| Correlation factor | Cf | 1,3[3] | 4,0 | 1,0 | 1,0 | 1,7 | 1,8 | -7% |
| Calculated cooking energy consumption per household | [kWh/ month] | 156 | 372 | 93 | 192 | 157 | 231 | -32% |

[1] The base of this estimation was the size (and assumed income level of the inhabitants of the building). The income of the USFH was assumed to be the average value of Brazil. The weighted average from the values of the other building types was validated with the total average from Brazil.
[2] The average inhabitant of the USFH was assumed to be the average value of Brazil. Due to higher average inhabitants in rural areas, the average number was assumed to be 4. The average inhabitants in multi family houses is slightly beneath three, therefore the values was set to three for the small dwelling and 4 for the large .
[3] Weighted average value of the cooking scenarios (only gas stove, in 65% of households and gas and firewood stove, in 20% of households)
Source: Calculation on base of (Abreu de Queiroz and Tramontano, 2009; EMBRAESP, 2008; EPE, 2009a; IBGE, 2009; PROCEL/Eletrobrás, 2007).

Following table describes the calibration of the parameters inhabitants, income and consumption ranges:

**Table 19:** Overview of the calibration of parameters

| Parameter | Calibration |
|---|---|
| Habitants | In general the distribution of habitants has an extreme effect of the consumption so the calculation factor obtained from the linear regression was revised. The linear regression of the habitants was made with intersection in 0/0 to smooth the curve. The results were much better. |
| Income | The same change has been made with the parameter income and the results were already better. |
| Electricity consumption ranges | It was recognized that the >500 kWh/month class distorted the results in all three regression curves, so the last class was quit. The reason could be the missing information of data. The given range only was defined as > than 500kWh/month, but this was no exact value. Moreover it was assumed that the other values already showed a clear orientation of the curve. |

Source: Elaboration of author

After the calibration of the parameters mentioned, there was made a qualitative check of data obtained by the calculation. The following trends based on literature should be reflected in the results (table 20).

**Table 20:** Trends to be reflected by the building types

| | |
|---|---|
| **Electricity consumption** | Ownership of electrical appliances is getting higher with income, that means (low, middle, high class) (IBGE, 2009) |
| | Electricity consumption is getting higher with higher class and income (Tavares, 2006). |
| | Electricity consumption should be distributed as found by the study of PROCEL (PROCEL/Eletrobrás, 2007) |
| **Situation of building (rural/ urban)** | Slightly higher number of habitants per dwelling in rural than in urban areas (IBGE, 2009) |
| | More cooking energy is used in rural than in urban spaces due to the higher inefficiency of firewood than LPG (Anoziea, 2004; Geller, 1982; Gupta. D., 1998; Yuanbo, 1989). |

Source: Elaboration of author

Finally, the projection of the consumption of cooking energy was compared with the real consumption given in the BEN 2008 (EPE, 2009a). Cooking energy was projected much too low, with -32,0% what means that the correlation factor (cf) was too low. This could have various reasons (table 21):

**Table 21:** Possible reasons for the low projection of cooking energy consumption

| | |
|---|---|
| **Reason 1** | The assumed efficiency of firewood is too low, with an increasing efficiency of firewood the ratio of cooking energy: electricity consumption would increase and with that also the calculated amount of cooking energy.<br>This is a parameter that could not be checked because there is no data available and it was decided to stay with the assumption from Tavares (Tavares, 2006). |
| **Reason 2** | The significance of the scenarios is not reflected in the building types and therefore the projection is not correct. This is partly true, the scenario that reflects households with two cook stoves is reflected only with 16,5% instead of the real 20% (IBGE, 2003). But this is due to the occurrence of building types in the total stock and cannot be changed. |
| **Reason 3** | The factors that determine the consumption of cooking energy in relation to the electricity consumption are not correct. This cannot be proved due to missing data, but it is assumed that a big part of the firewood in the residential sector is consumed in the rural area. |

Source: Elaboration of author

The most logical reason seems reason three; rural households need more firewood in comparison to electricity than assumed. Therefore the ratio factor was elevated from 4 to 6 that means the relation is 83,3% firewood to 16,7% electricity. It should be noted that this assumption are averages and due to the lack of data are afflicted with high insecurity. The calibration could also be realized changing not only one but constellation in all of the three scenarios. But with a missing data base it was decided to change only the correlation factor (cf) in the first scenario (table 22).

**Table 22:** Corrected scenarios for the relation gas/firewood and factors to calculate cooking energy on base of the electricity consumption

| | **Consumption 100% firewood** | **Consumption 65% firewood, 35% gas** | **Consumption 100% gas** |
|---|---|---|---|
| Occurrence | 15% | 20% | 65% |
| Characteristics | Rural dwellings, low income and difficult access | Rural dwellings and urban periphery, low to middle class income | Urban dwellings, all income ranges |
| Division of energetic | 16,7% electricity, 83,3% cooking energy | 33% electricity, 66% cooking energy | 52% electricity, 48% cooking energy |
| Cf | 6,0 | 2,5 | 1,0 |

Source: Elaboration of the author on base of (EPE, 2009a; IBGE, 2003)

After the calibration of the results the deviations were considered acceptable. Following table summarizes the key values of the energy consumption per building type, the correlation factor and the calculated cooking energy for the reference year 2005.

**Table 23:** Overview of information on energy consumption by building type

| | **Unit** | **Urban SFH** | **Rural SFH** | **Small MFH** | **Large MFH** | **weighted average** | **statistic value** | **deviation** |
|---|---|---|---|---|---|---|---|---|
| Family income | [x MI] | 4,9 | 2,0 | 3,0 | 16 | 4,7 | 4,9 | -4,% |
| Number of inhabitants | [number] | 3,3 | 4,0 | 3,0 | 4,0 | 3,4 | 3,3 | -3% |
| Calculated electricity consumption per household | [kWh/ month] | 138 | 94 | 94 | 285 | 133 | 131 | 1% |
| Correlation factor | Cf | 1,3 | 6,0 | 1,0 | 1,0 | 2,0 | 1,8 | 11% |
| Calculated cooking energy consumption per household | [kWh/ month] | 187 | 562 | 94 | 285 | 236 | 231 | 3% |
| Calculated electricity consumption of building stock | [GWh/ a] | 65 268 | 8 979 | 5 228 | 3 960 | 83.435 | 83.199 | 1% |

Source: Calculation of author

## 4.5. Conclusions

The Brazilian energy matrix is different to many countries of higher income and colder winters where the HVAC systems have a predominant role in the energy consumption of dwellings. In Brazil however, the residential consumption is mostly comprised of energy for cooking. Although its participation in the energy mix has been decreasing steadily due to the substitution of firewood by the more efficient LPG or natural gas it is not expected that the share of cooking energy will fall below 50% in the near future (EPE, 2009a). Its prevalence in the energy matrix is a result of the lower calorific value and yield of firewood that makes it being used in greater quantity. Although the use is in significant decline for the last 20 years, firewood became again, after the crisis of 2001, the main source of energy in the residential sector of Brazil until 2008 when electricity superseded firewood from this role. This is particularly relevant in relation to the participation of residential consumption, with 11.5% in the total energy consumption in Brazil (EPE, 2009a).

The average electricity consumption has been calculated for every building type as an average value of linear regression of electricity consumption as function of inhabitants, income and constructed area of the building. Due to lack of data the cooking energy consumption per building type k has been calculated based on assumptions of distribution of cooking with firewood and gas with a correlation factor. After calibration these values seem reasonable and will be used for the development of reference buildings.

# 5. Reference buildings

To generate scenarios there has to be developed reference buildings reflecting the actual situation. These reference buildings were based on the building typology.

First step in predicting future energy consumption and energy related savings is to identify the drivers for energy consumption in the region studied. Depending on country characteristics the construction of a generic scenario for future energy use depends on various factors. In countries with a template climate e.g. about half of the energy is used for space heating (IEA, 2004). The amount of energy used for space heating is dependent from the energy intensity of floor space; therefore floor space is a driver for energy consumption. In contrast in warmer developing countries energy consumption in the residential sector is mainly driven by the number of households, the ownership rate, the *Unit Energy Consumption* (UEC) (McNeil and Letschert, 2008).

In Brazil floor space is not considered a key driver for energy consumption, because of almost no existent space heating (Lamberts, 2010). Instead the main drivers for energy consumption identified are the ownership rate, the UEC and the number of dwellings. Appliance energy consumption can be broken down into two factors, the penetration of appliances (expressed as ownership rate) and the annual UEC per appliance. UEC is a function of the efficiency and the capacity of the appliance used as well as the level of use (denominated operation time).

End uses were broken out into air conditioning, hot water heating, refrigerator, lighting, and the category “other appliances”. The end use cooking could not be disaggregated by different cook stoves technologies. There was no information available on cook stoves efficiency and the characteristic of fuel (e.g. moisture content of wood). On base of the calculated energy consumption per building type (item 4.5.) and with the end uses disaggregated there were modeled reference houses that reflect average energy consumptions in each reference buildings. This served to project the energy consumption in the future.

### 5.1.1. Method - Calculation of operation time per end use

Energy can be expressed as the product of capacity and time. These two parameters can change in the future. However due to lack of data on time (hours of operation of a appliance) it was decided to calculate this parameter for the reference year 2005 and not to change it any more in the future. The *operation time* of the different appliances was calculated assuming that

a. the operation time is the same for one appliance independent of the building type. That means e.g. that inhabitants of low income households spend the same time in the shower as people of high income households.
b. the operation time will be stable in the future. That means e.g. that people will take the same time for a shower in 2005 as by 2020.

It is evident that the parameter operation time may change in the future, but due to lack of data and high insecurity it was decided to keep this parameter stable throughout the projection. In the case of the refrigerator the PROCEL survey does not provide data on capacity of refrigerators. But the annual UEC was calculated with an assumed operation time of 24 hours a day the whole year.

The average operation time per appliance for the reference year 2005 can be calculated by dividing the electricity consumption of appliance j in the building stock in 2005 by the product of the ownership rate of appliance j with its capacity and its total number, expressed in the following formula:

**Equation 10:** Average operation time per appliance in 2005

$$\boldsymbol{t_j = \frac{El_{bs,j,2005}}{\left(O_{bs,j,2005} \times P_{bs,j,2005} \times A\right)}}$$

Where:

A = number of buildings

j = type of appliance (e.g. shower, etc.)

t = annual unit operation time

O = ownership rate

P = capacity

Bs = building stock

Source: Elaboration of author

The total electricity consumption of appliance j in the building stock is calculated by multiplying the total electricity consumption obtained from the (EPE, 2009a) with the fraction of the electricity consumption of all appliances j. This fraction was obtained by PROCEL (PROCEL, 2007):

**Equation 11:** Total electricity consumption of the sum of all appliances j (e.g. shower) in 2005

$$El_{bs,j,2005} = El_{bs} + fr_{j,2005}$$

Where:
$El_{bs,\,2005}$ = Total electricity consumption in the residential sector in 2005
$fr_{j,2005}$ = fraction of electricity consumption of appliance j of the total electricity consumption in 2005
Source: Elaboration of author

Therefore the operation time for the reference year 2005 can be calculated, merging the equation 10 and 11:

**Equation 12:** Average operation time per appliance in 2005

$$t_j = \frac{El_{bs,j,2005} \times fr_{j,2005}}{(O_j \times P_j \times A)}$$

Source: Elaboration of author

In the case of the refrigerator the annual UEC was calculated with an assumed operation time of 24 hours a day the whole year. With the given ownership rate, the number of dwellings and the fraction of electricity consumption of refrigerators in the Brazilian electricity matrix there was calculated the average annual electricity consumption disaggregated by building type k, using the following formula:

**Equation 13:** Annual unit energy consumption of a refrigerator in year 2005

$$UEC_{j,k} = \frac{El_{bs,2005} \times fr_{j,2005}}{(O_{j,k} \times A_k)}$$

Where:
$UEC_{j,k}$= Annual unit energy consumption of appliance j (refrigerator in this case) in building k
Source: Elaboration of author

All other appliances will not be further disaggregated but only calculated on base of their share in the stock in 2005, applying the following formula:

**Equation 14:** Electricity consumption of other appliances in 2005

$$El_{others,2005} = El_{bs} \times fr_{others,2005}$$

Where:
$El_{others,k,2005}$ = total electricity consumption of other appliances in year 2005 in building k
Source: Elaboration of author

Following table (24) gives an overview of the parameters needed to solve the equation

**Table 24:** Parameter required for the disaggregation of energy consumers by end uses and building type

| **Decomposition of electricity consumption by end use and building type** | |
|---|---|
| **Input parameter needed** | **Data generation** |
| Total electricity consumption disaggregated by building type | BEN, PROCEL |
| Capacity | PROCEL survey |
| Ownership rate | |
| Energy efficiency (in the case of air condition) | |
| Share of appliance in the total electricity consumption of the building stock | |

| | |
|---|---|
| Unit Energy Consumption (in the case of refrigerator) | Literature |
| Operation time | calculated |

Source: Elaboration of author

Following table gives an overview of information expected from that chapter:

**Table 25:** Ownership rate, capacity and operation time of appliances j by building type and building type k

| Appliances j | | Urban SFH | Rural SFH | Small MFH | Large MFH |
|---|---|---|---|---|---|
| Actual appliance | [kW] | | | | |
| Ownership rate | | | | | |
| New appliance | [kW] | | | | |
| Ownership rate | | | | | |
| Operation time / unit | [h/a] | | | | |

Source: Elaboration of author on base of (EPE, 2009a; IBGE, 2009; PROCEL/Eletrobrás, 2007)

## 5.2. Data on energy end uses

Figure 29 shows the decomposition of energy consumption in the residential sector by end uses. The predominant energy requirement serves the basic need of cooking through wood and gas (mainly LPG), representing about 2/3 of household energy needs. Electricity for water heating, lighting, refrigerator and the air condition constitute the major consumption of this energy source (Figure 30). The substantial difference of final energy use between urban and rural areas arises from the fact that rural households use much more inefficient fuel wood for cooking. Hence, their requirement to provide equivalent energy services is much higher than in urban households.

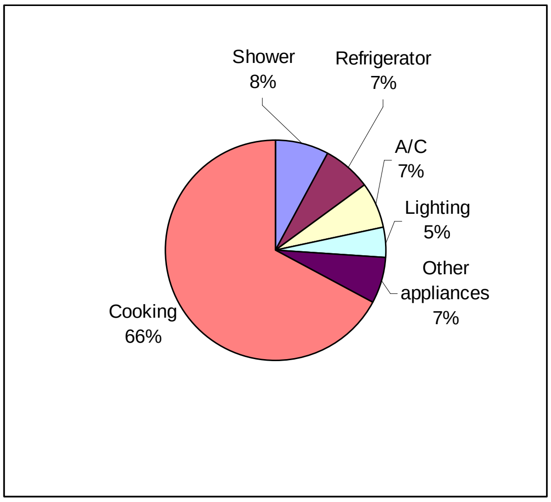


**Figure 29:** Share of end uses in the residential sector

Source: (PROCEL/Eletrobrás, 2007)

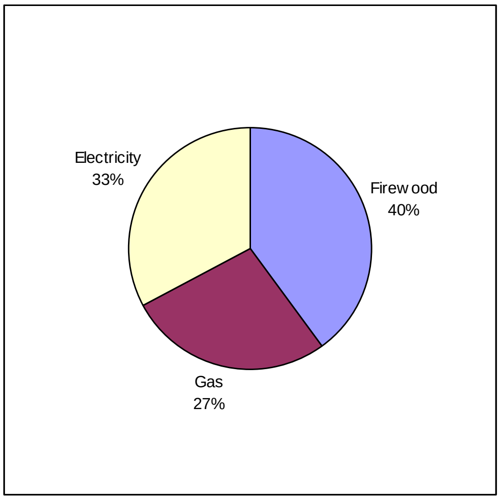


**Figure 30:** Final consumption by source in the residential sector

Source: (EPE, 2009a)

### 5.2.1. Cooking

The historical evolution of the stove market in Brazil indicates that the number of LPG stoves evolves together with the number of households, whereas the wood stoves nearly stay equal since 25 years.

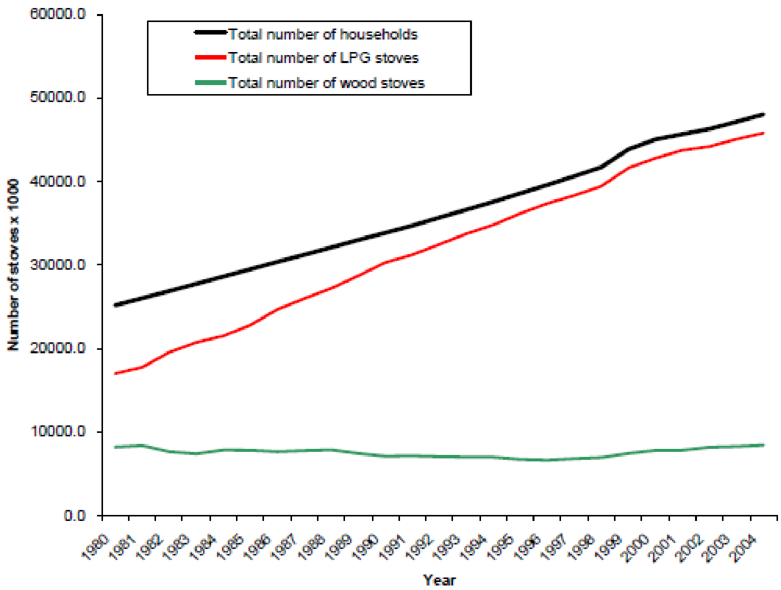


**Figure 31:** Stove market in Brazil

Source: (MME, 2006)

Today there are 21 distribution companies and 70 000 retail posts throughout the country, including small vendors in rural areas. LPG is sold in every Brazilian village and even in the Amazon region. It reaches about 42.5 million Brazilian households (Shell, 2007a). But increased international oil prices, the elimination of general subsidies, higher tax and profit increases, forces the poor and even some in the lower-middle class to switch back to firewood or charcoal as the primary household fuel. If the actual trend is taken as indicator, the future of LPG does not look promising.

### 5.2.2. Electrical appliances

The PROCEL study provides valuable data on ownership indices, the habits and attitudes of the consumers and the final use in residential buildings. The study revealed that only four appliances are responsible for 80% of the total electricity consumption in residential houses, see figure 32.

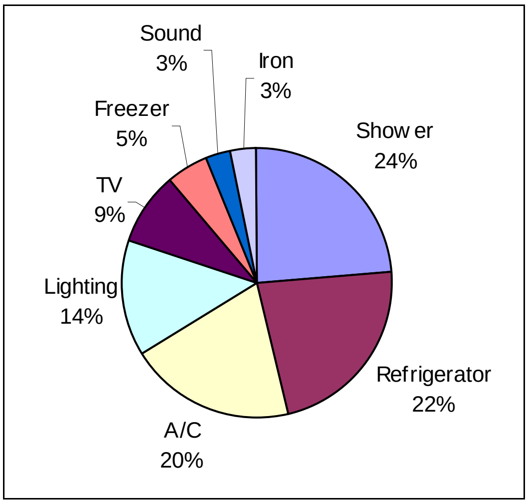


**Figure 32:** Final electricity end use in the residential sector in Brazil in 2005

Source: (PROCEL/Eletrobrás, 2007)

Because of the high relevancy for the residential sector, the four most important electricity consumers that is shower, refrigerator, air condition and lighting are discussed in detail.

### 5.2.2.1. Domestic water heating

The data related to water heating is of high relevance for energy efficiency scenarios because of its high share in the electricity consumption matrix. The PROCEL research assumes that all the heated water is used in the shower and there are almost none other water heating actions, such as in the kitchen or the sink (PROCEL/Eletrobrás, 2007). The research revealed that 81% of the population heats the water whereas 18% do not. The heating with electricity is predominant (92%) and to a small part, water is heated with gas (7%), although in BEN this is not taken into account and there is no data on the quantity of the final consumption of gas for this purpose. Solar heating and other means of heating water are not significant. The ownership rate of the electrical shower is 0,89 (PROCEL 2007). Almost all the households that heat water with electricity use the electric shower head system that will be described beneath.

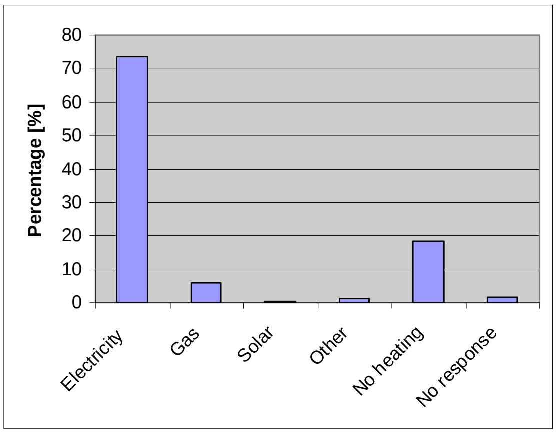


**Figure 33:** Sources used for water heating

Source: Elaboration of the author on base of (PROCEL/Eletrobrás, 2007)

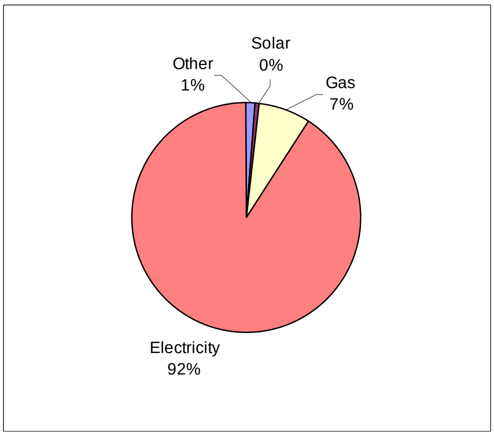


**Figure 34** Sources used for water heating, excluded the households that do not heat water

Source: Elaboration of the author on base of (PROCEL/Eletrobrás, 2007)

The central peace of the Brazilian shower is the showerhead that contains the resistance that heats up the water. Sometimes the electrical wires are protected with plastic cable sometimes only with a bit of insulating tape at their end. Normally the showerhead has two bottoms. The first bottom is to switch on or off the heating mechanism of the shower, which is called *connect* or *disconnect* and the second one permits to choose the temperature of the water (cold, warm and hot).

**Figure 35:** Typical electric shower in a Brazilian household

Source: photo of author

The nominal power of these showers is mostly within a range from 2 kW to 6 kW with a trend towards increasing power. The average nominal power in Brazil is about 4 kW (PROCEL/Eletrobrás, 2007). The cheapest models found cost between US$10-12 and have a nominal capacity of 2.0-4.5 kW.

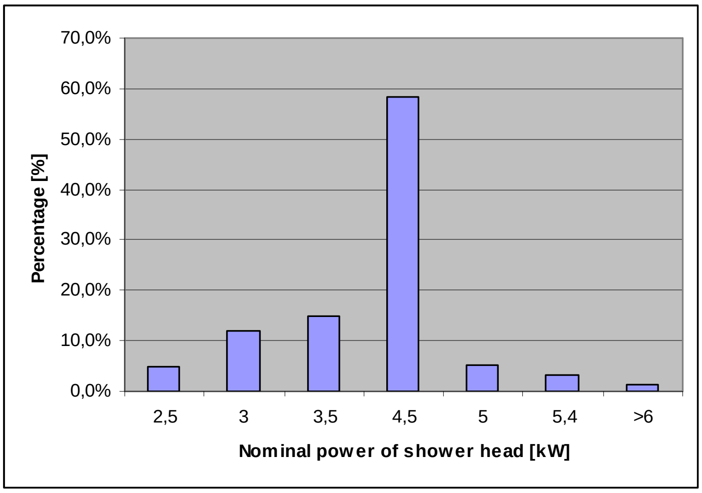


**Figure 36:** Range of the nominal power of showers found in Brazilian households

Source: (PROCEL/Eletrobrás, 2007)

### 5.2.2.2. Air conditioning

Only 16% of the households have an air condition. And the share in the electricity consumption already was 20% in 2005 (PROCEL 2007). There is no exact data which type of systems are used in the residential sector but most of them are window air conditioners and some are split systems (Lamberts, 2007b). A window air conditioner unit implements a complete air conditioner in a small space. The units are made small enough to fit into a standard window frame (figure 38). A split system is a system of refrigeration that is similar to the equipment of the window air condition, divided into two modules, called the indoor unit (evaporator) and outdoor unit (condenser). This system is quieter than the conventional system and the equipment cost is about 30-40% more expensive than the window air condition (HowStuffWorks, 2010; Nanomagnetics, 2007). PROCEL do not provide data on which systems have been found in their investigation but it is supposed that the majority have been windows air conditioner due to the lower price and easier installation (Lamberts, 2007b).

**Figure 37:** A typical window air conditioner

Source: (HowStuffWorks, 2010)

Most of the air conditioners in the residential sector have a capacity of to 7.500 BTU/h and are at most 10 years old (figure 38 and 39).

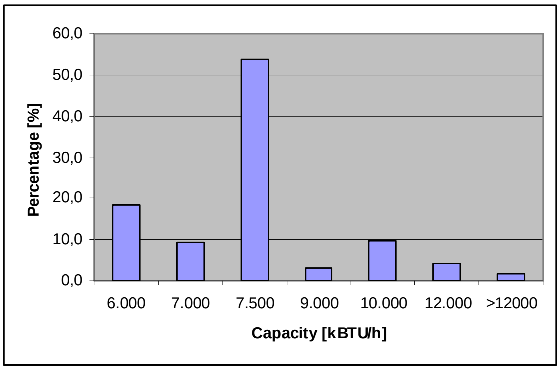


**Figure 38:** Capacity of air conditioners in Brazil

Source: (PROCEL/Eletrobrás, 2007)

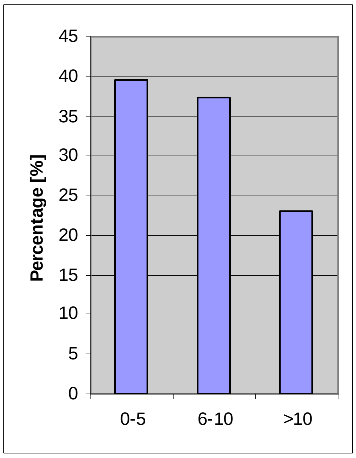


**Figure 39:** Age of air conditioners

Source: (PROCEL/Eletrobrás, 2007)

There is no exact data on the efficiency of the systems in the actual building stock. PROCEL reveals that 30,8% of the stock is considered efficient, but it is not near classified what is understood to be efficient (PROCEL/Eletrobrás, 2007). Window air conditioners sold in Brazil have been relatively inefficient due to use of reciprocating compressors and low cost designs. PROCEL began testing and labeling the efficiency of window air conditioners in 1996, as well as recognizing, awarding, and publicizing the top-rated models (Geller, et al., 1997). Window air conditioners are selling well due to the bad thermal performance of the buildings built without energy efficient building codes. The window air conditioners produced in Brazil for the internal market use reciprocating (the most inefficient) compressors opposed to those for the export market that use rotating compressors. In average, the air conditioners sold in Brazil have an EER below 8.0 Btu/(h x W) (ranging from 5.7 to 10.6 Btu/(h x W), that correspondents to COP 1,64 - 3,10) (Lamberts and Westphal, 2007).

Considering the age of the apparatus and the minimum requirements for air conditioners it can be considered that the stock has an average somewhere in-between the efficiency ranging from the minimum efficiency of 2,08 COP till the newer ones with A labeling by INMETRO with 2,91 COP.

#### 5.2.2.3. Lighting

Lighting is very relevant for the electricity consumption and the high share of electricity consumption by this consumer is directly connected with the use of incandescent lamps with high nominal power and low efficiency. In 2005 there has already been a substitution of 20% with compact fluorescent lamps, mostly due to the energy crisis in 2001. The predominant lamp used in Brazilian households is the 60W incandescent lamp. In average every household has four incandescent and four compact fluorescent lamps (PROCEL/Eletrobrás, 2007). Following figure gives a good overview of the distribution of the different lambs in the households (figure 40). Detailed figures are found in the annex 4.

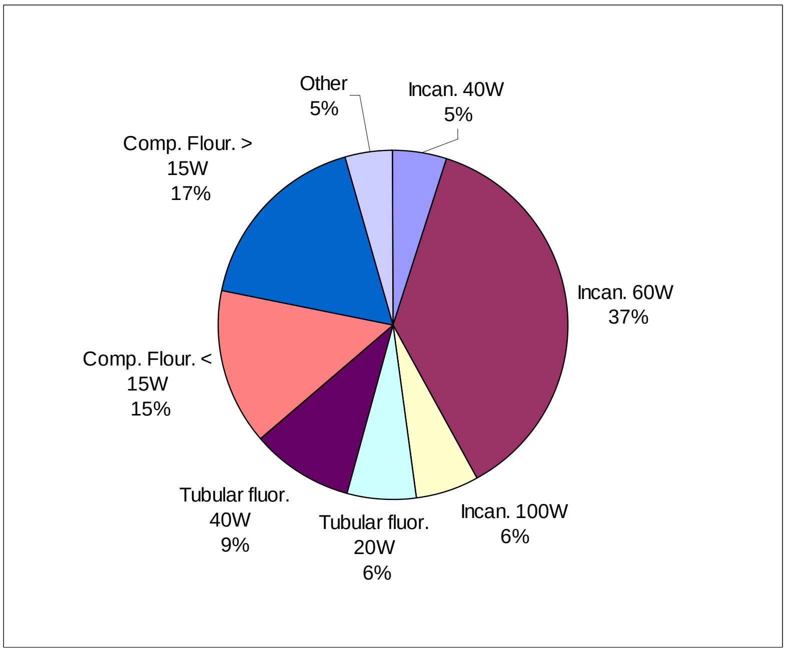


**Figure 40:** Distribution of different types of lamps in Brazil

Source: Elaboration of author on base of (PROCEL/Eletrobrás, 2007)

#### 5.2.2.4. Refrigerator

The total stock of refrigerators increased from 1999 till 2007, especially driven by the increase of two door refrigerators, already reaching an ownership rate of about 0,2 in

2005 (IBGE, 2009). In total about 96% of Brazilian households have refrigerators and about 30% of Brazilian refrigerators are ten or more years old (PROCEL/Eletrobrás, 2007). The age of the refrigerators indicates also a decrease in efficiency that means increased electricity consumption due to worse insulation and doors seals after five years and a worse functioning of the thermostat and the compressor from ten years onwards (Nogueira, 2006). Refrigerator consumption was not measured by the PROCEL study, but other sources provide values that will be used in the calculations for the projection in the scenarios. As average consumption for refrigerators already in the market an average UEC of 50 kWh per month was assumed (Mascarenhas and Pinhel, 2006). About the half of the refrigerators of the 2005 refrigerator stock had been labelled efficient and almost the other half not efficient, although it is not known exactly what is understood as efficient from the source (PROCEL/Eletrobrás, 2007).

#### 5.2.2.5. Other appliances

The rest of electrical appliances that have not been mentioned yet account for the rest of 20% of the electricity consumption of the residential sector. There exist a clear relationship between income and the ownership of these appliances whereas with exception of air condition the main consumers (refrigeration, shower and lighting) are found in the majority of the households, independent from income (Tavares, 2006). With raising income level, the number of households owning appliances is increasing rapidly in Brazil and it is very probable that with increasing income the share of these appliances in the electricity consumption will increase (MME, 2007b; Tavares, 2006). Most of the electricity consumed in the residential sector is used to power appliances.

Some hierarchical level of preference among appliances can be observed. Basic appliances such as fans and TVs are more evenly distributed among households with different levels of income, while other appliances are owned only by households with the highest level of income, such as e.g. air conditioners or dishwasher, which can be considered as more luxurious goods (IBGE, 2009; Tavares, 2006).

## 5.3. Results

### 5.3.1. Time of operation of end use

The electrical consumption disaggregated by building type and end use are summarized in table 26. The basic calculation sheet is found in the annex 4.

**Table 26:** Electricity consumption by end use

| | Shower | Air condition | Refrigeration | Lighting |
|---|---|---|---|---|
| Fraction of total electricity consumption [%] | 24 | 20 | 22 | 14 |
| Annual time of operation [h] | 92 | 2 016 | 8 760 | 675 |

Source: Elaboration of author on base (PROCEL/Eletrobrás, 2007)

### 5.3.2. End uses disaggregated by technologies

The end uses have been disaggregated by building type. The data only provides information on average ownership rate and capacity of appliance but not related to building type. For the further disaggregation of technologies by building type there following assumptions were made:

a) **The urban SFH,** due to high occurrence of this building type, was assigned the values from the survey of PROCEL that is, the average values of Brazil, both in ownership rate and in capacity of appliances.
b) **The rural SFH** and the **small MFH**, representing low income households, were assigned lower values, both in ownership rate and in capacity of appliances.
c) **The large MFH**, representing middle to high income class houses, was always assigned a value above the average, both in ownership rate and in capacity of appliances.

The weighted average of the four building types of the ownership rate and of the capacity of the appliance was validated with the Brazilian average values from PROCEL(PROCEL/Eletrobrás, 2007). The validation sheet is found in annex 4.

**Table 27:** Tendencies for the ownership and capacity of the appliances by building type

| | Urban SFH | Rural SFH | Small MFH | Large MFH |
|---|---|---|---|---|
| Shower | average | lower | lower | higher |
| Air condition | average | much lower | much lower | much higher |
| Refrigeration | average | lower | average | higher |
| Lighting | average | average | average | average |

Source: Elaboration of author on base of (PROCEL/Eletrobrás, 2007)

On base the assumptions and tendencies described each end use was assigned appropriate devices, with diffusion rates (expressed in ownership rate), capacity based on survey data from PROCEL and literature research. Apart from the trends described recent market trends and actual share of efficient appliances has been taken into account in the following way:

a) Refrigerators have been disaggregated by the one- and the two-door model, reflecting recent trends in the market. The electricity consumption is determined by the composition of the actual stock, which is composed of almost 50% efficient refrigerators (label A and B) and 50% of non-efficient refrigerators (PROCEL/Eletrobrás, 2007). The average monthly consumption of non-efficient one-door refrigerators was assumed to be 50 kWh (USAID, 2007) and the monthly consumption of efficient one-door refrigerators was assumed to be 30 kWh per month (INMETRO, 2009b). The calculated average of the stock of one-door refrigerators therefore was 40 kWh per month. The actual consumption in the case of the two door refrigerator is about 50 kWh per month (INMETRO, 2009b).
b) Air conditioner. The efficiency of the air conditioning assigned to the reference houses are within category C (INMETRO, 2009a), reflecting the fact that more than 66% of the air conditions is not efficient (PROCEL/Eletrobrás, 2007).
c) Lighting. Today in Brazil 20% of the lamp stock is already composed of efficient light bulbs. According to data available, two light bulbs were assumed to be efficient light bulbs (15 W), four were assumed to be incandescent light bulbs (60 W) and two were assumed to be 30 W fluorescent tubular (PROCEL, 2007).

The following tables give an overview of the disaggregation of technologies by building type. It should be noted that the appliances that have an ownership rate of 0 indicates that these appliances will only be installed in the future.

**Table 28:** Ownership rate and capacity of actual and new showers by building type

| Showerhead | | Urban SFH | Rural SFH | Small MFH | Large MFH |
|---|---|---|---|---|---|
| Actual shower | [kW] | 4,0 | 3 | 3 | 5,5 |
| Ownership rate | | 0,89 | 0,80 | 0,80 | 1,9 |
| New shower | [kW] | 6 | 4,5 | 4,5 | 8 |
| Ownership rate | | 0 | 0 | 0 | 0 |

Source: Elaboration of author on base of (EPE, 2009a; IBGE, 2009; PROCEL/Eletrobrás, 2007)

**Table 29:** Ownership rate and UEC of actual and new refrigerators by building type

| Refrigerator | | Urban SFH | Rural SFH | Small MFH | Large MFH |
|---|---|---|---|---|---|
| **Actual - One door** | UEC [kWh/month] | 40 | 40 | 40 | 40 |
| Ownership rate[1] | | 0,8 | 0,72 | 0,8 | 1,2 |
| **NEW - One door** | UEC [kWh/month] | 30 | 30 | 30 | 30 |
| Ownership rate | | 0 | 0 | 0 | 0 |
| **NEW - Two door** | UEC [kWh/month] | 50 | 50 | 50 | 50 |
| Ownership rate[2] | | 0,2 | 0,18 | 0,2 | 0,3 |

[1] 80% of calculated on the total ownership of refrigerators in Brazil
[2] 20% of calculated on the total ownership of refrigerators in Brazil
Source: Elaboration of author on base of (EPE, 2009a; IBGE, 2009; PROCEL/Eletrobrás, 2007)

**Table 30:** Ownership rate and capacity of incandescent and efficient light bulbs by building type

| Lighting | | Urban SFH | Rural SFH | Small MFH | Large MFH |
|---|---|---|---|---|---|
| **Incandescent** 60 Watt | [kW] | 0,06 | 0,06 | 0,06 | 0,06 |
| Ownership rate | | 4 | 4 | 4 | 4 |
| **Fluorescent Tubular** 30 W | [kW] | 0,03 | 0,03 | 0,03 | 0,03 |
| Ownership rate | | 2 | 2 | 2 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| **Efficient** 15 W | [kW] | 0,15 | 0,15 | 0,15 | 0,15 |
| Ownership rate | | 2 | 2 | 2 | 2 |

Source: Elaboration of author on base of (EPE, 2009a; IBGE, 2009; PROCEL/Eletrobrás, 2007)

**Table 31:** Ownership rate and capacity of various air conditioners by building type

| Air condition | | Urban SFH | Rural SFH | Small MFH | Large MFH |
|---|---|---|---|---|---|
| **Actual 1 A/C** | [kW] | 0,90 | 0,90 | 0,90 | 1,13 |
| Ownership rate | | 0,16 | 0,08 | 0,08 | 0,8 |
| COP | [W/W] | 2,44 | 1,95 | 2,44 | 2,59 |
| **Actual 2 A/C** | [kW] | 0,75 | 0,75 | 0,75 | 0,75 |
| Ownership rate | | 0 | 0 | 0 | 0 |
| COP | [W/W] | 2,93 | 2,93 | 2,93 | 2,93 |
| **New 1 A/C** | [kW] | 0,97 | - | - | 0,97 |
| Ownership rate | | 0 | 0 | 0 | 0 |
| COP | [W/W] | 3,02 | - | - | 3,02 |

Source: Elaboration of author on base of (EPE, 2009a; IBGE, 2009; PROCEL/Eletrobrás, 2007)

## 5.4. Discussion and validation

To determine the reference buildings there have been described and discussed the data on appliances especially focused on energy efficiency, capacity respective UEC and ownership rate. The typical use was determined by the operation time calculated for every appliance, not disaggregated per building type. The disaggregation of appliances of the same type but with different capacity, and also of different ownership rates for the same appliance by building type was based on the effort to reflect real circumstances, in which these parameters are influenced by income situation of the household. To secure a reasonable disaggregation every disaggregation was validated with the total average regarding the ownership rate and the capacity. The reference buildings were validated making a projection for the total building stock in 2005 with the determined values. The electricity consumption of each appliance by building type was calculated.

Therefore it was possible to validate a) the projection of the total electricity consumption with the BEN data and b) the share of the electricity consumption of this appliance in the electricity matrix from 2005 with data combined from PROCEL 2007 and BEN 2009 (with reference data from 2005).

The projection calculated on base of the reference buildings for the reference year 2005 was compared to the consumption calculated on base of the PROCEL study with top down values from BEN. The electricity consumption resulted about 2% too high (table 33). Such small variations are considered insignificant and are due to small deviations from the average capacity of the reference buildings compared to the total average capacity reported by PROCEL. These deviations may have the origin in the determination of the reference buildings where it was tried to assign realistic technologies based on averages, sometimes differing slightly from it. For example the average capacity of the shower heads was 4,17 kW (PROCEL/Eletrobrás, 2007), but such a showerhead does not exist in the market, only a bigger or smaller one (4,0 or 4,5 kW). Therefore the average capacity of the reference buildings may differ slightly from the average reported by PROCEL resulting in small deviations in the bottom-up projection.

What really stands out was that the electricity consumption of the total refrigerator stock was projected about 9% higher than it should have been according to the share reported by PROCEL. Analyzing the data this seems reasonable because calculated on the base of the ownership rate and given electricity consumption of the refrigeration stock in Brazil by PROCEL the monthly consumption would be between 20 and 30 kWh (PROCEL/Eletrobrás, 2007), which is impossible with a refrigerator stock where more than half of the appliances are not efficient. For the calculation there was assumed a value of 40 kWh per month, the calculated average of a non-efficient refrigerator with 50 kWh per month consumption (USAID, 2007) and an efficient one with 30 kWh per month consumption (PROCEL/Eletrobrás, 2007). Due to case studies and data from INMETRO (MME, 2007c; Vendrusculo, 2009) it was decided to take this projection as realistic. The problem caused by this decision is the implication that if the refrigerator in fact has a higher share, other appliances have a lower share. The scenario projected too low the shower (-4%), air condition (-2%) and lighting (-1%). In other words, the projection already shifted share in the electricity matrix from these appliances to the refrigerator, although it cannot be validated if this shift in that form was correct or not. Due to relatively small deviations and missing possibilities to validate the share of end uses, it was decided to construct the scenarios on base of those projections.

**Table 32:** Comparison of results from projection and top down values from BEN combined with PROCEL (to calculate the end uses)

| | **Water heating** | **Lighting** | **Refrigeration** | **Air condition** | **Other** | **Total** |
|---|---|---|---|---|---|---|
| PROCEL share | 24% | 14% | 22% | 20% | 20% | |
| Calculated share | 20% | 13% | 31% | 18% | 20% | 102% |
| BEN 2005 [TWh] | 20 | 12 | 18 | 17 | 17 | 83 |
| Calculated for 2005 [TWh] | 17 | 11 | 26 | 15 | 17 | 85 |

Note of author: Yellow values are the given values and blue values represent the calculated ones.
Source: Projection of author, (EPE, 2009a; PROCEL/Eletrobrás, 2007)

# 6. The reference scenario

The methodology used for this study essentially looks at the opportunities to reduce power demand by improving energy efficiency on the demand–side. First step concerns the development of a detailed reference scenario to be able to estimate potentials for energy-efficiency improvement in 2020. The reference scenario is developed as a business-as-usual (BAU) scenario. That means that current trends continue in the future and planned activities are carried out without big changes in the policy. This approach implies using a dynamic baseline taking into account these expected trends. This type of baseline is more complex than a frozen baseline (Blok, 2007), but it was decided to use this approach to permit the inclusion of actual trends. For the BAU scenario there had to be identified the key drivers of energy consumption and made assumptions regarding their development in the future.

Many studies have shown that the technical potential for energy efficiency improvements is large. But the world we live in is imperfect, and not all of the technical or economic options for energy conservation will necessarily be adopted. Therefore the study makes a number of assumptions to produce what is termed a ‘realistic but challenging’ technical potential. The reference scenario considers actual penetration of efficient technology, such as the share of efficient refrigerators, air conditioners or light bulbs in the actual stock. The rate of introduction of more energy efficient appliances was based on data where available otherwise on justified assumptions of the author.

## 6.1. Drivers of energy use in the residential sector

First step in predicting future energy consumption and energy related savings is to identify the drivers for energy consumption in the region studied. Depending on country characteristics the construction of a generic scenario for future energy use and intensity depends on various factors.

In Brazil a driver for energy consumption is the increase of the stock of electrical appliances that is directly connected with the construction and demolition rate of buildings. For a more detailed analysis of the building stock is important to consider future developments referring to situation (rural or urban) and type (house or flat) of the building, which have impact on energy consumption. Taken into account the short term forecast orientation of this research, actual short term trends have much more importance than they had for a long-term scenario, such as e.g. for global long term models developed of the IPCC *Special Report on Emission Scenarios* (IPCC, 2007) and the *World Energy Outlook* (WEO) of the International Energy Agency (IEA, 2006).

Apart from the construction rate the development of future ownership is a very relevant driver for energy consumption. Especially in developing countries it is strongly connected with increasing GDP, population growth and urbanization rate. Special interest should be given to appliances that still have a big market potential and a relatively low ownership rate. With increasing income the ownership rate could increase fast and so the electricity consumption (McNeil and Letschert, 2008; Morna and vanVuuren, 2009). First there was made a prediction about future developments in the market of appliances. According to Mc Neil, in mature markets, ownership levels are near saturation and sales are driven by replacement and population increase and ownership of multiple appliances. However, for developing countries and countries in transition, stock is driven mainly by affordability. Normally there consists a strong correlation between household income ownership rate of household appliances. The further development of the ownership rate can be different from country to country and from appliance to appliance. For example the ownership rate of televisions is determined mainly by the electrification rates. Refrigerators normally show a steep curve of ownership versus income, indicating that refrigerators are purchased even by low income families. Other end uses such as washing machine, blender and kitchen appliances are purchased in a sequence one after the other with increasing income.

The ownership rate development of air conditioning is different to the mentioned ones and follows a more s-shaped curve (item 6.2.2.). This ownership rate forecast model for air condition has been developed by McNeil  (McNeil and Letschert, 2008) and its basic assumptions have been used in this thesis research for the forecast of the ownership of air condition. One exception has been made; the climate factor also included in the model as limiting factor was excluded because of its complexity and because of its insignificance for Brazil at the moment of a still low ownership rate. This factor lowers the potential saturation of market penetration. Due to a low saturation in Brazil this seems negligible for the near future forecast and the affordability factor was assumed to be the key factor.

In general the ownership modelling in this study was based on historic growth and on estimated future potential that in turn was based on actual ownership rate and the assumed implications that:

a. The lower the ownership rate, the higher the potential to grow
b. The higher the ownership rate the slower the growing of the ownership rate

A third important main driver is the unit energy consumption (UEC). It can be expected that in future the efficiency of appliances increase. Also the unit UEC may increase due to larger appliances, such as e.g. air conditioners with higher cooling capacity, bigger refrigerators, etc.. There had to be made assumptions regarding the development of these drivers. But in general the gain through efficiency is more than outweighed by bigger appliances (McNeil and Letschert, 2008).

The construction of a scenario for future energy demand had to take into account the change of these main drivers that can be:

a. Changing number of dwellings (new dwellings in this case)
b. UEC
    i. of new appliances due to new dwellings
    ii. of exchanged appliances due to end of lifetime of these appliances
c. Development of the ownership rate

The key drivers are summarized in the following box:

| **Main key drivers for energy consumption** |
| --- |
| • Construction rate<br>• Ownership rate<br>• Unit energy consumption |

**Figure 41:** Summary of key drivers for energy consumption in the Brazilian residential sector
Source: Elaboration of author

To determine the key drivers of the future energy demand the following data is needed:

**Table 33:** Parameter needed for the forecast of the energy demand

| Driver | Input parameter needed | Data generation |
|---|---|---|
| Activity | GDP [%] | (EPE, 2009a; IEA, 2006) |
| | Population [%] | (IBGE, 2009) |
| | Urbanization rate [%] | (MME, 2007b) |
| | Dwelling [%] | (Abreu de Queiroz and Tramontano, 2009; IBGE, 2009; MME, 2007b) |
| | Changes by situation and type of building from 2008 until 2020 | Calculation on base of historical data |
| Ownership rate | Ownership growth | (PROCEL/Eletrobrás, 2007), linear regression, assumptions |
| Unit energy consumption | Life time / Exchange rate of appliances | Literature |
| | Capacity or UEC of new appliances (in new buildings or refurbished appliances) | (PROCEL/Eletrobrás, 2007), assumptions |

Source: Elaboration of author

## 6.2. Data and methodology

In the reference year 2005, the total electricity consumption of an appliance j in all buildings type k in year n can be expressed as the product of time, ownership rate, the total capacity of appliance and the total number of buildings type k in year n.

**Equation 15:** Total electricity consumption of appliance j in year n in building k

$$El_{total,j,n,k} = t_j \times P_{j,n,k} \times O_{j,n,k} \times A_{n,k}$$

Where:
j = appliance
n = year
k = building type
$t_j$ = operation time of appliance
$P_{j,n,k}$ = capacity of appliance in buildings type k in year n
$O_{j,n,k}$ = ownership rate of appliance in buildings type k in year n
$A_{n,k}$ = number of buildings type k in year n
Source: Elaboration of author

In the case of the calculation of the energy consumption of the refrigerators there will be used a value for the UEC instead of calculating with the product of time and capacity. The formula was adapted as follows:

**Equation 16:** Electricity consumption of refrigerators

$$El_{total,j,n,k} = UEC_{ref,n,k} \times O_{j,n,k} \times A_{n,k}$$

Where:
$UEC_{ref,n,k}$ = unit energy consumption of refrigerator in year n in building type k
Source: Elaboration of author

In the case of other appliances the growth of electricity consumption is directly connected with GDP because of lack of data. The re-arranged formula for calculating the electricity consumption in the future for other appliances is:

**Equation 17:** Electricity consumption of other appliances

$$El_{total,others,n,k} = El_{total,others,2005,k} \times (1 + r_{GDP1})^n \times (1 + r_{GDP2})^n$$

Where:
$GPD_1$ = growth rate of gross domestic product from 2005 - 2014
$GPD_2$ = growth rate of gross domestic product from 2015
Source: Elaboration of author

The parameter operation time that was calculated (item 5.3.1) will be kept stable for the forecast. The method for the calculation of the different key drivers (A, O, UEC) will be presented in the chapter 6.2.1., respective 6.2.2. and 6.2.3..

### 6.2.1. Forecast of building stock disaggregated by building type

The projections in this thesis are partly based on the key assumptions given by the WEO and on data from Brazil. Following table gives an overview of these key assumptions (EPE, 2009a; IBGE, 2009; IEA, 2006). The growth rate of Brazilians population is declining since the 80ies. Based on the assumptions from the WEO Brazil will reach a population number of 214 million in 2020, from whom 188 million people will live in the cities. The urbanization rate will be 87,9%. This large share is explained by historically high rates of population growth in towns and cities, rural to urban migration and the urbanisation of areas previously classified as rural (IEA, 2006). The number of dwellings will grow faster than the population due to the declining average number of inhabitants per building. The annual average growth rate since 1989 until 2008 has been 2,8% therefore it was assumed that this trend will continue until 2015. Due to a decrease in the GDP and population growth it was assumed that the growth will be reduced to an annual average growth of 2,3%.

**Table 34:** Forecast GDP, population, urbanization and dwellings annual growth rates in Brazil until 2020

| | 2004-2010 | 2010-2015 | 2015-2020 | Source |
|---|---|---|---|---|
| GDP [%] | 3,3 | 3,3 | 2,8 | (IEA, 2006) |
| Population [%] | 1,2 | 1,2 | 0,8 | (IEA, 2006) |
| Urbanization rate [%] | 1,7 | 1,4 | 1,2 | (MME, 2007b) |
| Dwelling [%] | 2,8 | 2,8 | 2,3 | (IBGE, 2009) (calculated average 1989-2004) |

Source: (IBGE, 2009; IEA, 2006; MME, 2007a)

For the projections of the development of the specific building types there is a lack of data. Estimations had to be made, based on development of the stock, of the situation (rural and urban). Due to increasing urbanization rate the rural SFH will lose in the share. As discussed in (item 3.2.1) there is no clear trend, justified only in data. A case study of São Paulo indicates that MFH have an increasing trend in the building stock (Abreu de Queiroz and Tramontano, 2009). It was assumed that the share of MFH in the building stock will grow in a linear way from about 11% in 2008 to 15% until 2020. Within the MFH stock there is a clear trend to bigger apartments and to larger MFH buildings with more flats (item 3.2.3.) It is assumed that the share of small MFH will grow from 8,7% to 10% and the share of large MFH will more than double from 2,2% to 5% from 2008 till 2020 (table 37).

**Table 35:** Estimated changes by situation and type of building from 2008 until 2020

| | SFH | MFH | Urban SFH | Rural SFH | Small MFH | Large MFH |
|---|---|---|---|---|---|---|
| Share in 2008 [%] | 89,1 | 10,9 | 74,1 | 15,0 | 8,7 | 2,2 |
| Share in 2020 [%] | 85 | 15 | 74,0 | 11,0 | 10,0 | 5,0 |

Source: Elaboration of author on base of (EPE, 2009a; IBGE, 2009)

### 6.2.2. Forecast of ownership rates

Historic data on ownership of electric consumers in Brazilian households are very limited. The PROCEL study based on two surveys, realized in 1999 and 2005 provides data on development of ownership rates of most consuming end uses, such as refrigerators, light bulbs (only 2005), air conditioners, electric showers and other appliances (Table 37).

**Table 36:** Growth in percentage of the ownership of four selected items from 1999-2005

| Electrical apparatus | 1999 | 2005 | | Absolute growth [%] |
|---|---|---|---|---|
| Television | 1,37 | 1,41 | | 3 |
| Refrigerator | 0,89 | 1,00 | | 12 |
| Electrical shower | 0,73 | 0,89 | | 22 |
| Air condition | 0,08 | 0,16 | | 100 |
| Lighting | No data | 4,01 (incandescent) | 4,01 (fluorescent) | - |

Source: Elaboration of author on base of (PROCEL/Eletrobrás, 2007)

The difficulty to forecast the ownership rate based on information available is the uncertainty of the future development of ownership rate curve. In the case of the appliances the curve expect is a logistic curve. With only two points in the past, the logistic regression has almost the same shape of a linear regression. Therefore it was introduced a “slow-down” factor of 0,05% per year. That means ever year the factor subtracts 0,5% x n from the growth projected by the logistic regression. In the case of the air condition the shape of the curve is expected to be different and will be discussed separately in this chapter.

Because of interest for the research the four main electricity consumers (refrigeration, lighting, shower and air condition) will be discussed in detail. Regarding the cooking energy consumption, the ownership rate will not be considered due to the lack of data. Instead there will be made assumptions on general developments of efficiency and type of stoves.

<u>Shower and refrigerator</u>
It is expected that the electricity appliances ownership rate with exception of the air condition will have a similar development. Shower and refrigeration are found in most of the households, in contrast to many other appliances, such as for example the washing machine. With the underlying assumption that with higher ownership rate of appliances their growth will decrease in velocity, a scenario of a “slowing down” growth curve is assumed. This scenario was calculated on the base of the logistic regression obtained on base of historic development. It was assumed that the growth slows down by 0,05% per n years. That can be expressed in the formula:

**Equation 18:** Linear regression with a “slowing down factor”

$$F(x) = y - (y \times n \times 0{,}05\%)$$

Where:
y = value obtained by the linear regression
n = year (reference year 2005)
Source: Elaboration of author

Due to the lack of the possibility to base this assumption on a sound standing base it was made a sensitivity analysis comparing this scenario with a linear scenario, founded on the historical data ownership growth rate from 1999 to 2005 (PROCEL/Eletrobrás, 2007) .

The two scenarios for the forecast of the ownership rate are illustrated for refrigerators in figure 43 and for shower ownership rate in figure 44 (The detailed tables or data are found in the annex 5). The equations given in the diagrams are only the logistic functions.

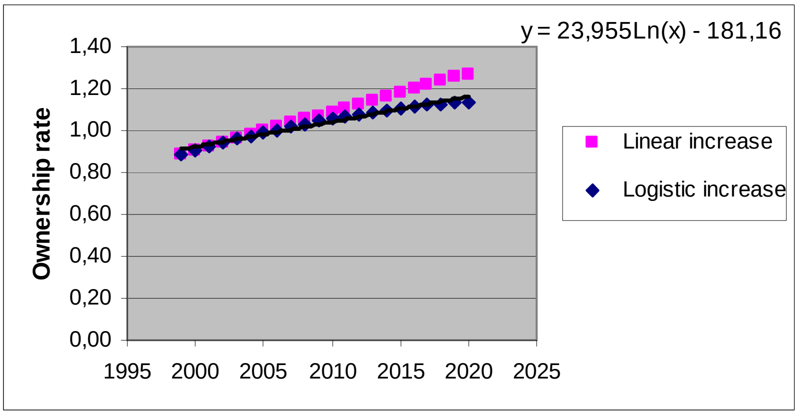


**Figure 42:** Two scenarios for the development of the future ownership rates of refrigeration
Source: Elaboration of author on base of (IBGE, 2009; PROCEL/Eletrobrás, 2007)

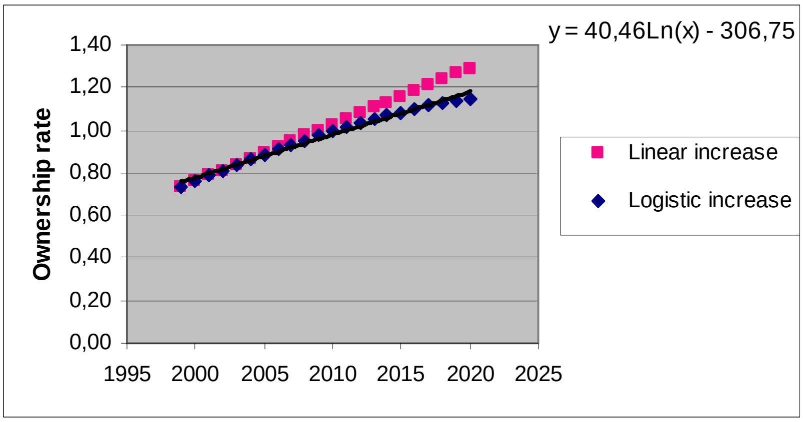


**Figure 43:** Two scenarios for the development of the future ownership rates of showers
Source: Elaboration of author on base of (IBGE, 2009; PROCEL/Eletrobrás, 2007)

In both cases the two scenarios already show quite a big difference in 2020 with about 12% deviation in the linear curve scenario and the logistic "slowing down" curve scenario (table 38). For the reference scenario it was assumed to expect the logistic "slowing down" curve scenario for the two appliances and not the linear scenario. This was considered the more conservative and realistic approach due to an already high ownership rate of refrigeration and shower and an almost 100% electrification rate in 2005 (PNAD 2009).

**Table 37:** Ownership forecast scenarios for the refrigerator and the shower

| | **Refrigeration** | | **Shower** | |
|---|---|---|---|---|
| | Linear curve scenario | Logistic curve scenario | Linear curve scenario | Logistic curve scenario |
| 1999 | 0,89 | 0,89 | 0,73 | 0,73 |
| 2005 | 1,0 | 1,0 | 0,89 | 0,89 |
| 2020 | 1,27 | 1,13 | 1,29 | 1,15 |

Source: elaboration of author on base of (IBGE, 2009; PROCEL/Eletrobrás, 2007)

Light bulbs

The data on ownership on electric light bulbs is very limited and exists only for the year 2005. So there cannot be assumed any growth rate based on historic data. It is assumed that the growth rate of ownership of light bulbs is equal to the growth rate of refrigerators in the logistic "slowing down" curve scenario (PROCEL/Eletrobrás, 2007). The ownership rate of light bulbs is considered to be high already in comparisons with other countries (R. Kadiana et al., 2007) and therefore only a moderate growth was expected in the near future. Following figure illustrate the development of the ownership rate of light bulbs.

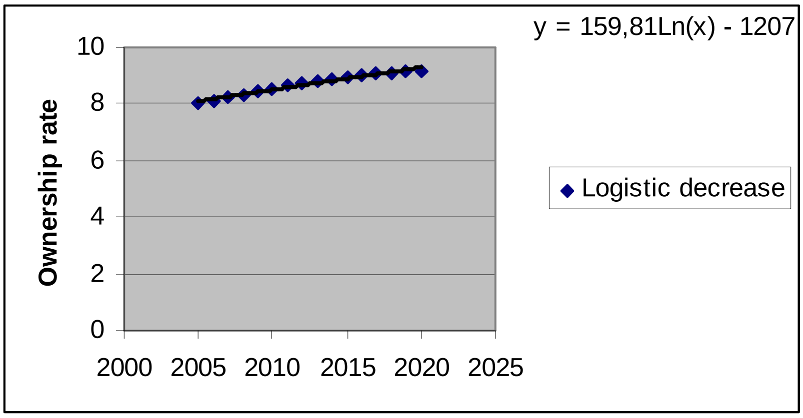


**Figure 44:** Ownership rate of light bulbs, based on ownership growth rate of refrigerators
Source: Elaboration of author on base of (IBGE, 2009; PROCEL/Eletrobrás, 2007)

Air condition

There are two important differences from modelling ownership rate of air conditioners than from other appliances discussed. First air conditioner ownership is climate dependent, which can be taken into account in the model as the variable Cooling Degree Days (CDD)[5], which limits the development of the ownership rate to a certain grade. This criterion is not considered (item 1.9.). Second an air conditioner is a more expensive purchase for an average household in a developing country and therefore a major investment without the people can survive easily. According to Mc Neil there can be expected a development of the ownership rate of air conditioners in the form of an s-curve, as already seen in many countries (Baumert and Selman, 2003; McNeil and Letschert, 2008). Figure 44 illustrates the dependence of availability of air condition from income in developing countries. The s-form indicates a relatively slow increase at the beginning of the occurrence of air conditioning and slowly taking up velocity in correlation with income. The crucial questions is at what point is the starting point for “take off” of the ownership rates and at which point will be reached the slowing down phase of saturation. The figure shows that e.g. China had its “take-off” much too early regarding the forecast of this model, whereas other countries are still waiting for their “take-off”, meaning that the ownership rate has not begun to grow fast yet, despise higher income.

Not knowing on which point Brazil stands in the curve, there are imaginable three different scenarios:

a. Scenario a: Acceleration of the ownership growth rate. This takes as basis that Brazil stands in the beginning of the curve.
b. Scenario b: Fast and linear development of the ownership growth rate. This takes as basis that Brazil stands in the middle or the curve more or less. The take-off phase has already been passed and the ownership rate will growth at its fast in the near future until reaching a ownership rate of about 70% and then beginning to slow down. (middle of the curve)
c. Scenario c: Slowing down growth rate. This takes as basis that Brazil stands at the end of the curve, has already a high ownership of air condition and a already saturated market.

[5] In his model Mc Neil uses national (average) CDD reported by the World resources Institute (Baumert, K. and M. Selman 2003 in Mc Neil 2008).

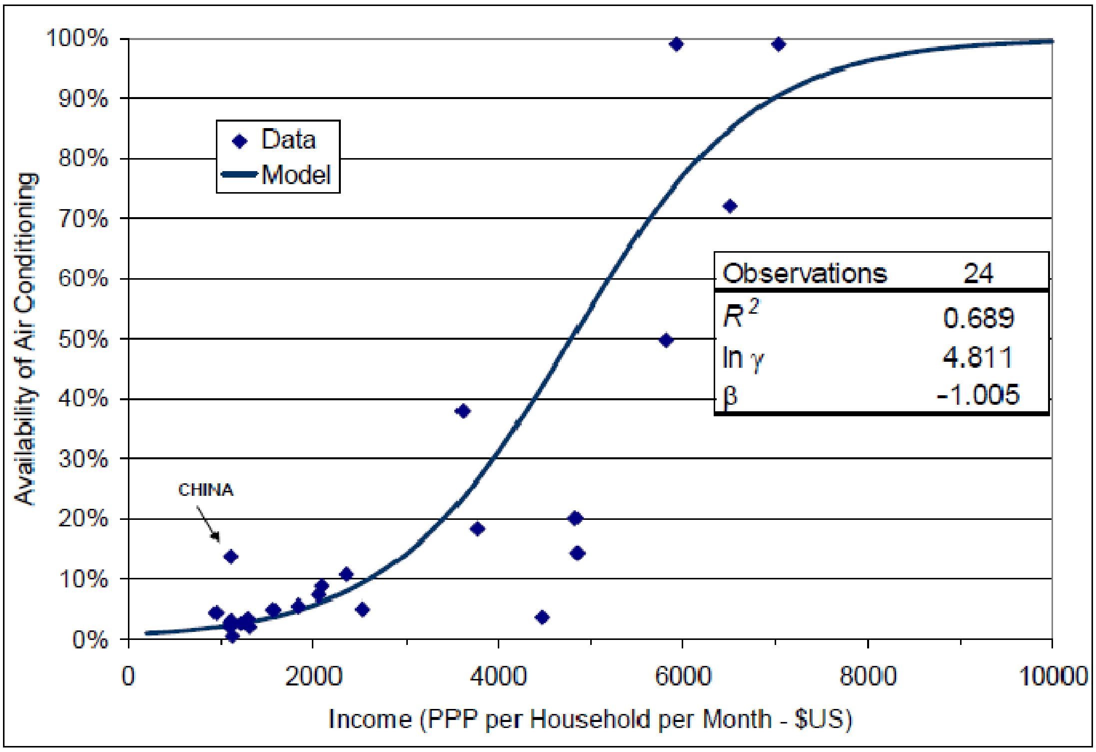


**Figure 45:** Dependence of income and availability of air condition

Source: (McNeil and Letschert, 2008)

Scenario c can be excluded because the ownership rate is still low. But there are no data that support scenario a or b. If Brazil lied exactly on the curve, with an income (PPP) per household per month of about 2.900 $US (UNDP, 2009) it would be more or less in the “take-off” phase. But as mentioned this is hypothetical and not known. Due to the still low ownership rate in Brazil, it was assumed that the growth curve is linear or accelerating, but not decreasing.

On basis of information available it could not be decided, which of the resting two scenarios were more probable. Due to a conservative approach there was assumed that the ownership growth rate will not accelerate in the near future. However there has been made a sensitivity analysis that showed that with an accelerated increase (+n 0,05% added per n years) the ownership rate in 2020 would be 0,39 instead of 0,32 (calculations sheets are found in annex 5).

Figure 47 shows the assumed growth of the ownership rate of air condition until 2020 and the formula of the linear regression.

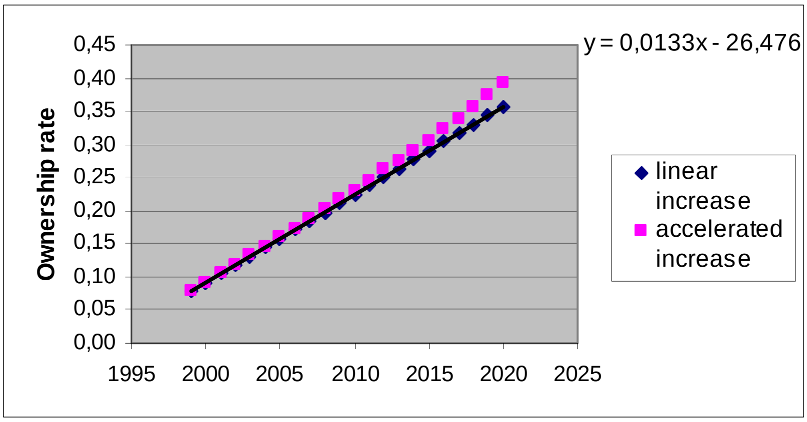


**Figure 46:** Development of air condition ownership rate until 2020
Source: Elaboration of author on base of (PROCEL/Eletrobrás, 2007)

Other electrical appliances

Most of the ownership rates of other electric appliances increase steadily. Only few have a decreasing ownership rate, such as radio or videocassette, but this is due to substitution through newer technologies (figure 48). The impact on electricity consumption is only in part equalized by higher efficiency. The electricity consumption is not calculated on base of ownership of each appliance, its capacity and operation time because of lack of data. The underlying assumption was that other appliances are bought one after the other with increasing income. Therefore it was decided to equal the electricity consumption growth rate of other appliances directly with the development of the GDP in Brazil that is a growth rate 3,3% until 2015 and from then on of 2,8% until 2020 (item 6.2.1.). It is assumed that these growth rates reflect the increase of the stock already corrected by higher efficiency of the appliances. According to the IEA energy efficiency gains many times are outstripped by the consumer trend towards higher levels of ownership and use (e.g. in the case of television larger screens (IEA, 2008).

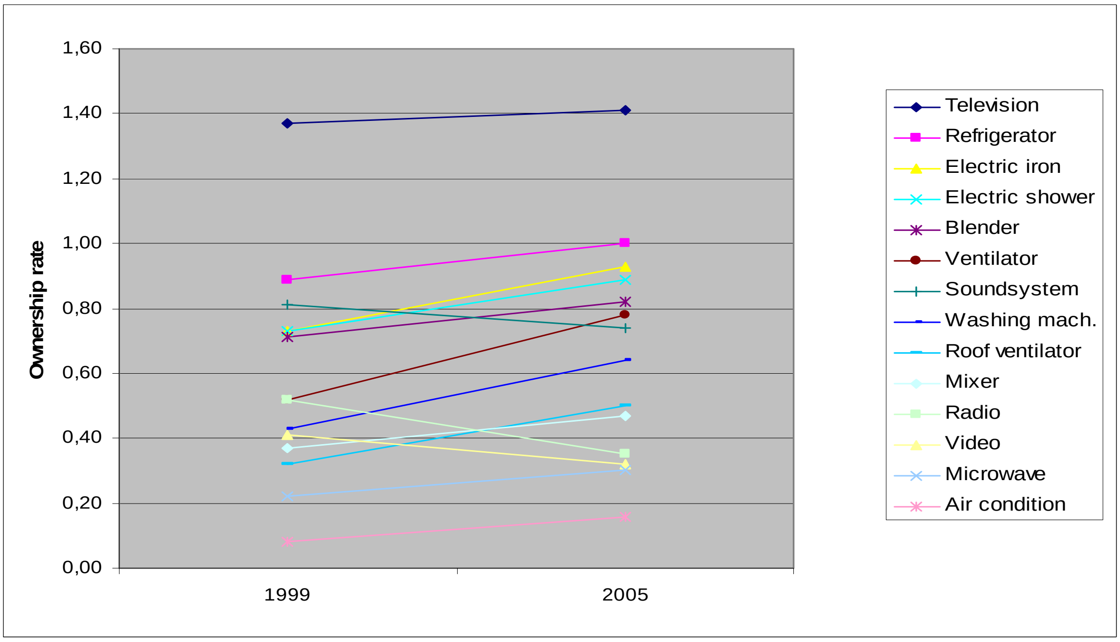


**Figure 47:** Development of ownership rates of appliances in 1999 and 2005
Source: Elaboration of author on base of (PROCEL/Eletrobrás, 2007)

Summary of regressions

**Summary of ownership rate forecast regressions**

| Appliance | Regression | "Slow down function" | Commentary |
|---|---|---|---|
| Shower | y = 40,46 ln (x) – 306,75 | f(x) = y – (y x n x 0,05%) | Logistic "slowing down" curve scenario |
| Refrigeration | y = 23,861 ln (x) – 180,44 | f(x) = y – (y x n x 0,05%) | |
| Air condition | y = 0,0133 x – 26,476 | - | Linear increase curve scenario |
| Light bulbs | y = 159,81 ln (x) -1207 | | Based on ownership rate of 2007 and on growth rate of refrigerator |
| Other appliances | - | - | Growth of electricity consumption linked to GDP growth rate |

* n = year

**Figure 48:** Summary of regressions

Source: Elaboration of author based on data of (PROCEL/Eletrobrás, 2007)

### 6.2.3. Forecast of unit energy consumption

Unit energy consumption depends from the power, operation time and efficiency of the appliances. The parameter operation time will no be changed, but the power and efficiency of appliances. The efficiency of appliances changes with refurbished and new appliances.

#### 6.2.3.1. Method for the calculation of unit energy consumption

This chapter presents the method to calculate the power installed in year n in buildings type k for application j (e.g. the electrical shower). The calculation sheets are found in the annex 5. The problematic was the same for all appliances. In the base year 2005 the stock is composed of an amount of appliances. In the forecast until 2020 there is a refurbishment rate (due to end of life time of the appliances) and there are new appliances due to new buildings constructed. This development has to be represented in the forecast and therefore in the calculation formulas. In the case of the refrigeration the calculation method differs slightly due to the fact that there it was not calculated with capacity and time but with annual UEC consumption. The calculation methods are presented in this chapter.

Shower, air condition and lighting

To make it more tangible the equations presented in this chapter refer always to the shower (s). In the case of other appliances the s is substituted with the other appliance (e.g. ac for air conditioning).

To forecast the future energy demand of showers, the exact composition of old and new showers in the market have to be known for every year. Old and new refer to capacity, because every new shower will have another capacity than the old shower. The amount of capacity of the end use depends on building type; the values which have been used for the calculation have been defined in the reference houses (item 5.3.2.).

Therefore the total capacity of all showers in buildings k in year n can be expressed as the sum of the total installed capacity of old and new showers. This can be calculated, adding the sum of the power of old showers to the sum of the power of new showers in new dwellings and to the power of all refurbished (exchanged) showers in the buildings type k in year n. This is expressed in the following formula:

**Equation 19:** Total power of showers installed in the buildings type k in year n

$$P_{total,s,n,k} = \Sigma \mathrm{P}_{\mathrm{s,old,n,k}} + \Sigma \mathrm{P}_{\mathrm{s,new,n,k}} + \Sigma \mathrm{P}_{\mathrm{s,ex,n,k}}$$

Where:
$P_{total,s,n,k}$ = total power of showers installed in all buildings type k in year n
$P_{s,old,n,k}$ = power of old shower in all buildings type k in year n
$P_{s,new,n,k}$ = power of new shower in all buildings type k in year n
$P_{s,ex,n,k}$ = power of exchanged shower in all buildings type k in year n
Soure: Elaboration of author

The $P_{total,s,n,k}$ depends from the showers installed in year n in buildings type k. The sum of showers installed in the buildings type k in year n ($S_{total,n,k}$) can be expressed as the sum of old, new and exchanged showers:

**Equation 20:** Distribution of old and new shower in buildings type k in year n

$$S_{total,n,k} = \left(\Sigma S_{old,2005,k} - \Sigma S_{old,ex,n,k}\right) + \Sigma S_{new,ex,2005,k} + \Sigma S_{new,n,k}$$

Where:
$S_{total,n,k}$ = Total showers in the year n in buildings type k
$S_{old,2005,k}$ = Old showers in the year n in buildings type k
$S_{old,ex,n,k}$ = Old showers already exchanged in the year n in buildings type k (therefore subtracted)
$S_{new,ex,n,k}$ = Exchanged showers in the year n in buildings type k
$S_{new,n,k}$ = New showers (due to new dwellings) in the year n in buildings type k
Source: Elaboration of author

In order to present a simple overview of the calculation steps realized the number of showers was calculated separated by old, new and refurbished showers.

The old showers in buildings type k in year n are calculated by the number of buildings type k in year n ($A_{n,k}$) multiplied with the ownership rate in building type k in year n ($O_{n,k}$) and subtracted by the amount of showers already exchanged.

**Equation 21:** Amount of old showers in the buildings type k in year n

$$S_{total,old,n.k} = \left(A_{s,2005,k} \times O_{s,2005,k}\right) - \sum_{2005}^{n} S_{new,ex,k}$$

Where:
$A_{2005,k}$ = number of buildings type k in the reference year 2005
$A_{n,k}$ = number of buildings type k in year n
$O_{2005,s,k}$ = ownership rate in buildings type k in the reference year 2005
$O_{2005,s,k}$ = ownership rate in buildings type k in year n
Source: Elaboration of author

The new showers in buildings type k are calculated by multiplying the new buildings (calculated as difference from new buildings type k in year and buildings type k in year 2005) with the ownership rate in year n ($O_n$).

**Equation 22:** New showers in buildings type k in year n

$$S_{total,new,n,k} = \left(A_{n,k} \times O_{s,n,k}\right) - \left(A_{2005,k} \times O_{2005,k}\right)$$

Source: Elaboration of author

Exchanged showers are calculated as the sum of all exchanged showers since the reference year 2005, as expressed:

**Equation 23:** Sum of exchanged showers in buildings type k in year n

$$S_{total,new,n,k} = \sum\nolimits_{2005}^{n} \left(A_{n,k} \times O_{s,n,k}\right) \times \ R_{ex}$$

Where:
$R_{ex}$ = exchange rate = 7%
Source: Elaboration of author

With the amount of old and new installed showers in year n in buildings type k the $P_{total,s,n,k}$ simply is multiplied with the capacity of the new, respective the old shower:

$$P_{total,s,old,n,k} = S_{total,old,n,k} \times P_{s,old,n,k}$$
$$P_{total,s,new,n,k} = S_{total,new,n,k} \times P_{s,new,n,k}$$
$$P_{total,s,ex,n,k} = S_{total,new,ex,n,k} \times P_{s,ex,n,k}$$

Source: Elaboration of author

Refrigerator
The calculation of the consumption of the refrigerators is based on the annual UEC.

According to the reference buildings there are three different average refrigerators that will be included in the calculation. On base of equation 16, the total consumption of refrigerators installed in the buildings type k in year n can be calculated as follows:

**Equation 24:** Total consumption of refrigerators installed in the buildings type k in year n

$$El_{total,refr,n,k} = \left(\Sigma UEC_{old,1-door,n,k} + \Sigma UEC_{new,1-door,n,k} + \Sigma UEC_{new,2-door,n,k}\right) \times \left(\mathrm{O}_{\mathrm{ref,n,k}} \times \mathrm{A}_{\mathrm{n,k}}\right)$$

Where:
$El_{total,refr,n,k}$ = Total of refrigerators installed in all buildings type k in year n
$UEC_{refr,old,1-door,n,k}$ = sum of UEC of old 1-door refrigerators in all buildings type k in year n
$UEC_{refr,new,1-door,n,k}$ = sum of UEC of new 1-door refrigerators in all buildings type k in year n
$UEC_{refr,new,2-door,n,k}$ = sum of UEC of new 2-door refrigerators in all buildings type k in year n
Source: Elaboration of author

The $El_{total,ref,n,k}$ depends from the different refrigerators in operation in year n in buildings type k. The sum of refrigerators in operation in the buildings type k in year n can be expressed as the sum of the energy consumption of old, new and exchanged refrigerators:

**Equation 25:** Distribution of old and new 1- and 2-doors refrigerators shower in buildings type k in year n

$$Ref_{total,n,k} = (\Sigma Ref_{1-door,old,n,k} - \Sigma Ref_{1-door,old,ex,n,k}) + (\Sigma Ref_{1-new,ex,n,k} + \Sigma Ref_{1-door,new,n,k} + \Sigma Ref_{2-door,new,n,k})$$

Where:
$Ref_{total,n,k}$ = Total refrigerators in the year n in buildings type k
$Ref_{1\text{-door old},n,k}$ = Old 1-door refrigerators in the year n in buildings type k
$Ref_{1\text{-door old},ex,n,k}$ = Old 1-door refrigerators exchanged in the year n in buildings type k (therefore subtracted)
$Ref_{1\text{-door new},ex,n,k}$ = Exchanged 1-door refrigerators in the year n in buildings type k
$Ref_{1\text{-door}, new,n,k}$ = New 1-door refrigerators (due to new dwellings) in the year n in buildings type k
$Ref_{2\text{-door}, new,n,k}$ = New 2-door refrigerators (due to new dwellings) in the year n in buildings type k
Source: Elaboration of author

In the following the refrigerators were disaggregated by old 1-door, new 1- and 2-door refrigerators. The old 1-door still in buildings type k in year n are calculated by the number of buildings type k in year n ($A_{n,k}$) multiplied with the ownership rate in building type k in year n ($O_{n,k}$) and subtracted by the amount of refrigerators already exchanged.

**Equation 26:** Amount of old refrigerators in the buildings type k in year n

$$Ref_{total,old,n,k} = (A_{s,2005,k} \times O_{s,2005,k}) - \sum_{2005}^{n} S_{new,es,k}$$

Where:
$A_{2005,k}$ = number of buildings type k in the reference year 2005
$A_{n,k}$ = number of buildings type k in year n
$O_{2005,refr,k}$ = ownership rate in buildings type k in the reference year 2005
$O_{refr,n,k}$ = ownership rate in buildings type k in year n
Source: Elaboration of author

The new refrigerators in buildings type k are calculated by multiplying the new buildings (calculated as difference from new buildings type k in year and buildings type k in year 2005) with the ownership rate in year n ($O_n$), due to building type the new refrigerator is a 1-door or a 2-door refrigerator.

**Equation 27:** New refrigerators in buildings type k in year n

$$Ref_{total,new,n,k} = (A_{n,k} \times O_{ref,new,n,k}) - (A_{2005,k} \times O_{2005,ref,k})$$

Source: Elaboration of author

Exchanged refrigerators are calculated as the sum of all exchanged refrigerators since the reference year 2005, as expressed:

**Equation 28:** Sum of exchanged refrigerators in buildings type k in year n

$$Ref_{total,new,ex,n,k} = \sum_{2005}^{n} (A_{n,l} \times O_{ref,new,n,k} \times R_{ex})$$

Where:
$R_{ex}$ = exchange rate = 7%
Source: Elaboration of author

### 6.2.3.2. Forecast of refurbishment and stock increase

Showers

In Brazil, electric showers are the main way of heating water in the residential sector. The use of electric shower heaters is likely to increase under a business-as-usual scenario. There is a clear relationship between increasing income and energy consumption for heating in Brazilian households. At the moment it is difficult to foresee the impact of the recent approved building code in São Paulo for solar water heating (item 2.3). That depends from the compliance and the adaption of this building code from other cities. For the reference scenario based on literature research, it was assumed that solar water heating will not play any role for water heating (Kaufman et al., 2010).

The stock of shower heads is mainly driven by the growth of dwellings and new installed showers with higher *unit energy consumption* (UEC) and by exchanged showers due to end of lifetime. The exchange rate for the showerheads was assumed to be 7%, based on the average lifetime of about 15 years (ANEEL, 2001). It is assumed that every time a showerhead is exchanged or installed in a new building, it will be a more powerful one (item 5.3.2.).

Refrigerators

The stock of refrigerators is mainly driven by the growth of dwellings and new installed refrigerators and by exchanged refrigerators due to end of lifetime. The exchange rate for the refrigerators was assumed to be 7%, based on the average lifetime of about 15 years (Vendrusculo, 2009). Data from IBGE provides detailed information on the development of the refrigerator stock. As discussed in item 6.2.2. the ownership rate of the refrigeration increases steadily. For a better forecast of energy consumption of refrigerators there will disaggregated the one door and the two door model, reflecting actual trends in the market. Whereas the total stock of refrigerators increased from 1999 till 2007 with an average growth rate of 1,4%, the stock of one-door refrigerators decreased with 0,4% in average and the two-doors refrigerators increased with 9,5% annually, already reaching an ownership rate of about 0,25 (IBGE, 2009). This growth rates are taken for the reference scenario.

The substitution rate of the one-door by the two-door refrigerators can be calculated multiplying the actual two-door refrigeration stock (20% of the total stock in the reference year) with the average annual growth rate of 9,5% the rest is substituted with new one-door refrigerators. In the case of the large multi family house (LMFH) it was assumed that all the exchanged refrigerators will be substituted with the two-door refrigerators due to the higher income of the inhabitants of this building type. Due to the recent expansion of two-door refrigerators it was assumed that these refrigerators are relatively new in the stock and will not reach the end of their life time until 2020. Also the electricity consumption of the new two-door refrigerator is assumed to be the same as the old one, because the stock is relatively new. The exchange rate for two-door refrigerators was assumed to be 0%. Furthermore it was assumed that every time a refrigerator is exchanged or installed in a new building, it will be an efficient one.

Lighting

The lifetime of the incandescent light bulbs, was assumed to be two years (about 1000 hours). This results in a calculated exchange rate of 50% per year. It was further estimated that about 5% of the exchanged light bulbs are efficient light bulbs with 15 Watt and the rest the standard 60 Watt incandescent light bulb. For all installed new light bulbs in the new dwellings it was assumed that about 20% of every new light bulb will be an efficient one.

Air condition

There is no data available on the systems used in Brazil. In the residential sector until now the window air condition seems to be most frequent system (Lamberts and Ghisi, 2008) (see 5.2.2.2.). With increasing income it seems probable that the systems and their cooling capacity in households increase (through substitution of window air condition by split systems). However due to lack of data this was not considered. The key driver for increasing energy consumption by air conditioning was assumed to be the increase of the ownership rate and the increase of the stock through the construction of new buildings with air conditioners (item 6.2.2 and 6.2.3.).

The stock rate exchange is assumed to be 7%, because of the assumed lifetime of 15 years (Vendrusculo, 2009). As in the case of refrigerators it was assumed that every exchange will lead to higher efficiency. In two third of the cases the cooling capacity will be the same as the old apparatus and in one third of the cases the cooling capacity will be increased. This assumption was made due to the purchase power. This assumption is due to the strong influence of INMETRO on the sellers and also due to very few price differences of apparatus with different efficiency.

Following table summarizes the exchange and growth rates of new and refurbished appliances

**Table 38:** Assumptions on exchange and growth rates per appliance

| | | Unit | Urban SFH | Rural SFH | Small MFH | Large MFH |
|---|---|---|---|---|---|---|
| **Air condition** | NEW 1 (2,93 kW) | exchange rate [%/a] | 4,69 | 7 | 7 | 3,5 |
| | NEW 2 (2,93 kW) | exchange rate [%/a] | 2,31 | 0 | 0 | 3,5 |
| **Shower** | New shower | exchange rate [%/a] | 7 | | | |
| **Refrigerator** | NEW 1 - One door | exchange rate [%/a] | difference between sum of old, one-door refurbished refrigerator (7% exchange) minus new two-door refrigerators | | | |
| | NEW 2 - Two door | growth rate [%/a] | 9,5 | | | |
| **Light bulbs** | Incandescent light bulbs 60 Watt | Exchange rate [%/a] | 45% | | | |
| | Efficient light bulbs with 15 | Exchange rate [%/a] | 5% | | | |
| | | Share in new dwellings [%/a] | 20% | | | |

Source: Elaboration of author on base of (ANEEL, 2001; Faria, 2010; IBGE, 2009; PROCEL/Eletrobrás, 2007)

<u>Cooking stoves</u>

The future forecast of energy demand for cooking that is the consumption of gas and firewood has to be based on overall tendencies because there is a lack of data on how the energy is used. For a detailed bottom up estimation there would be needed data on the number and characteristics of the cooking stoves. It is assumed that in the longer term the use of firewood will decrease. However the time horizon of this thesis is until 2020 and according to various sources it does not seem probable that the consumption of firewood will decrease in larger amounts (MME, 2007a; MME, 2007b). The increase of LPG stoves goes hand in hand with the increase of the number of dwellings, which could be an indicator that new dwellings install mostly LPG stoves, whereas the number of wood stoves stays almost equal (figure 31) (Shell, 2007b).

A possibility to forecast the cooking energy consumption for the reference scenario would be to forecast the development of the correlation factor and to determine future cooking energy consumption on base of that correlation (figure 50).

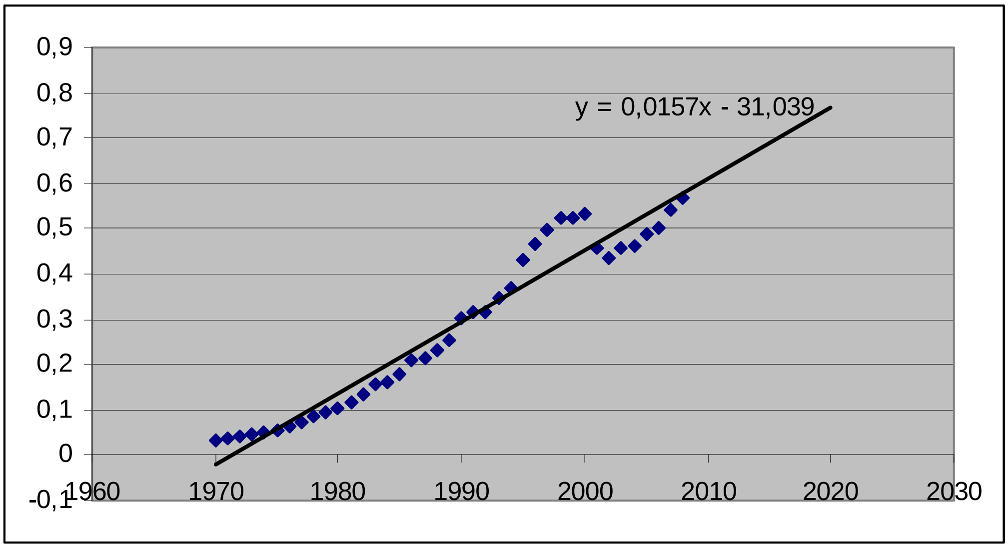


**Figure 49:** Development of the ratio of electricity: cooking energy
Source: Elaboration of author on base of (EPE, 2009a; PROCEL/Eletrobrás, 2007)

With the linear regression it would be possible to forecast the correlation factor in 2020. However this method has a disadvantage. Due to the dependence of the cooking energy from the electricity, the amount of cooking energy would automatically increase with increasing electricity consumption.

Therefore it was decided to approach the problematic differently and make assumptions on the distribution of wood and gas stoves and therefore the implicit change in efficiency and energy consumption:

- All new constructed dwellings will install one gas stove that means the gas consumption will increase equal to the growth rate of the building stock.
- Firewood demand is not increasing due to a stable number of wood stoves (almost no new constructions in the rural area and all new constructions in the urban area install gas stoves)
- The lifetime of the stoves is set to 15 years (Kadiana et al., 2007).
- The stoves that are exchanged do not have better efficiency. That is because there is no incentive from the government and efficient stoves are much more expensive (Shell, 2007b). Especially in the rural area where a big part of the population is poor it seems not probable that these households acquire a more expensive stove.

It has to be mentioned that these assumptions are one of the less sound standing ones and therefore the most insecure. On the other hand cooking energy consumption in 2008 accounted for more than two third of the overall energy consumption in the residential sector. This is partly because of the high inefficiency of fire wood and the necessity for a higher quantity of fuel wood required in comparison with gas or electricity to realize the same activities. Therefore it was decided to include the end use cooking in the scenario.

## 6.3. Summary of key assumptions

### Summary of the key assumptions - BAU

**Refrigerator and shower**

- Exchange rate is 7% per year
- Every exchanged refrigerator is an efficient refrigerator
- The actual stock is composed of 50% efficient and 50% not efficient refrigerators (reference year 2005)
- The actual stock is composed of 20% two-door and 80% one-door refrigerators (reference year 2005)
- The growth rate of the two-door refrigerators is 9,5% per year
- The substitution of one- by two-door refrigerators is determined by the growth rate of two-door refrigerators, the rest will be substituted by new one-door refrigerator
- In the case of the large MFH, all substituted or new refrigerators will be two-door refrigerators.
- The consumption of the old one-door refrigerator is 40 kWh, of the new one-door refrigerator it is 30 kWh and of the two-door refrigerator it is 50 kWh per month
- Two-door refrigerators are not exchanged

**Shower**

- Exchange rate is 7% per year
- Every new installed showerhead will be more powerful than the old one
- No replacement by solar water heating

**Lighting**

- Actual stock is composed of 20% efficient lamps (15 Watt)
- Exchange rate is 50% per year
- 5% of replaced lamps are efficient lamps (15 Watt)
- 20% of the lamps installed in new buildings are efficient lamps (15 Watt)

**Air conditioning**

- No estimations type of system (only window air condition considered)
- Exchange rate is 7% per year
- Every new air conditioner will be more efficient than the replaced one
- In urban SFH, two third of the replaced equipment will be apparatus with the same cooling capacity and one third with higher cooling capacity.
- In rural SFH and in small MFH the replaced air condition will have the same cooling capacity.
- In the large MFH the air condition will have more cooling capacity in 50% of the cases.

**Cooking stoves**

- All new constructed dwellings will install one gas stove
- The number of firewood stoves will not increase
- Exchange rate is 7 % per year
- Exchanged stoves do not have better efficiency in the BAU scenario

**Figure 50:** Summary of key assumption

Source: Elaboration of author

## 6.4. Results and discussion

In the BAU scenario the energy consumption will growth from a total of 262 TWh in 2005 by 40% up to 385 TWh in 2020. Electricity consumption will growth much stronger with 85% whereas cooking energy will grow by 32%. The shares of the energy barriers in the energy mix shift towards electricity. Whereas the share of electricity in 2005 was about one third in 2020 it will be almost account for half of the energy consumption of the residential sector (table 40).This is mainly due to two reasons. First, electricity consumption will grow faster than cooking energy (see figure 48) because the ownership of electrical appliances will increase in the future. Low income households with low ownership will acquire appliances that become available to them and higher income households will multiply their appliances (two showers or air conditioners instead of one for example). Second the scenario assumed almost no growth in the rural area and all new buildings equipped with gas stoves. That implies that the consumption of firewood will not rise due to new dwellings, only the gas consumption. Due to the higher efficiency of gas in relation to firewood the growth will be more moderate as it would have been with more firewood stoves installed.

**Table 39:** BAU scenario: Energy demand source use in 2008 and in 2020 [GWh]

| | 2005 | BAU 2020 | Growth [%] | Share [%] | |
|---|---|---|---|---|---|
| | | | | 2005 | 2020 |
| Electricity | 85 | 181 | 113% | 32% | 47% |
| Gas | 72 | 98 | 37% | 27% | 25% |
| Firewood | 106 | 106 | 0% | 41% | 28% |
| Total | 262 | 385 | 47% | 100% | 100% |

Source: Elaboration of author

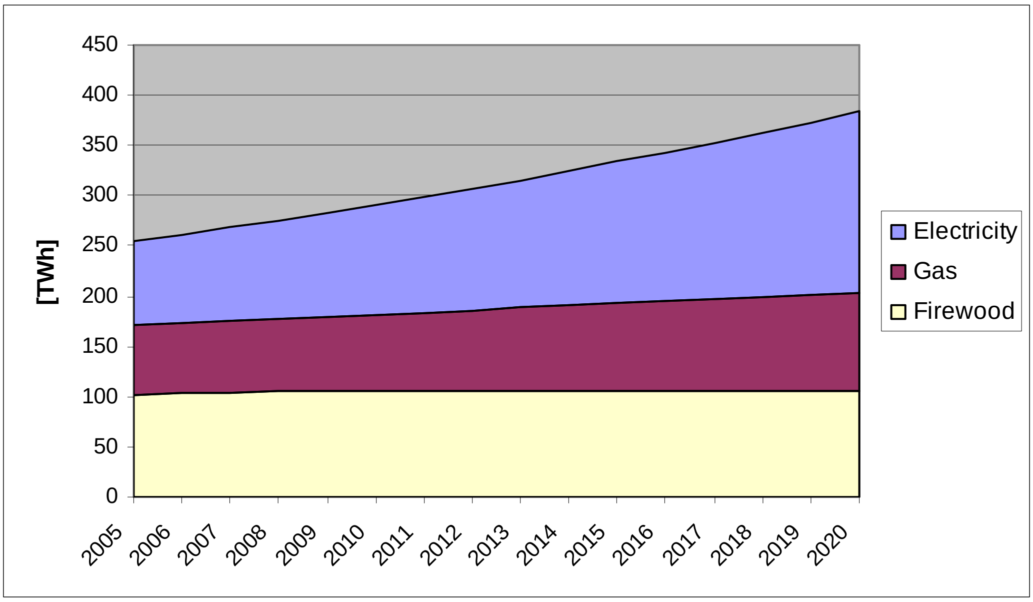


**Figure 51:** Projection of the energy demand 2005-2020 by source

Source: Elaboration of author

The disaggregation of end uses permits a more detailed analysis of electricity consumption of the residential sector. Drivers of the increasing electricity consumption are to a large amount the shower and the air condition. This is due to ownership development, to refurbishment and new appliances in new dwellings. The projection of end uses indicates that by 2020 shower and air conditioning will be responsible for more than half of the electricity consumption in n Brazil (figure 53).

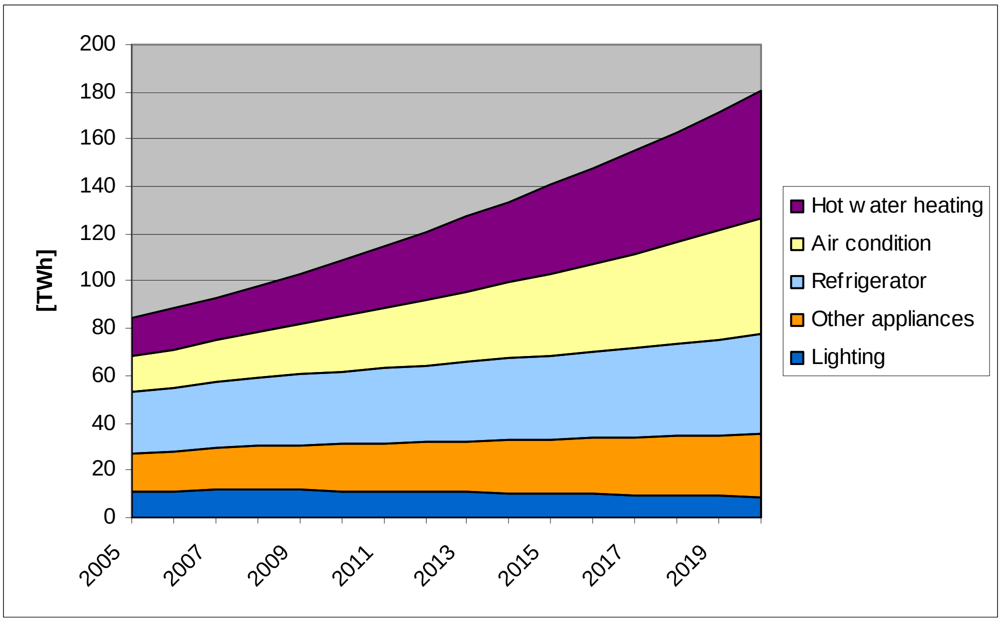


**Figure 52:** Projection of the energy demand 2005-2020 by electricity end use

Source: Elaboration of author

Comparing the share in the electricity matrix in 2020 it is notable that the energy demand by air condition and shower increase whereas the demand caused by refrigeration, lighting and other appliances decrease their share. In the case of lighting this seems reasonable. In the BAU scenario there are already adapted efficient measures and by 2020 almost all the light bulbs are supposed to be efficient ones (15 Watt). By 2020 air condition and shower will be responsible for more than 505 of the electricity demand, which indicate that under the BAU scenario there are no effective measures that can reduce the energy demand by these end uses. Although PROCEL, through the labeling program of INMETRO, seems to give pressure to the producers to put more efficient appliances in the market it seems that in the case of the air condition the progress is much slower as in the case of refrigeration for example. What is a remarkable difference to other scenarios, such as the forecast from EPE is that the other appliances lose proportion in the electricity demand share. In the scenario from EPE the other appliances gain share (MME, 2007b). This can be due to methodological differences in the approach. In the thesis research growth of other appliances, due to lack of end use data was set to growth equal to the GDP not to the ownership growth rate, as the other appliances (further discussion of the EPE study see item 8.1.)

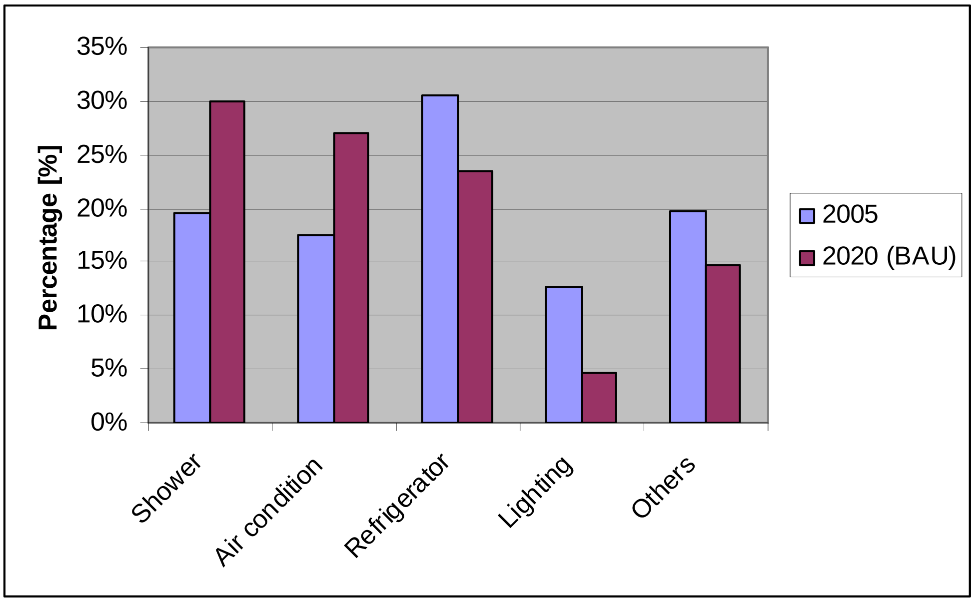


**Figure 53:** Comparison of share of end uses for electricity demand in 2005 and by 2020
Source: Elaboration of author

The bottom-up modeled end use consumption disaggregated on building type level permits detailed analysis by building type. For example in 2005 the rural SFH only spends about 15% on electricity consumption; the large main part of energy consumption, about 85% is used for cooking (firewood). In the BAU scenario in 2020 the share by end uses shift. In the large MFH where the shift is most evident, the share of energy for cooking falls from 50% in 2005 to almost 20% in 2020. This is mainly because of the increasing electricity consumption and here mainly by the end uses air conditioning and shower in relation to cooking energy. This growth is slower in the rural than in the large MFH, citing the both extremes. In the rural area in 2020 still more than 80% of the energy will be used for cooking, whereas in the large MFH this amount will be reduced to 20% (figure 52 and 53).

A closer look at the electricity consumption and the underlying definitions of the reference building reveals the reasons for this shift in the matrix. It should be remembered that for the definition of the reference buildings it was assumed that the large MFH in general has a higher the ownership rate than any other building types. For example it was assumed that 80% of the large MFH buildings are equipped with an air conditioning, whereas in the other buildings this was between 8% and 16%.

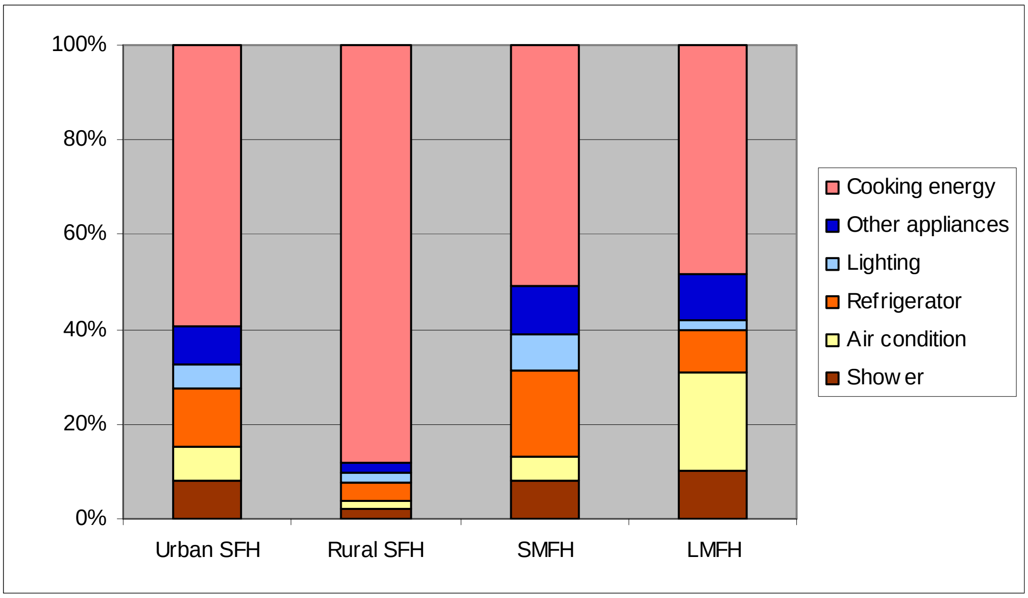


**Figure 54:** Energy mix per building type in 2005
Source: Elaboration of author

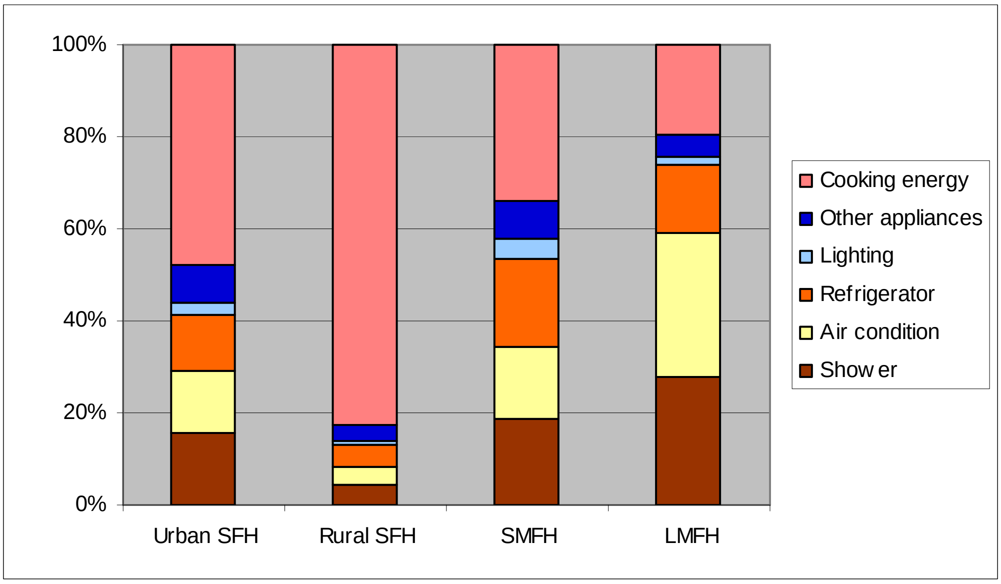


**Figure 55:** Energy mix per building type in 2020
Source: Elaboration of author

In general it can be observed that in all building types the share of the refrigerator, with exception of the large MFH, it was the largest end use consumer in 2005, but then fell behind the air condition and shower in 2020 appliance (figure 55 and 56). That has various reasons. The ownership increase surely is one of them; especially the assumed linear growth in the case of the air condition gives a real push to this end use. Second the assumption that every new shower will be a shower with higher capacity as the older one reflecting actual trends in the market, whereas there is almost no big price difference between the 4 and 6 kW electrical showerhead for example. This scenario of the shower is considered very probable. Third, on the other hand, the assumption that old refrigerators will be refurbished with newer and more efficient ones have some effect here and hold down the increase of the energy demand of refrigerators. Also it should be taken into account possible scenarios. For example, although the refrigerators have become more efficient this could be outweighed by the higher UEC of the bigger.

Lighting due to high availability of efficient light bulbs, due one fifth of the light bulb stock already being efficient in 2005 and due to assumed refurbishment in part of efficient light bulbs the share in the electricity matrix will decrease in the BAU scenario because in relation with other end sues this appliances are becoming faster efficient. Until the ownership rate will not outweigh this trend, it is likely that energy demand by light bulbs is further reduced until saturation of the market through efficient light bulbs (figure 57 and 58).

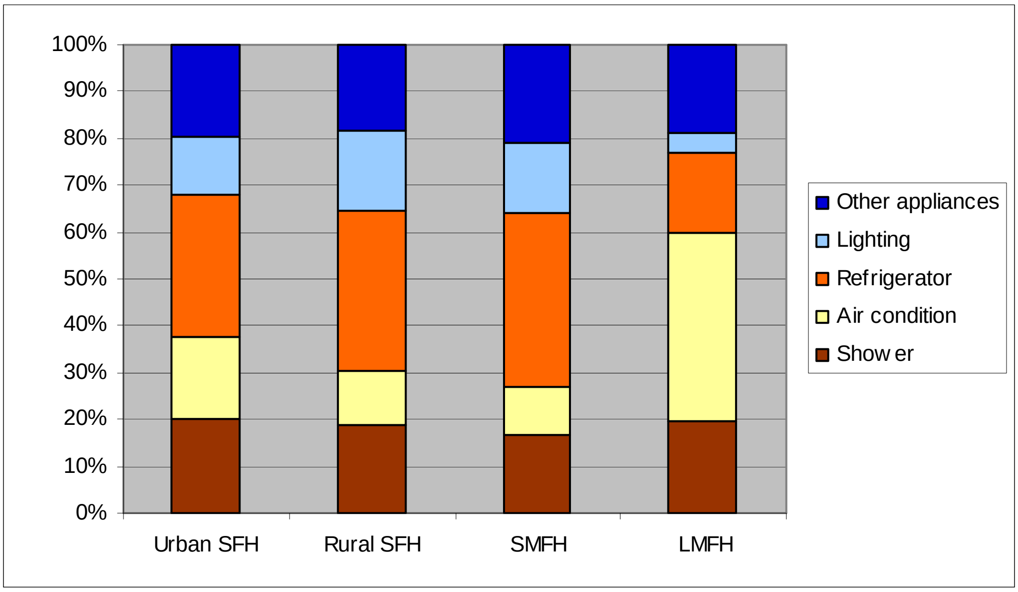


**Figure 56:** Electricity mix per building type in 2008
Source: Elaboration of author

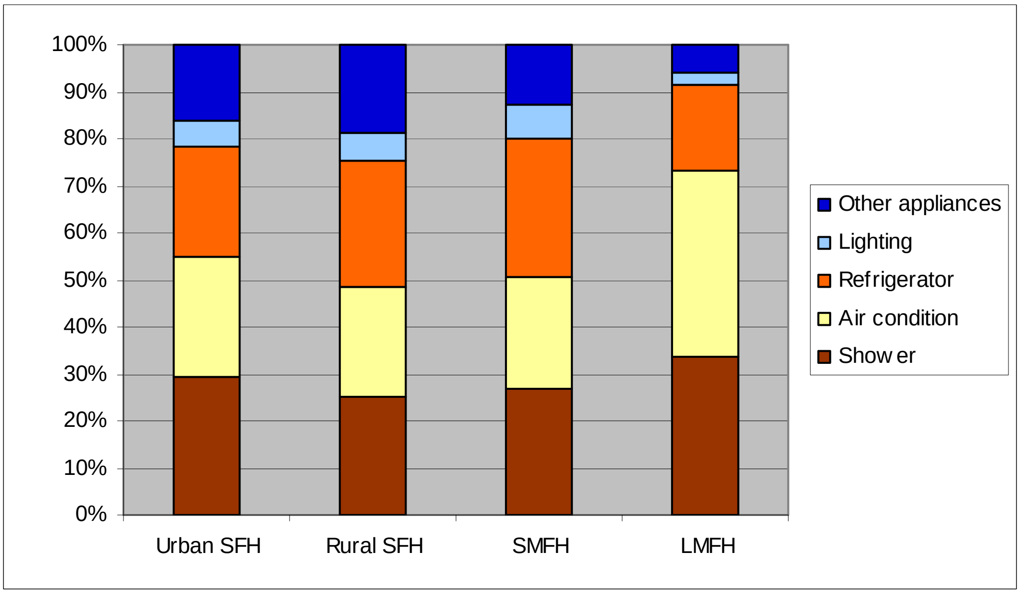


**Figure 57:** Electricity mix per building type in 2020
Source: Elaboration of author

# 7. The efficiency scenario

The efficiency scenario analyzes various measures to reduce energy demand until 2020. The highest effect on energy saving would occur if the measures were realized in parallel. The energy efficiency options investigated are:

- Replacement of electricity water heaters with solar water heaters
- Improvement in energy efficiency of electric appliances by main end uses
- Improvement in cooking energy efficiency

Due to the developed BAU scenario these three measures are considered of high importance. The electric water heating is a big problem because of the large contribution to the peak demands, the ownership rate of appliances will increase relatively fast and in part possible improvements in efficiency can be outweighed by a increasing stock and higher unit energy consumption. The improvement in cooking efficiency is the most difficult measure to analyze due to lack of data. However the fact that in 2005 this end use was responsible for two third of the energy consumption in the residential sector in Brazil it is considered an important end use to investigate the energy saving potential. The measures investigated are challenging, and require strong politics, although they are ambitious there not theoretical.

The latest data on energy data used in this research is from 2008 (EPE 2009a and IBGE 2009) and it was decided to start the efficiency measures in the year 2009.

## 7.1. Efficiency measure 1: Introduction of solar water heating

Solar water heaters are an effective and competitive solution, capable of replacing part of the electricity used for heating. Brazil has an average of 280 days of sun, representing a multiple potential of the amount of electricity consumed in Brazil in 2008. At the moment less than 1% of the households heat water with solar thermal energy, and almost nothing of this potential is used by photovoltaic systems (D. Rodrigues, 2007). Figure 55 give an impression of the different solar radiation of Brazil and Germany. It is noteworthy that the solar radiation in the sunniest region of Germany is 40% less then in the worst region in Brazil. In Brazil the annual average radiation is between 1500 and 2300 kWh/m²/a. The annual variability is less than 20% for the most part of the country (Agopyan and Lamberts, 2009; Lamberts, 2007a; Lamberts, 2007b).

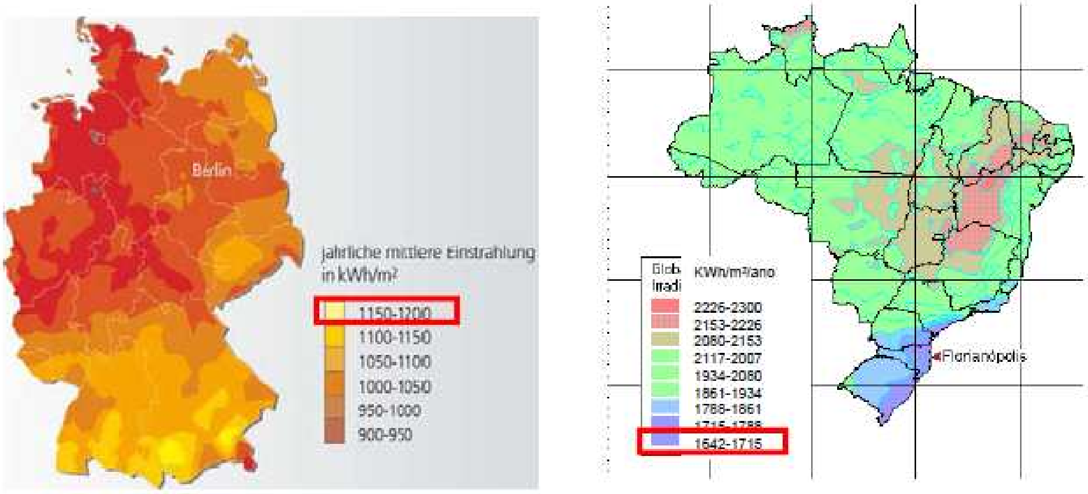


**Figure 58:** Solar radiation in Germany (left) and in Brazil (right)

Source: (Agopyan and Lamberts, 2009)

For the calculation of the potential of replacing electric water heating with solar thermal heating there has been assumed an annual average solar fraction for Brazil of 60% for single family houses and 50% for multifamily houses. The so-called *solar savings fraction* or *solar fraction* is the amount of energy provided by the solar technology divided by the total energy required (Hedenberg and Wallander, 2008; Solarserver, 2010). In Germany a typical solar fraction is between 60-70% and Brazil with higher solar radiation has a higher solar fraction. Due to a conservative approach the solar fraction in Brazil had been set to the lower value of the range found in Germany. Typically the solar fraction in multifamily houses is less (Fisch et al., 1998) and therefore had been assumed to be 50%. It is evident that the solar fraction of a particular system depends on many factors such as the collection and storage sizes, the operation, the load and the climate. Due to the approach of the study and there has been calculated with a national average value without going into system specific or regional detail.

In this scenario it is assumed that the relatively new municipal law of São Paulo that makes it mandatory for all new residential buildings with more than three bathrooms per unit to install solar water heating is applied to all new buildings in Brazil. In the scenario it was assumed that all new buildings will install solar water heaters. Apart it was assumed that there is a small refurbishment rate of 1% every year.

## 7.2. Efficiency measure 2: Increase share of efficient appliances in stock

This measure assumes that old electrical equipment will be replaced with a more efficient one after its lifetime. For the projection there has been selected the most efficient air conditioners and refrigerators at the moment available according to INMETRO. For refrigerators it was assumed that the UEC per month will be 20 kWh for one-door refrigerator and 30 kWh for the two-door refrigerator. The capacity of air conditioners was assumed to be 0,67 kW, 0,94 kW and 1,125 kW for the different sizes of air conditioners. All of these air conditioners had the highest efficiency rate according to INMETRO. The average efficiency of these three apparatus is 3,14 COP. Although these efficiency rates are the best of the Brazilian air conditioning stock the efficiency rates seems achievable in part due to the strong influence of INMETRO on the market and producers. Comparing with assumptions made by Mc Neil for his global HVAC forecast model the assumptions are quite congruent (see figure 60). He assumes that Brazil has a future development of efficiency in two steps until 2015 reaching 3,2 COP.

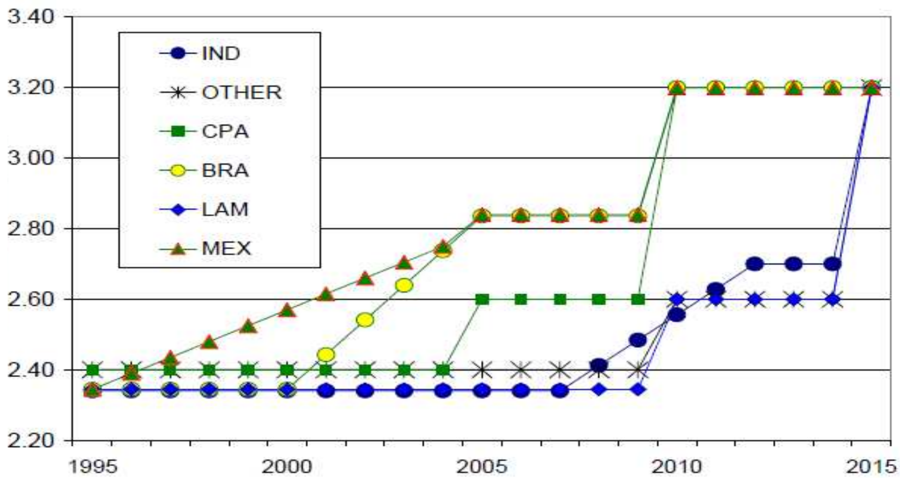


**Figure 59:** High efficiency scenario - efficiency by region in COP

Source: (McNeil and Letschert, 2008)

The replacement of refrigerators and air conditioners will only take place after the end of their life time, that was assumed to be 15 years (EcoTopten.de, 2008; Graus and Blomen, 2008; Vendrusculo, 2009). Therefore the annual exchange rate was calculated to be 7% in order that the whole stock will be replaced after 15 years. One problem that is ignored in this study is the further use of old equipment. It can be assumed that old and inefficient refrigerators and air conditioners, if still working, find their way to people with low purchase power and therefore will still exist, although in the forecast they will be treated as if exchanged.

Assumptions regarding the replacement of incandescent light bulbs are:

- The lifetime of an incandescent light bulb is estimated to be 1000 hours, with the calculated use in the forecast model that is about 2 years.
- Efficient light bulbs replacing the incandescent ones are assumed to have 11 W
- 10% of the stock replacement of light bulbs are efficient ones (11 W)
- 30% of the light bulbs in new dwellings are assumed to be efficient (11W) light bulbs

Other appliances are assumed to reduce the overall electricity consumption due to reduced stand-by consumption. Studies indicate that about 10% of the electricity consumption is caused by stand-by consumption in Brazil and that it could be reduced to 5% or less. For the projection it is assumed that every year the consumption is 5% less due to reduced stand-by power consumption.

## 7.3. Efficiency measure 3: Improvement in cooking efficiency

The highest end use consumption in the residential sector is the energy used for cooking. Reduce energy consumption for this activity has a big potential, but are not very realistic in the near future because for many households switching away from tradition fuel wood is not feasible in the short term (Shell, 2007b). Improving the way biomass is supplied and used for cooking is therefore an important way of reducing energy consumption. That could be biomass with higher energy content, such as charcoal e.g. But charcoal is often produced with low transformation efficiency. Another approach is to improve the use of biomass use through improved stoves. Improved stoves can reduce biomass from 10-50% for the same cooking service provided (IEA, 2006; REN21, 2007).

The two main possibilities would are the gradual substitution of firewood by LPG. With the termination of the subsidies of LPG and increasing prices this scenario is very improbable in the near future. The second possibility is the gradual increase of more efficient stoves in the market. This includes:

- replacement of old stoves through new more efficient ones (this can be the replacement of a old fire wood stove through a new fire wood stove or through a new gas stove). Due to improbability of substitution of firewood through LPG it is assumed that an old stove replaced by a new one will be based on the same fuel (a firewood stove will be replaced by a firewood stove and a LPG stove by a LPG stove).
- Due to increasing urbanization rate it is assumed that the biggest part of new constructions will be furnished with a LPG stove. Therefore the share of LPG stoves is probable to increase, whereas the relative share of firewood stoves in the stock will decrease. This means that in general the cooking services will require less energy, the ratio cooking energy to electricity will decline. In other words a household in 2020 will use less part of its energy consumption for cooking than in 2005.

The following assumptions have been made:

- Lifetime of the stoves is 15 years which results in a yearly exchange rate of 7%
- Every stove (firewood and gas) that is exchanged due to end of his lifetime is a more efficient one
- The new stoves are assumed to be 20% more efficient. In the case of woodstoves this seems still a conservative approach. In the case of gas stoves that could be more challenging because this stoves are already more efficient. But due to the lack of data there are o further assumptions made.
- Ever new dwelling installs a new and efficient gas stove (20% more efficient)

## 7.4. Summary of key assumptions

The following box gives an overview of the key assumptions for the development of the efficiency scenario described in this chapter. Furthermore the more technical data is summarized in table 41.

**Key assumptions**

**Introduction of solar water heating**

- solar fraction is 60% in single family and 50% in multi family houses
- annual refurbishment rate is 1% (substitution of electric water heater through solar water heater)
- every new building will be installed with solar thermal heating

**Increase of efficient appliances in the stock**

- Refrigerators and air conditioners are replaced only with the most efficiency apparatus due to INMETRO. The size is related to income of the household
- Exchange rate every year is 7%
- Incandescent light bulbs are replaced by 11W CFLs, annual refurbishment rate is 10%, in new buildings 30% of the new light bulbs are efficient
- Other appliances will gain every year 0,05% more energy saving through less stand-by consumption, until gaining 5%.

**Improvement in cooking energy efficiency**

- Lifetime of the stoves is 15 years which results in a yearly exchange rate of 7%
- Every new stove (firewood and gas) are assumed to be 20% more efficient.

**Figure 60:** Summary of key assumptions

Source: Elaboration of author

**Table 40:** Overview of data of new appliances and refurbishment rates by building type

| Appliance | | Unit | Urban SFH | Rural SFH | Small MFH | Large MFH |
|---|---|---|---|---|---|---|
| Shower | Refurbishment rate | [% / year] | 1 | | | |
| | New buildings that install SWH | [%] | 100 | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Solar fraction | | [%] | 60 | 60 | 50 | 50 |
| Air condition | Refurbishment rate | | [% / year] | 7 | | | |
| | Capacity [kW] | 2,2[1] | [% of refurbished] | 67 | 100 | 100 | - |
| | | 2,9[2] | | 33 | - | - | 50 |
| | | 3,5[3] | | - | - | - | 50 |
| Efficient Refrigerator | Refurbishment rate | | [% / year] | 7 | | | |
| | UEC [kWh / month] | 20 (1 door) | [% of refurbished] | Calculated (total refurbished minus substitution through 2-door refrigerator) | | | |
| | | 30 (2 door) | | 9,5% growth rate per year | | | |
| Efficient lighting | Refurbishment rate | | [kW] | 50 | | | |
| | Capacity [kW] | 0,011 | [% of refurbished] | 10 | | | |
| | | 0,06 | | 40 | | | |
| | New buildings that install efficient lamps | | [%] | 30 | | | |

Source: Elaboration of author on base of (EPE, 2009a; IBGE, 2009; PROCEL/Eletrobrás, 2007)
[1] Efficiency: 2,93 COP
[2] Efficiency: 3,02 COP
[3] Efficiency: 3,2 COP

## 7.5. Calculation method

The resulting energy demand is calculated using the formula introduced in item 6.2.3.1. The formulas are developed referring to the electric shower to make it more tangible, but they have been applied also for the refrigerator, the air condition and the lighting, only changing the parameter UEC (or capacity) and the refurbishment rate.

The electricity used for the electric shower in the efficiency scenario can be calculated as difference of electricity used under the BAU scenario minus the energy saved through the efficiency scenario. In the case of solar water heating there has to be calculated the showers that are refurbished respective the new dwellings that lower their energy demand for hot water through this measure. The parameter to be changed is the A parameter (number of dwellings) because this parameter is the multiplicator for the installed power for electric water heating. Through this efficiency measure this parameter gets smaller because there will be less dwellings with installed electric showers.

**Equation 29:** Calculation of the buildings with electrical shower in year n

$$A_{n,k} = A_{n,k} - \left(A_{solar,ex,n,k} + A_{solar,new,n,k}\right)$$

Where:
$A_{n,k}$ = number of buildings type k in year n
$A_{solar,ex,n,k}$ = number of buildings type k in year n that are refurbished with solar water heater

$A_{solar,new,n,k}$ = number of new buildings type k in year n (all with solar water heater)
Source: Elaboration of author

The new buildings type k with solar thermal water heating in year n can be expressed as follows:

**Equation 30:** Fraction of new buildings covered by solar thermal heating

$$A_{solar,new,n,k} = \left(A_{n,k} - A_{2005,k}\right) \times fr_{solar,k}$$

Where:
$fr_{solar,k}$ = fraction of solar coverage in buildings type k
Source: Elaboration of author

The refurbished buildings type k with solar thermal water heating in year n can be expressed as follows:

**Equation 31:** Fraction of refurbished buildings covered by solar thermal heating

$$A_{solar,ex,n,k} = A_{n,k} \times r_{solar} \times fr_{solar,k}$$

Where:
$r_{solar}$ = refurbishment rate (solar water heating substitutes electric shower) for the building stock
Source: Elaboration of author

The resulting formula expresses the buildings that are not covered by this measure.

**Equation 32:** Buildings not covered by solar thermal heating

$$A_{ES,n,k} = (A_n - A_{2005}) - \left(A_{solar,ex,n,k} + A_{solar,new,n,k}\right)$$

Source: Elaboration of author

In the case of other appliances based on the assumption the energy consumption in the ES was calculated as follows, adapting the equation …:

**Equation 33:** Electricity consumption of other appliances

$$EL_{total,others,n,k} = \left(El_{total,others,n,k} - El_{total,others,n,k}\right) \times \left[1 - \left(m \times fr_{standby,saving}\right)\right]$$

Where:
m = number of years
$fr_{standby\ saving}$ = 0,05% (energy that is saved, increases successive up to 5%
Source: Elaboration of author

## 7.6. Results

In the efficiency scenario considering all measures together, the overall consumption in relation to the BAU scenario is reduced from 385 TWh to 311 TWh that is by 69 TWh (18%). In relation to the reference year 2005 this is an increase of about 121%, instead of 151% in the BAU scenario. In the developed scenario the three energy barriers electricity, firewood and gas contribute relatively equal to the energy savings. But within the different end uses and distinguished by building type there are some differences,

**Table 41: Energy savings by 2020 in the energy efficiency scenario**

| | 2005 | BAU 2020 | ES 2020 | energy saved | saved in percent |
|---|---|---|---|---|---|
| Electricity | 85 | 181 | 139 | 42 | 23% |
| Gas | 69 | 98 | 83 | 15 | 16% |
| Firewood | 102 | 106 | 90 | 17 | 16% |
| Total | 255 | 385 | 311 | 74 | 19% |

Source: Elaboration of author

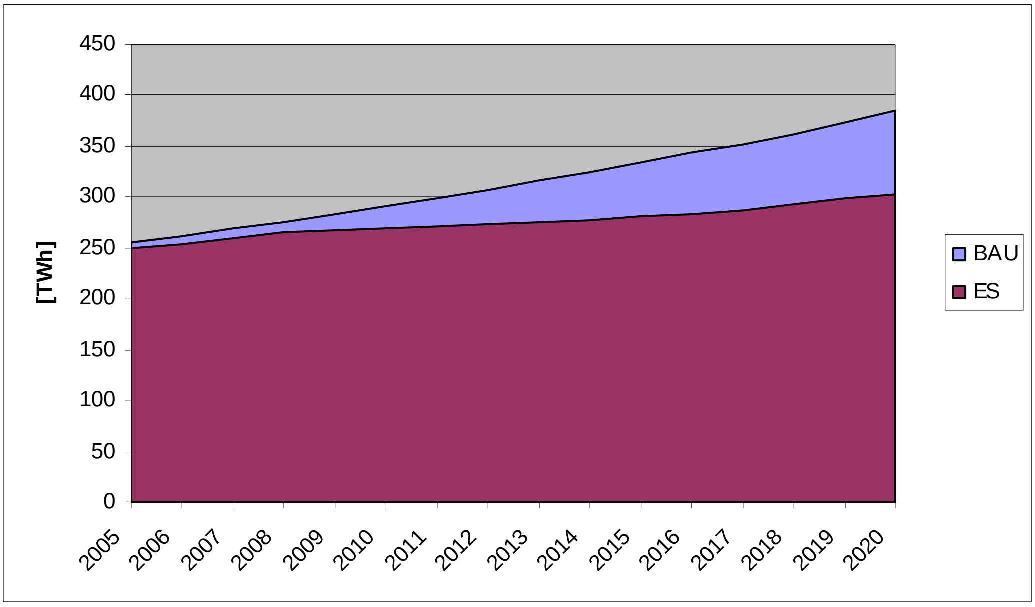


**Figure 61:** Projection of energy consumption for the BAU and ES scenario from 2008 until 2020 of the Brazilian residential sector.

Source: Elaboration of author

The assumptions on the improvement of the cooking efficiency results in a slightly decrease until 2020 (figure 62. Due to the high inefficiency of woodstoves and the assumed exchange rate together with the assumption that all new buildings will be equipped with a gas stove lead to a large reduction of 32 TWh that is about 15% less as in the BAU scenario. Although the construction rate is relatively high in Brazil the refurbishment of old wood stoves through more efficient one outweighs the increase of the stock of gas cook stoves. This may be due to the assumptions of the efficiency of wood stoves in relation to gas stoves (figure 63).

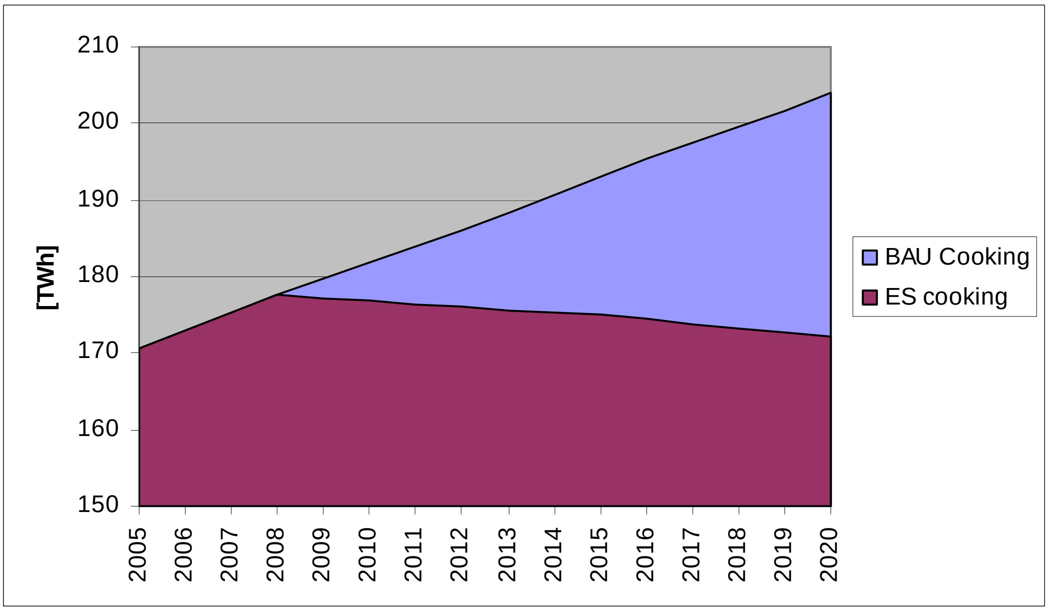


**Figure 62:** Projection of energy consumption for the BAU and ES scenario from 2008 until 2020 of the Brazilian residential sector

Source: Elaboration of author

In Brazil the electricity demand is increasing fast. Efficiency measures are an important way to slow down the increase. The BAU scenario projects an increase of electricity consumption of 212% from 2005 until 2020. With the investigated efficiency measures this is reduced to an increase of 163%, which is still large (figure 64). One of the most important reasons for this growth is the use of inefficient appliances and the rapid increase of ownership rate due to higher income.

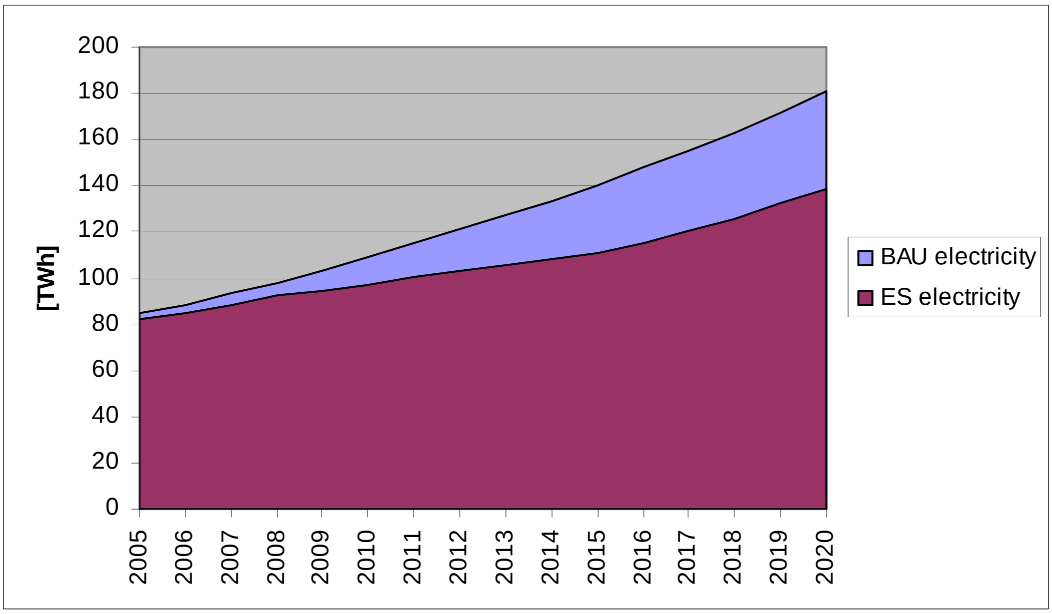


**Figure 63:** BAU and efficiency scenario for the electricity consumption 2008-2020

Source: Elaboration of author

Under the efficiency scenario it is possible to save an amount of energy equal to 74 TWh until 2020 that is 19% from the BAU scenario (figure 65)

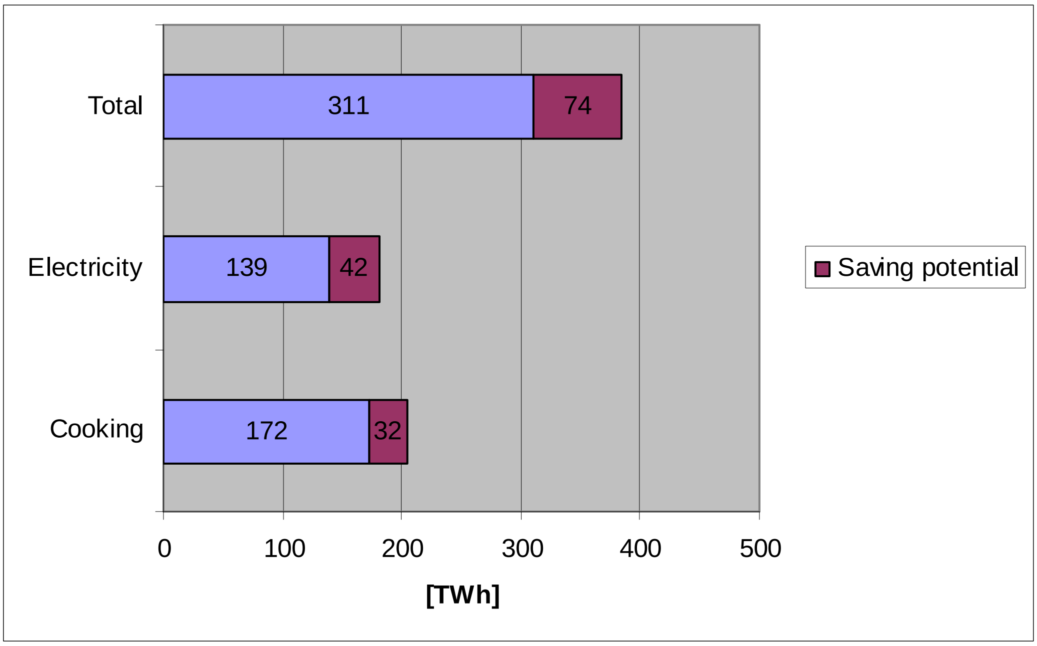


**Figure 64:** Saving potential of the efficiency scenario until 2020

Source: Elaboration of author

Appliances, consumer electronics and other electrical appliances of Brazilian households, such as lighting and electric shower account for a growing fraction of total electricity use in households. Energy-saving options include more efficient appliances, efficient cooling (refrigerators, freezers and air-conditioning equipment) and efficient lighting. In the efficiency scenario, through the deployment of the best available technology (through refurbishment at the end of lifetime and all appliances in new constructed dwellings) the energy consumption can be brought down. For instance the energy consumption of refrigerators, accounting for about 30% of the total electricity demand in Brazil could be cut by 37% on average, with a total power saving of 16 TWh by 2020. Stand-by and low-power-mode use by consumer electronics is responsible for about 10 % of residential and service power demand in Brazil. Current regulation to reduce stand-by option energy use on appliances to 1 W is lacking implementation. However with reducing the stand-by loss by only the half to 5% this would bring a reduction in electrics consumption for these appliances of 8% that is about 2 TWh (figure 66).

Electric shower heaters consume about 8% of all Brazil's electricity production and around 18% of the peak demand (WWF - Brasil, 2007). Electrical shower-heads are extremely cheap, costing US$ 10 or less. However, given their high life-cycle electrical consumption, each shower-head requires an investment of more than US$ 1 000 in new electricity generation capacity to guarantee the peak power needed to fuel them. The efficiency scenario assumes a power saving up to 17 TWh and brings down the BAU projection from 54 to 37 TWh. This would save 32% of the BAU projection by 2020 (figure 66).

Lighting already with reduced consumption in the BAU scenario has the potential to further reduce its consumption about 38% from 9 to 5 TWh by 2020 in the efficiency scenario (figure 66).

The savings reached by efficient air condition is very low (figure 66) and can only slow down the consumption growth curve a little. A reason might be the decision in the efficiency scenario to only consider the most efficient appliances in the market and not to take the possible development of the efficiency into account. But although it is expected that in the near future the standards are getting higher, this is assumed to be more than outweighed by the increase in the unit energy consumption due to the trend to bigger (split-) systems with higher cooling capacity and higher electricity consumption that have not been considered (Engineered Systems, 2000).

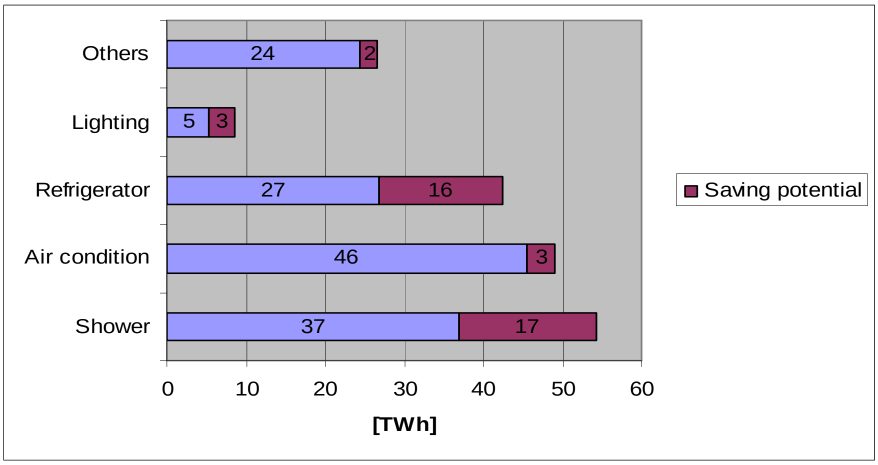


**Figure 65:** Saving potential by end uses in TWh

Source: Elaboration of author

It is notable that the water heating with the electric shower and the air conditioning has the strongest increase in the BAU scenario and overtake the consumption of the refrigerator (figure 66). The efficiency scenario can slow down the curve, in the case of the shower its decrease is considerably and the consumption by water heating falls beyond the curve of the air condition. An effect observed in the energy demand curves of the refrigerator and the lighting in the efficiency scenario is that at the beginning the efficiency measure slows down the demand, in the case of the lighting it even decreases. However after a few years, towards the end of the considered time frame in this study, the consumption curve begins to increase or even accelerate its increase respectively. This indicates that the construction activity is no more compensated by efficiency measures and that the consumption will begin to increase again. Once the market is refurbished with a lot of new and efficient equipment the saving potential is getting to zero until the market proved new and more efficient apparatus than the old one (figure 67 and 68). The curve of each end use is found in the annex f.

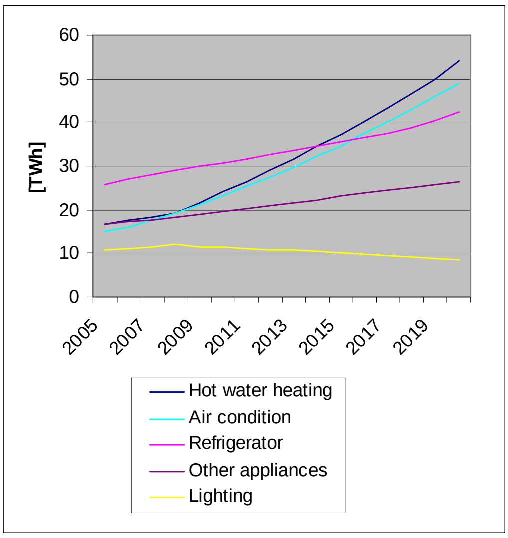


**Figure 66:** Projection of electricity consumption by end use of the building stock in the BAU scenario

Source: Elaboration of author

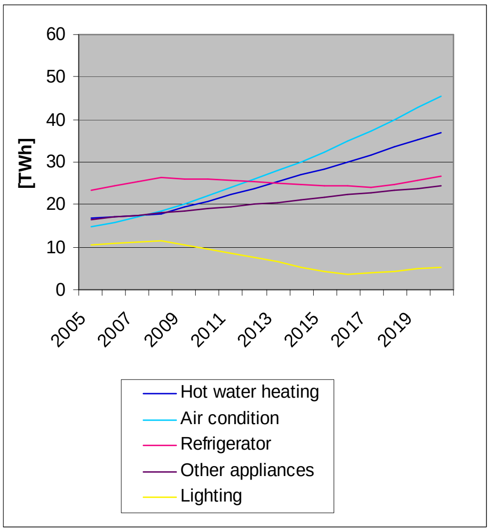


**Figure 67:** Projection of electricity consumption by end use of the building stock in the ES scenario

Source: Elaboration of author

Comparing the end uses in the BAU and in the ES there can be observed a few interesting points: in general there can be compared the efficiency measure due to their impact. E.g. comparing the energy demand for water heating and for air condition it can be observed that in the BAU scenario the energy demand of the shower stays higher as that of the air condition. And the energy demand of the two end uses almost develops in parallel. However in the ES the energy demand for water heating is less steep than the air condition curve and by 2020 the energy demand is already 10 TWH higher than that for water heating. In this case this could be an indicator that the efficiency replacement of electric shower by SWH has a high impact or that the efficiency measure of introducing more efficient appliances in the market has only a small effect. For sure this depends on penetration and the efficiency introduced. The saving potential in this scenario for air conditioning is relatively low compared with other saving potentials. This could also be indicator that the standards in air condition efficiency are very low and although applying very efficient air conditioners the saving potential is little due to low efficiency gain through new appliances.

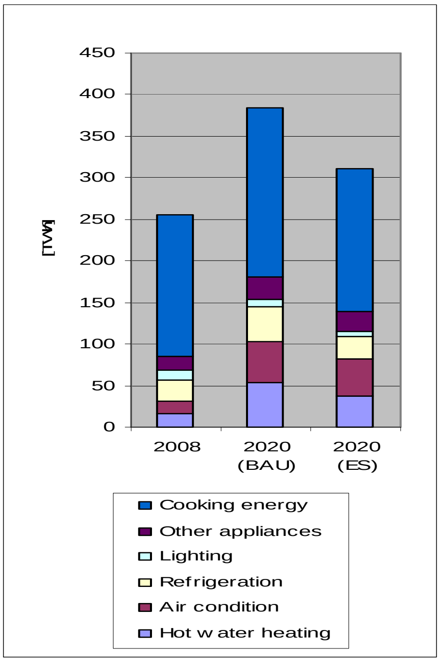


**Figure 68:** Energy demand of the building stock under the BAU and the ES scenario
Source: Elaboration of author

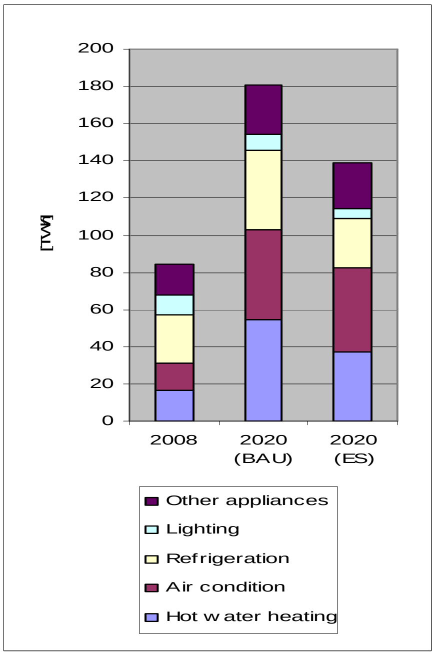


**Figure 69:** Electricity demand of the building stock under the BAU and the ES scenario
Source: Elaboration of author

Comparing the energy demand per building in the different scenarios it can be observed that in rural households the energy consumption diminishes from about 10 MWh per year to about 8,5 MWh per year. This is due to the 20% more efficient cook stoves. However due to lack of data it cannot be evaluated if this is a probable scenario. But due to the high consumption this would be an important field for further research. The savings in the other building types are more moderate (figure 69 and 70).

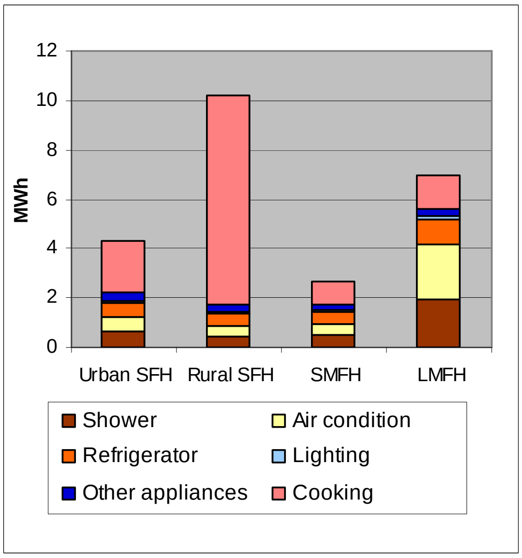


**Figure 70:** Energy demand under the BAU scenario by 2020 by building type
Source: Elaboration of author

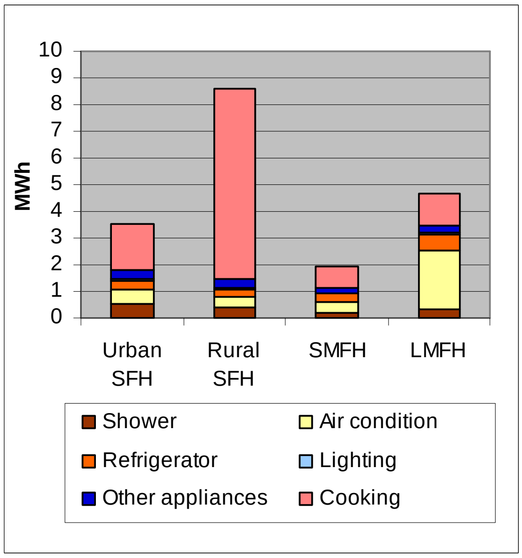


**Figure 71:** Energy demand under the ES scenario by 2020 by building type
Source: Elaboration of author

Comparing the electricity demand by building type there can be observed that the urban and rural SFH and the small MFH has more or less the same electricity consumption. This is due to high ownership rates in the large MFH, especially the shower and the air condition. It can be observed that more than two third of the electricity consumption is used by these two appliances. With the underlying assumption that the large MFH reflects the middle to higher class building and due to the higher purchase power of these households this can be seen as an indicator of the development of future electricity demand, driven by the electrical appliances purchased one after the other with rising income. Comparing the BAU scenario with the ES scenario it seems interesting that the amount of energy demanded by the end use air condition almost not changes although the most efficient air conditioner had been used for the ES. The reason is that apart from having used a more efficient system, reflecting actual trends, the refurbished system in the efficiency scenario are air conditioners to 50% with more cooling capacity than the old one (instead of a 2,9 kW air conditioner there is installed a 3,5 kW air conditioner). In this case the higher efficiency is outweighed by the higher consumption (figure 71 and 72).

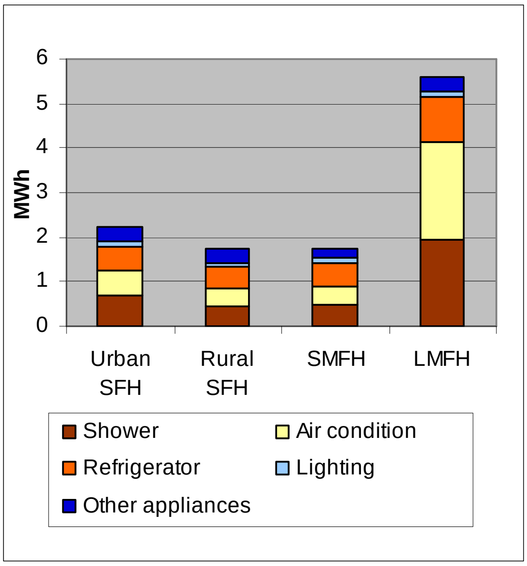


**Figure 72:** Energy demand under the BAU scenario by 2020 by building type

Source: Elaboration of author

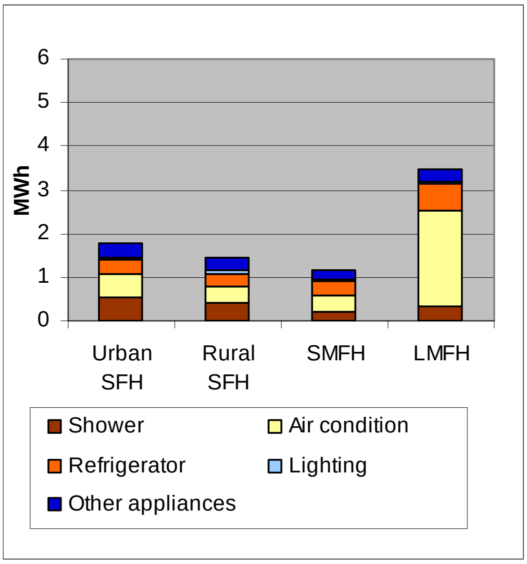


**Figure 73:** Energy demand under the ES scenario by 2020 by building type

Source: Elaboration of author

# 8. Discussion

## 8.1. Comparison to other studies

In Brazil there is being done a lot in the field of energy efficiency in buildings. The *Laboratory of Energy Efficiency in Buildings* (LABEEE) led by Professor Lamberts is surely the best known institution for energy efficiency related research in Brazil. Its investigation focus is rather deep case studies, such as efficiency strategies for specific buildings in a specific climate zone (LabEEE, 2010a). Results from these case studies cannot be compared with this report because of a different level of investigation. This report investigated the national potential of energy efficiency in the residential sector, therefore rather looking on generalities than specific details. The representative building described in the typology perhaps cannot be found anywhere in Brazil because it is an average house. But because of that it serves well for calculation purposes. Apart from these studies EPE and WWF both have studies containing energy demand in the future.

EPE makes projections of energy demand by 2030. Their model is based on macroeconomic data and with a clear focus on the supply side. The data is not broken down to end uses and but stays on a sector level (MME, 2007b). It is interesting that despise a different approach the forecasted electricity demand for 2020 in Brazil is according to EPE (distinguished by different scenarios) between 150 and 176 TWh (MME, 2007b). Compared to the findings of this thesis research with a range between 181 TWh for the BAU and 149 TWh for the efficiency scenario it seems that the forecasted energy consumption based on modeled end uses in this research produce similar results. However there are few points were the EPE study differs considerably from this thesis research. EPE does neither take into account the development in the building sector nor developments on unit energy consumption of appliances.

In this report the underlying main drivers for energy consumption are the ownership rate, the construction activities and the unit energy consumption (calculated by the capacity and operation time). The forecast is made on the base of linear or logistic regression of historic development ownership rate development. Future trends are expected to follow actual trends more or less. Comparing the ownership forecast of the thesis with that from EPE there is found some important difference. The ownership rate assumed by EPE is much lower as the ones in this thesis report, although they are taken from the same source (MME, 2007b; PROCEL/Eletrobrás, 2007).

Another study that focuses on energy efficiency in Brazil is from WWF (WWF - Brasil, 2007). It investigates the demand and the supply side options to reduce energy consumption and GHG emissions for Brazil. The BAU scenario from the WWF report projects a total energy demand of 172 TWh by 2020 (WWF - Brasil, 2007). This projection stays about five percent under the projection from this thesis research. The WWF report was realized with data from BEN from the year 2005, whereas this study included the fast increase from 2005 until 2008 in its forecast. In this three years electricity consumption increased from 83 TWh to 96 TWh that is 16% in 3 years (EPE, 2009a). Taking into account this development the BAU scenario from this thesis report may be rather conservative compared to the WWF projection.

The WWF study makes assumptions on what it calls “realistic technical potential”. The underlying assumption for the forecast is that appliances are not substituted before the end of their real life time and the rate of introduction of more efficient appliances is based on experience in comparable countries. Unfortunately it is note revealed what that means in detail in the study. That is the reason that the following comparison has to stay on a superficial level because of the impossibility to analyze the assumptions that lead to the results. That makes it impossible to compare the methodological approach of the two reports more detailed. On the other hand however the two studies consider the same period (until 2020) and develop similar scenarios what makes it interesting to compare the results. Similar to this thesis research WWF develops also an efficiency scenario (which they call Power Switch) and evaluates the replacement of electric showers by solar water heating and the introduction of more efficient appliances. In contrast to this thesis the WWF report considers machines and they do not consider cooking energy demand.

The replacement of electric showers through solar water heaters according to the WWF report comes to a possible saving potential of 27 TWh compared to 17 TWh in the thesis study. This seems quite high; due to the challenging assumptions for the efficiency scenario of this report (all new buildings in Brazil are equipped with solar water heater instead of electric showers). But also the assumed solar fraction plays a role for the saving potential. In this report, due to a rather conservative assumption for

Brazil (50-60% according to building type), the calculated saving potential may be still too low.

Other notable differences of the reports are the energy demand and the saving potential of air conditioners and lighting in both scenarios. In this study the lighting has already considerable decreased energy demand under the BAU scenario in comparison to the WWF study. This is due to the assumption on the refurbishment rate of the stock and the fact that already about 20% of the stock had been using efficient lambs in the reference year 2005. This thesis already takes into account a relatively high refurbishment rate of the lamps due a short lifetime of incandescent light bulbs.

In contrast to a lower projection of energy consumption through lighting, this thesis study projects much higher the energy consumption by air conditioners in 2020 in comparison to the WWF report. According to the efficiency scenario of this report, the air conditioner stock in Brazil will consume more energy than any other appliance. This may be originated in the assumptions made. The maximum efficiency applied in the efficiency scenario was equal the maximum efficiency available in the market in the moment of the research (May 2010), not considering further improvements that are likely to happen. Apart from that, the methodological approach of this thesis are also a potential cause of these differences.

## 8.2. Reflection on methodology and uncertainties

The methodology in this thesis was developed as a result of the data needed and the data available. To better understand how the thesis report comes to its results of the energy saving potential the methodology will be reflected.

In the beginning the report presented the methodology and its four main steps to be realized in order to develop the scenarios (item 1.7). The juncture between the building stock in Brazil and the energy consumption in these buildings was the survey from PROCEL in 2005 (marked yellow in the methodology plan). This is the only study that has available data on size of dwellings (in m²), number of habitants and family income distinguished per range of electricity consumption. This facilitated to establish important relations for the determination of the electricity consumption of the building types. On base of that three variables mentioned there was determined the electricity consumption of the different building types. The calibration of the model revealed that PROCEL overestimated the electricity consumption by almost 37%. Therefore it was introduced a correction factor for the energy projection of the building. After adjusting the data (described in item 4.4.) the building types with their related energy consumption were validated. It is very important to consider that the base of the further process of defining reference buildings for the development of the scenarios is the PROCEL study; in providing data on the electricity consumption in function of inhabitants, constructed area and income. This study is the connection point between building typology and energy consumption in the buildings and therefore a crucial juncture. Its quality was validated with top down data from the *National Energy Balance* (BEN).

The second most important information, also from the PROCEL study was data on the share of each end use (such as shower, air condition etc.) in the total electricity consumption. Apart from PROCEL there is no other data available on that. The first insecurity on that data is that this data was not measured but based on interviews. In the case of refrigerators an error was evident. Its annual unit energy consumption based on the calculation of the share in the total electricity consumption, 22% in 2005 divided by the total number of refrigerators in Brazilian (derived from the ownership rate, given by PROCEL) is much too low and with an average unit energy consumption value, found in case studies and in the data provided by INMETRO, it became clear that the share given by PROCEL (22% for refrigerators) was too low, or the other indicator, the ownership rate (the number of refrigerators), was too high.

Here the problem becomes evident. Due to the limited possibilities to validate data with data from other sources it is almost impossible to validate the information. In the case of the refrigerators it was assumed that the average value found in case studies and given by INMETRO were right and due to no other information on ownership rates this were assumed to be correct with the conclusion that the share of the refrigerator electricity consumption must be higher as 22% given by the PROCEL study. This directly provokes the next problem. If the share of refrigerators is more than predicted by PROCEL, than which other end use has a too high share? In this case the projection was kept and further calculation were base on it because the deviation was not too high and also because due to the lack of data.

A third and very crucial point for future energy demand was the forecasting of the ownership rates. Apart from the unit energy consumption and the activity (number of dwellings and new constructions), the ownership rate forecast is determining the development of an energy scenario. Due to lack of more data the ownership forecast was based only on two surveys and therefore afflicted with insecurity. The future development of the curve had to be assumed taking into account the actual trend without knowing if the actual growth is slowing down, staying equal or increasing. The decision on that was done with the help of the actual ownership rate, assuming that high ownership rates, although still growing has a decreasing growth rate. This was assumed for all appliances with exception of the air condition which ownership rate was assumed at least to grow linear. A sensitivity analysis showed that already with a small difference on the assumption of the further development of the grow rate the deviation was more than 10% in 2020. However there is a lack of specific data in Brazil to prove this.

This reveals the great dependence on data from the PROCEL study. In order to secure the quality of the results there had been made validation of the output of every main step in the thesis, whenever possible with top down values from the IBGE and EPE. This was discussed at the end of each chapter.

The calculation of the reference and efficiency scenario was made on the base of reference buildings. First the buildings have been equipped with appliances based on average values but considering different income levels in different building types. For example the large multi family building type was equipped with high consumption appliances (more powerful and expensive) and it was assumed that in this building type the ownership rate is higher due to higher purchase power. In contrast the rural single family house was equipped with less powerful appliances and the ownership rate was assumed to be lower because of less purchase power.

Second, to develop a scenario the information on the unit energy consumption of the appliance is needed. With the exception of refrigerators there was no information available on the energy unit consumption. So this had to be calculated by the product of capacity and operation time. It was decided to calculate the operation time for every appliance once for the reference year 2005. Further it was assumed that the operation time (for example, the time a person takes a shower) a) in the future and today does not differ much and b) is not very sensible to the income level. Therefore the operation time was set equal for all building types for a specific appliance for the whole scenario.

Apart from the electricity demand by 2020 there was calculated the cooking energy, in the present responsible for two third of the energy consumption and therefore the main end use consumer of energy, exclusively gas and firewood according to BEN. The forecast on cooking energy demand was quite a challenge due to lack of data. The

BEN only differentiates between cooking energy disaggregated by gas and firewood (mainly). The sum of the energy that is no electricity is defined as cooking energy in the BEN, leaving out gas, used for showering e.g.. Due to lack of data it is not possible to know how many efficient respective not efficient stoves are used. More detailed information on the type of firewood stove (with chimney or not, open or closed fireplace, etc.) and on the condition of the fuel wood (e.g. moisture content) are factors with strong influence on the efficiency and energy demand, but this data was not available.

Therefore it was decided to establish a ratio of the electricity (non-cooking) and cooking energy consumption for the different building types based on the reference year 2005 and permitting to calculate the demand of cooking energy in function of electricity demand. Averages of these correlation factors were calculated for each building type. These correlation factors were based on the assumptions a) that in Brazil in average a firewood stove is about seven times less efficient than a gas stove and b) on scenarios of the distribution of the different constellations in Brazilian dwellings (only firewood -, only gas – and firewood and gas stove). For the efficient scenarios there were assumed refurbishment rates and general efficiency improvements. However due to unknown parameters the probability of these scenario is not known.

# 9. Conclusion and desiderata

The analysis presented in this report advances the understanding of sources of actual and future energy demand in the residential sector in Brazil. To produce results there have been realized various steps. First it was characterized the actual building stock of Brazil and developed a building typology weighted by occurrence. To know the energy demand by building type there had to be developed a method to calculate a) the electricity demand on base of income, inhabitants and size and b) the cooking energy demand. Due to the importance of this data output for the next step, the data had to be calibrated first. On that base there have been determined reference houses and together with main drivers of energy demand there had been created a BAU and an efficiency scenario.

This thesis developed a methodological framework that permits energy forecasts for different building types something that has not been done in Brazil on nationwide level yet. By providing calculation methods for each step in the development of the scenario the thesis provides also a useful tool for future research. More detailed data on the parameters can only improve the results.

In general the thesis presented a consistent and robust framework of national level demand forecasting for the residential building stock, which separates the drivers of energy demand from intensity. However in this thesis there were not developed different scenarios on base of different assumptions on the activity parameter (number of dwellings). But the separation of these parameters is believed to be a critical step in developing comprehensive strategy of national energy demand management which is becoming more necessary urgent every day, not only for Brazil.

Ultimately, the value of an analysis such as presented in this report will be measured by its use in subsequent research for energy demand in residential buildings in Brazil. The analytical framework presented in detail here can be of big help toward the development of detailed, realistic and robust energy efficiency scenarios for Brazil. This kind of scenarios can be developed by applying various measures, as e.g. high efficiency technology options at the level of end use providing the analytical elements for a comprehensive energy strategy for Brazil however with a good sound standing base.

The thesis always intended to use a wide array of available data and also in the most detailed level possible. It seems that the greatest gaps in data availability arise from a lack of accurate statistics. In this sense, the report can help to highlight areas where data would be really needed but is not available and big gains could be made through more detailed data or completing existing statistical data on some indicators to generate new data sources. It was found that the residential sector lacks consistent data reporting from national source, specifically on the building stock on a detailed level and also the electricity consumption. The PROCEL study cannot be appreciated enough. Without this study Brazil would have almost no clue about the energy demand in residential sector in the detail available. As discussed the study has some weaknesses could be further improved. Similar studies could help to improve the data quality and amplify the very thin database.

Last, only a few data points were found to forecast the ownership rate of appliances and on unit energy consumption per appliances types, little is known on their hour of use and typical lifetime. Same is true for the end use coking energy. Although the share of cooking energy will be decreased by 2020 to half the energy consumption this still we be a large part and therefore deserves more attention than it deserves at the moment. Future data collection on these issues will allow refining the energy use breakdown matrix developed in this report for Brazil.

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# Annex A - Energy efficiency in Brazil

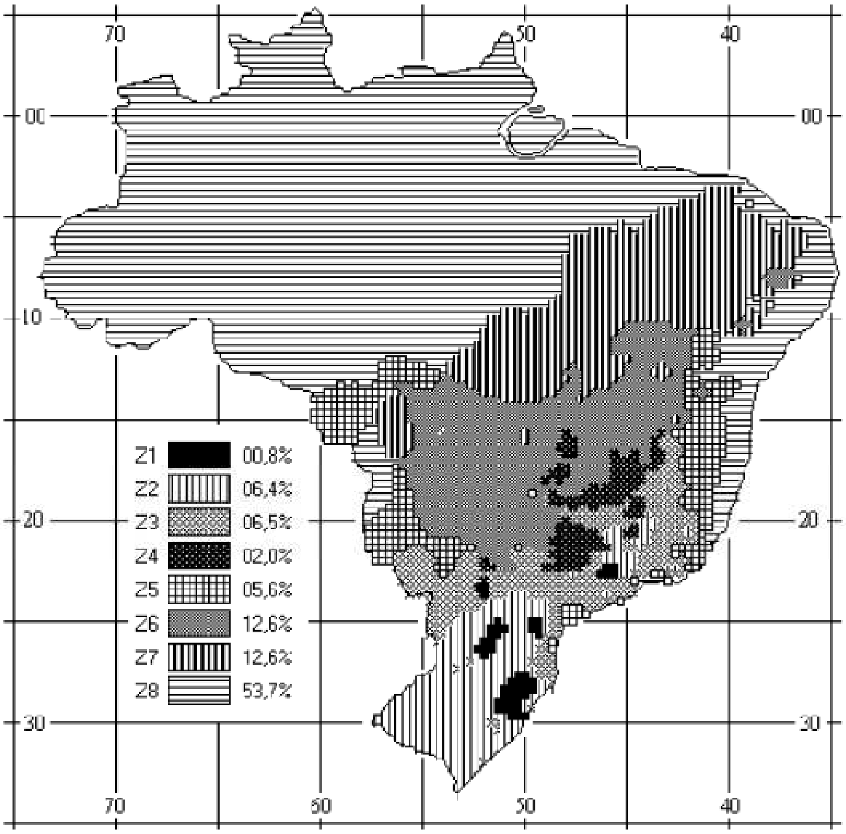


**Figure 74:** Bioclimatic zoning of Brazil
Source: NBR 15220 -3 (ABNT, 2005)

**Table 42:** Opening area for ventilation and windows shading to each zone

| Zone | **Opening are for ventilation** (“A”, in percentage of floor areas) | Window shading |
|---|---|---|
| 1 | Medium: 15% < A < 25% | Allow sun during the cold period |
| 2 and 3 | Medium: 15% < A < 25% | Allow sun during the cold period |
| 4,5 and 6 | Medium: 15% < A < 25% | Shadow on the windows |
| 7 | Shall: 10% < A < 15% | Shadow on the windows |
| 8 | Large: A > 40% | Shadow on the windows |

Source: Source: NBR 15220 -3 (ABNT, 2005)

**Table 43:** Thermal transmittance, thermal delay and solar heat factor for walls and roofs to each zone

| Zone | External components | U-value (W/m2.K) | Thermal delay (φ, h) | SHF (%) |
|---|---|---|---|---|
| 1 and 2 | Wall: Light | U≤ 3.00 | φ ≤ 4.3 | SHF ≤ 5.0 |
| | Roof: Light and insulated | U≤ 2.00 | φ ≤ 3.3 | SHF ≤ 6.5 |
| 3 and 5 | Wall: Light and reflective | U≤ 3.60 | φ ≤ 4.3 | SHF ≤ 4.0 |
| | Roof: Light and insulated | U≤ 2.00 | φ ≤ 3.3 | SHF ≤ 6.5 |
| 4 and 6 | Wall: Light and insulated | U≤ 2.20 | Φ ≥ 6.5 | SHF ≤ 3.5 |
| | Roof: Light and insulated | U≤ 2.00 | φ ≤ 3.3 | SHF ≤ 6.5 |
| 7 | Wall: Heavy | U≤ 2.20 | Φ ≥ 6.5 | SHF ≤ 3.5 |
| | Roof: Heavy | U≤ 2.00 | Φ ≥ 6.5 | SHF ≤ 6.5 |
| 8 | Wall: Light and reflective | U≤ 3.60 | φ ≤ 4.3 | SHF ≤ 4.0 |
| | Roof: Light and reflective | U≤ 2.30xFT* | φ ≤ 3.3 | SHF ≤ 6.5 |

*FH is the factor that allows higher U-values when attic ventilation is guaranteed (ANBT, 1998)

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# Annex B - Building stock in Brazil

**Table 44:** Development of the number of apartments in Sao Paulo

| Year | Total | 0 or 1 | | | 2,0 | | | 3,0 | | | 4,0 | | | 5 ou + | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | # | % | $m^2$ | # | % | $m^2$ | # | % | m2 | # | % | m2 | # | % | m2 |
| 2000 | 28 631 | 4931,0 | 17,2 | 41,3 | 13007,0 | 45,4 | 57,2 | 7921,0 | 27,7 | 91,8 | 2697,0 | 9,4 | 213,1 | 75,0 | 0,3 | 546,8 |
| 2001 | 21 688 | 3492,0 | 16,1 | 38,6 | 8938,0 | 41,2 | 56,4 | 6764,0 | 31,2 | 85,9 | 2480,0 | 11,4 | 220,9 | 14,0 | 0,1 | 447,1 |
| 2002 | 20 243 | 1904,0 | 9,4 | 44,1 | 7711,0 | 38,1 | 65,7 | 5390,0 | 26,6 | 98,8 | 5193,0 | 25,7 | 197,3 | 45,0 | 0,2 | 758,6 |
| 2003 | 24 426 | 3115,0 | 12,8 | 41,3 | 8726,0 | 35,7 | 70,2 | 8137,0 | 33,3 | 107,2 | 4424,0 | 18,1 | 192,2 | 24,0 | 0,1 | 600,0 |
| 2004 | 19 720 | 1141,0 | 5,8 | 66,7 | 7725,0 | 39,2 | 66,3 | 6211,0 | 31,5 | 104,1 | 4588,0 | 23,3 | 214,6 | 55,0 | 0,3 | 690,1 |
| 2005 | 23 541 | 1746,0 | 7,4 | 58,9 | 6951,0 | 29,5 | 60,7 | 8229,0 | 35,0 | 95,8 | 6572,0 | 27,9 | 210,4 | 43,0 | 0,2 | 337,3 |
| 2006 | 19 862 | 959,0 | 4,8 | 45,7 | 6340,0 | 31,9 | 57,7 | 5995,0 | 29,7 | 92,7 | 6519,0 | 32,8 | 209,6 | 149,0 | 0,8 | 914,1 |
| 2007 | 37 107 | 534,0 | 1,4 | 67,2 | 11775,0 | 31,7 | 56,9 | 11699,0 | 31,5 | 86,9 | 13054,0 | 35,2 | 188,5 | 45,0 | 0,1 | 390,8 |

Source: Elaboration of author on base of EMBRAESP

**Table 45:** Calculation of average constructed area of buildings

| **Categories of constructed area [sqm]** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| <50 m² | 51-75 m² | 76-100 m² | 101-150 m² | 151-200 m² | >200 m² | | | | | |
| **Mean values [sqm]** | | | | | | | | | | |
| 40 | 62 | 85 | 120 | 170 | 210 | no data (n.d.) | total | % total | total excl. n.d. | average [sqm] |
| **Number of dwellings** | | | | | | | | | | |
| 232 | 240 | 67 | 10 | 6 | 0 | 101 | 656 | 15,2 | 555 | 48,9 |
| 202 | 452 | 106 | 32 | 9 | 4 | 147 | 952 | 22,1 | 805 | 53,9 |
| 195 | 493 | 311 | 70 | 18 | 13 | 231 | 1331 | 30,9 | 1100 | 59,3 |
| 78 | 257 | 192 | 70 | 22 | 13 | 90 | 722 | 16,8 | 632 | 69,6 |
| 27 | 104 | 101 | 69 | 21 | 26 | 54 | 402 | 9,3 | 348 | 83,1 |
| 12 | 50 | 38 | 57 | 23 | 35 | 32 | 247 | 5,7 | 215 | 100,9 |
| 746 | 1596 | 815 | 308 | 99 | 91 | 655 | 4310 | 100,0 | 3655 | |
| **% dwellings/consumption category (detailed)** | | | | | | | | | | |
| 35,4 | 36,6 | 10,2 | 1,5 | 0,9 | 0,0 | 15,4 | | 100,0 | | |
| 21,2 | 47,5 | 11,1 | 3,4 | 0,9 | 0,4 | 15,4 | | 100,0 | | |
| 14,7 | 37,0 | 23,4 | 5,3 | 1,4 | 1,0 | 17,4 | | 100,0 | | |
| 10,8 | 35,6 | 26,6 | 9,7 | 3,0 | 1,8 | 12,5 | | 100,0 | | |
| 6,7 | 25,9 | 25,1 | 17,2 | 5,2 | 6,5 | 13,4 | | 100,0 | | |
| 4,9 | 20,2 | 15,4 | 23,1 | 9,3 | 14,2 | 13,0 | | 100,0 | | |
| **% dwellings/constructed area category** | | | | | | | | | | |
| 17,3 | 37,0 | 18,9 | 7,1 | 2,3 | 2,1 | 15,2 | | | | 74 |
| **% dwellings/constructed area category, excluded n.d.** | | | | | | | | | | |
| 20,4 | 43,7 | 22,3 | 8,4 | 2,7 | 2,5 | excluded | | 100,0 | | 74 |

Elaboration of author on base of (PROCEL, 2007)

**Table 46:** Development of building typology (Ranges from PROCEL, Model 1,3 and 4 are the base for the urban single family house)

| | **6 ranges from PROCEL** | | | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** |
| **Characteristics** | | | | | | |
| **Typology** | **Unifamilar (low class)** | **unifamilar (low class, rural)** | **Unifamilar (middleclass)** | **unifamilar (high class)** | **apartment, low class (4 floors, 16 units)** | **apartment, middle (16 floors, 32 units)** |
| Area of unit [$m^2$] | 56 | 56 | 85 | 146 | 56 | 137 |
| Number of dwellings per building | 1 | 1 | 1 | 1 | 16 | 32 |
| Number of rooms | 2 | 3 | 3 | 4 | 2 | 3 |
| Family income | 3 | 2 | 5 | 14 | 3 | 12 |
| Number of habitants | 3 | 4 | 3 | 4 | 3 | 3 |
| Significance in residential sector only within unifamilar bloque [%] (SINPHA) | 64,1 | | 22,3 | 13,6 | | |
| Significance in residential sector including rural, shifitng 15% to rural [%] (SINPHA) | 54,4 | 15,0 | 18,9 | 11,6 | | |
| Significance in residential sector only within apartment bloque [%] (no data) | | | | | 80 | 20 |
| Overall significance in residential sector (considering overall distribution of apartments (10,9%) and of houses (89,1%)) [%] | 48,5 | 13,4 | 16,9 | 10,3 | 8,7 | 2,2 |
| Signifcance [%] (correction rural) | 47,5 | 15,0 | 16,5 | 10,1 | 8,7 | 2,2 |

Source: Elaboration of author

**Table 47:** Consolidation of PROCEL ranges in building types

| New Building typology | SFH urban | SFH rural | MFH small | MFH large |
|---|---|---|---|---|
| Occurence | 74,1% | 15,0% | 8,7% | 2,2% |
| Area of unit [$m^2$] | 74,78 | 56,00 | 56,00 | 137,00 |
| Number of habitants | 3,1 | 4,00 | 3,00 | 3,00 |
| Income [mutliply minimal salary] | 4,9 | 2,0 | 3,0 | 12,0 |

Source: Elaboration of author

**Table 48:** Population and dwellings in Brazil

| By regions 2008 | | Mayor regions | | | | | Metropolitan area | |
|---|---|---|---|---|---|---|---|---|
| | Brazil | North | North-east | South-east | South | Mid-west | Rio de Janeiro | Sao Paolo |
| Population [%] | 100 | 8 | 28,2 | 42 | 14,5 | 7,3 | 6,1 | 10,3 |
| Urban [%] | 83,8 | 78 | 72,4 | 92,1 | 83 | 87,7 | 99,4 | 95,5 |
| Rural [%] | 16,2 | 22 | 27,6 | 7,9 | 17 | 12,3 | 0,6 | 4,5 |
| Dwelling [%] | 100 | 7 | 26 | 44 | 15,6 | 7,4 | 6,8 | 10,8 |
| House [%] | 89,11 | 95,7 | 93,3 | 85,8 | 87,6 | 91,2 | 75 | 81,1 |
| Apartment [%] | 10,6 | 3,3 | 6,3 | 14 | 12,3 | 8,2 | 24,5 | 18,7 |
| Room [%] | 0,3 | 1 | 0,4 | 0,2 | 0,1 | 0,6 | 0,5 | 0,2 |
| Average habitant [number] | 3,3 | 3,8 | 3,6 | 3,1 | 3,1 | 3,2 | 3 | 3,1 |

Source: Elaboration of author (PNAD 2008)

**Table 49:** Age structure of building stock

| age structure (raw data) | before 1919 | 1920-1949 | 1950-1959 | 1960-1969 | 1970-1979 | 1980-1989 | 1990-1999 | 2000-2008 | total |
|---|---|---|---|---|---|---|---|---|---|
| [%] | 0,18 | 5,12 | 7,33 | 9,41 | 16,79 | 22,74 | 26,66 | 11,76 | 100,00 |
| projection (2005) | 97.883 | 2.716.255 | 3.890.852 | 4.992.036 | 8.907.359 | 12.064.088 | 14.144.103 | 6.240.045 | 53.052.621 |
| projection incl 2006-2008 dwellings | 97.883 | 2.716.255 | 3.890.852 | 4.992.036 | 8.907.359 | 12.064.088 | 14.144.103 | 10.843.424 | 57.656.000 |
| total qm [average 74] | 7.045.882 | 195.523.239 | 280.073.828 | 359.340.006 | 641.175.305 | 868.405.014 | 1.018.130.017 | 780.538.431 | 4.150.231.722 |
| Anteil 2008 [%] | 0,17% | 4,71% | 6,75% | 8,66% | 15,45% | 20,92% | 24,53% | 18,81% | 100% |

Source: Elaboration of author (PROCEL 2007)

# Annex C - Energy consumption disaggregated by building type

**Table 50:** Electricity consumption in function of constructed area

| | | Categories of constructed area [sqm] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <50 $m^2$ | 51-75 $m^2$ | 76-100 $m^2$ | 101-150 $m^2$ | 151-200 $m^2$ | >200 $m^2$ | | | | | |
| | | **Mean values [sqm]** | | | | | | | | | | |
| | | 40 | 62 | 85 | 120 | 170 | 210 | no data (n.d.) | total | % total | total excl. n.d. | average [sqm] |
| **Consumption category [kWh/month]** | **Mean values [kWh/month]** | **Number of dwellings** | | | | | | | | | | |
| 0-50 | 40 | 232 | 240 | 67 | 10 | 6 | 0 | 101 | 656 | 15,2 | 555 | 48,9 |
| 51-100 | 75 | 202 | 452 | 106 | 32 | 9 | 4 | 147 | 952 | 22,1 | 805 | 53,9 |
| 101-200 | 150 | 195 | 493 | 311 | 70 | 18 | 13 | 231 | 1331 | 30,9 | 1100 | 59,3 |
| 201-300 | 250 | 78 | 257 | 192 | 70 | 22 | 13 | 90 | 722 | 16,8 | 632 | 69,6 |
| 301-500 | 400 | 27 | 104 | 101 | 69 | 21 | 26 | 54 | 402 | 9,3 | 348 | 83,1 |
| >500 | 550 | 12 | 50 | 38 | 57 | 23 | 35 | 32 | 247 | 5,7 | 215 | 100,9 |
| total | | 746 | 1596 | 815 | 308 | 99 | 91 | 655 | 4310 | 100,0 | 3655 | |
| | | **% dwellings/consumption category (detailed)** | | | | | | | | | | |
| 0-50 | 40 | 35,4 | 36,6 | 10,2 | 1,5 | 0,9 | 0,0 | 15,4 | | 100,0 | | |
| 51-100 | 75 | 21,2 | 47,5 | 11,1 | 3,4 | 0,9 | 0,4 | 15,4 | | 100,0 | | |
| 101-200 | 150 | 14,7 | 37,0 | 23,4 | 5,3 | 1,4 | 1,0 | 17,4 | | 100,0 | | |
| 201-300 | 250 | 10,8 | 35,6 | 26,6 | 9,7 | 3,0 | 1,8 | 12,5 | | 100,0 | | |
| 301-500 | 400 | 6,7 | 25,9 | 25,1 | 17,2 | 5,2 | 6,5 | 13,4 | | 100,0 | | |
| >500 | 550 | 4,9 | 20,2 | 15,4 | 23,1 | 9,3 | 14,2 | 13,0 | | 100,0 | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * source: (SINPHA) | | | | | | | | | | | | |
| | | **% dwellings/constructed area category** | | | | | | | | | | |
| | | 17,3 | 37,0 | 18,9 | 7,1 | 2,3 | 2,1 | 15,2 | | | | 74 |
| | | **% dwellings/constructed area category, excluded n.d.** | | | | | | | | | | |
| | | 20,4 | 43,7 | 22,3 | 8,4 | 2,7 | 2,5 | exclude d | | 100,0 | | 74 |

Source: Elaboration of author

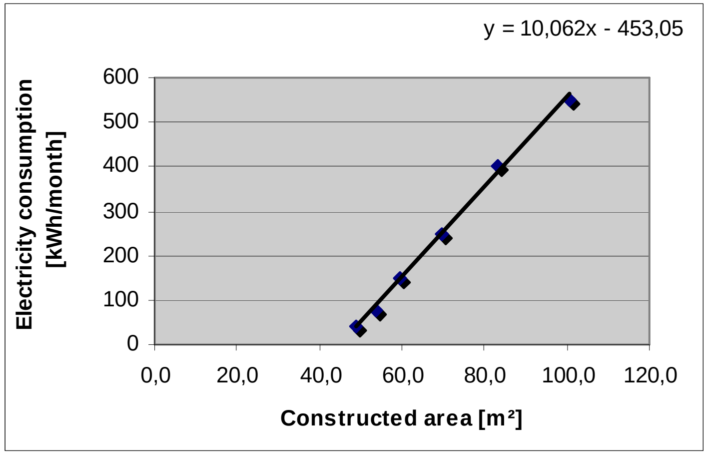


**Figure 75:** Linear regression

Source: Elaboration of author

**Table 51:** Electricity consumption in function of minimum income

| | | Minimum income (415R$, PNAD 2008, but reference year 2005!) [factor] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Consumption category [kWh/month]** | **Mean values [kWh/month]** | 0,5 | 1,5 | 2,5 | 3,5 | 4,5 | 6 | 8,5 | 12,5 | 17,5 | 25 | 35 | 45 | n.d. | **total excl. n.d.)** | **total income** | **average** |
| 0-50 | 40 | 85 | 177 | 89 | 74 | 48 | 27 | 15 | 2 | 3 | 1 | 0 | 0 | 135 | 521 | 1398 | 2,7 |
| 51-100 | 75 | 59 | 202 | 133 | 131 | 95 | 73 | 36 | 5 | 1 | 1 | 0 | 0 | 216 | 736 | 2400 | 3,3 |
| 101-200 | 150 | 29 | 162 | 173 | 141 | 140 | 162 | 111 | 29 | 10 | 5 | 2 | 1 | 366 | 965 | 4507 | 4,7 |
| 201-300 | 250 | 4 | 43 | 61 | 79 | 75 | 106 | 88 | 37 | 18 | 8 | 2 | 0 | 201 | 521 | 3265 | 6,3 |
| 301-500 | 400 | 2 | 12 | 22 | 19 | 44 | 38 | 45 | 33 | 21 | 7 | 4 | 0 | 155 | 247 | 2044 | 8,3 |
| >500 | 550 | 2 | 5 | 8 | 12 | 12 | 22 | 20 | 23 | 20 | 9 | 5 | 3 | 106 | 141 | 1599 | 11,3 |
| | | **% minimum income / consumption category** | | | | | | | | | | | | | 3131 | 15212 | 4,9 |
| 0-50 | 40 | 16,3 | 34,0 | 17,1 | 14,2 | 9,2 | 5,2 | 2,9 | 0,4 | 0,6 | 0,2 | 0,0 | 0,0 | 25,9 | 100,0 | | |
| 51-100 | 75 | 8,0 | 27,4 | 18,1 | 17,8 | 12,9 | 9,9 | 4,9 | 0,7 | 0,1 | 0,1 | 0,0 | 0,0 | 29,3 | 100,0 | | |
| 101-200 | 150 | 3,0 | 16,8 | 17,9 | 14,6 | 14,5 | 16,8 | 11,5 | 3,0 | 1,0 | 0,5 | 0,2 | 0,1 | 37,9 | 100,0 | | |
| 201-300 | 250 | 0,8 | 8,3 | 11,7 | 15,2 | 14,4 | 20,3 | 16,9 | 7,1 | 3,5 | 1,5 | 0,4 | 0,0 | 38,6 | 100,0 | | |
| 301-500 | 400 | 0,8 | 4,9 | 8,9 | 7,7 | 17,8 | 15,4 | 18,2 | 13,4 | 8,5 | 2,8 | 1,6 | 0,0 | 62,8 | 100,0 | | |
| >500 | 550 | 1,4 | 3,5 | 5,7 | 8,5 | 8,5 | 15,6 | 14,2 | 16,3 | 14,2 | 6,4 | 3,5 | 2,1 | 75,2 | 100,0 | | |
| | | **total/income range** | | | | | | | | | | | | | | | |
| | | 181 | 601 | 486 | 456 | 414 | 428 | 315 | 129 | 73 | 31 | 13 | 4 | 1179 | | | |
| | | **% of income range** | | | | | | | | | | | | | | | |
| | | 5,8 | 19,2 | 15,5 | 14,6 | 13,2 | 13,7 | 10,1 | 4,1 | 2,3 | 1,0 | 0,4 | 0,1 | | 100,0 | | |

Source: Elaboration of author

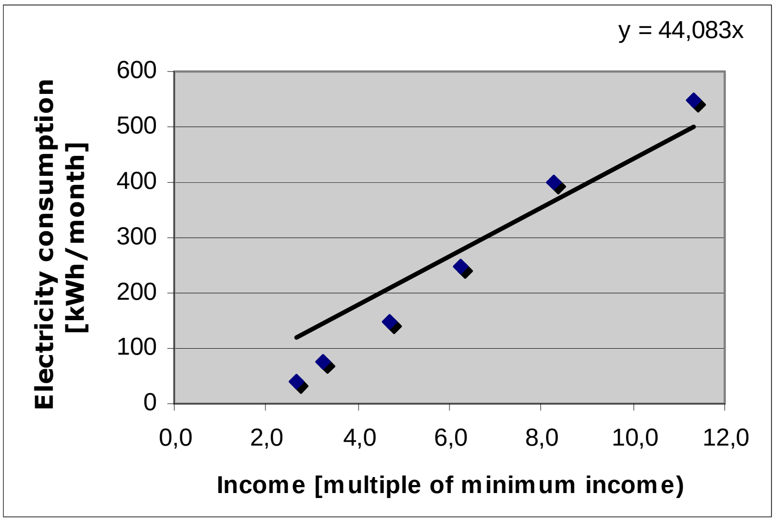


**Figure 76:** Linear regression - Electricity consumption in function of minimum income

Source: Elaboration of author

**Table 52:** Electricity consumption in function of inhabitants

| | | Number of habitants | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Consumption category [kWh/month]** | **Mean values [kWh/month]** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | **total households** | **total habitants** | **average** |
| 0-50 | 40 | 132 | 209 | 132 | 102 | 42 | 21 | 9 | 4 | 1 | 4 | 656 | 1834 | 2,8 |
| 51-100 | 75 | 120 | 277 | 270 | 166 | 72 | 23 | 10 | 6 | 6 | 2 | 952 | 2838 | 3,0 |
| 101-200 | 150 | 59 | 278 | 459 | 315 | 129 | 46 | 22 | 14 | 4 | 5 | 1331 | 4525 | 3,4 |
| 201-300 | 250 | 36 | 116 | 201 | 197 | 104 | 41 | 14 | 8 | 0 | 5 | 722 | 2637 | 3,7 |
| 301-500 | 400 | 10 | 36 | 101 | 126 | 74 | 33 | 14 | 3 | 2 | 3 | 402 | 1627 | 4,0 |
| >500 | 550 | 11 | 36 | 38 | 87 | 49 | 12 | 7 | 2 | 2 | 3 | 247 | 975 | 3,9 |
| | | **Total cases per habitant** | | | | | | | | | | | | |
| | | 368 | 952 | 1201 | 993 | 470 | 176 | 76 | 37 | 15 | 22 | 4310 | 14436 | 3,3 |
| | | **%** | | | | | | | | | | | | |
| | | 8,5 | 22,1 | 27,9 | 23,0 | 10,9 | 4,1 | 1,8 | 0,9 | 0,3 | 0,5 | | | |

Source: Elaboration of author

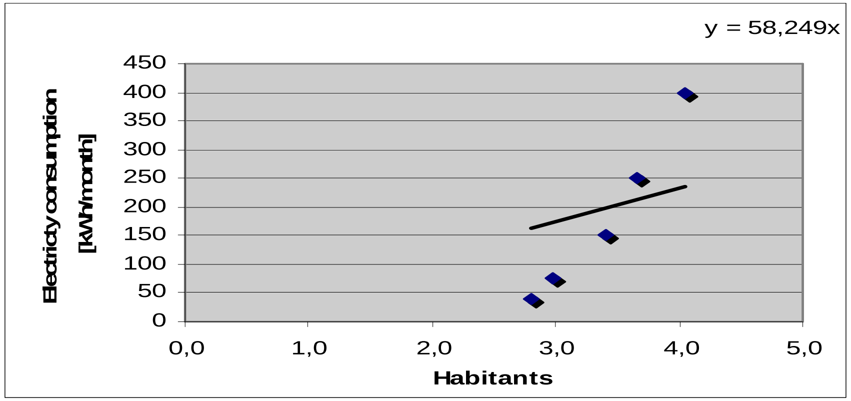


**Figure 77:** Linear regression - Electricity consumption in function of inhabitants
Source: Elaboration of author

**Table 53:** Calculation sheet for the energy consumption of Brazilian households

| Line | Model | 1 | ... |
|---|---|---|---|
| Line 1 | Area [$m^2$] | | |
| Line 2 | Factor a | | |
| Line 3 | Partial consumption a | | |
| Line 4 | Inhabitants [number] | | |
| Line 5 | Factor h | | |
| Line 6 | Partial consumption h | | |
| Line 7 | Income [MI] | | |
| Line 8 | Factor i | | |
| Line 9 | Partial consumption I | | |
| Line 10 | Electricity (El) [kWh/month] (= (a+b+c)/3) | | |
| Line 11 | Correlation factor | | |
| Line 12 | Energy cooking (Ec) [kWh/month] (= El * Cf) | | |
| Line 13 | Total energy consumption per building type [kWh/year] | | |
| Line 14 | Energy consumption per building type per $m^2$ [kWh/$m^2$/year] | | |

Source: Elaboration of author

**Table 54:** Legend of colors

| Colour | Description |
|---|---|
| (light yellow) | Results of equations |
| (orange) | On base of the models |
| (pink) | Sum of the energy of equipments and cooking |

Source: Elaboration of author

**Table 55:** Description of table 12

| Line | Description |
|---|---|
| Line 1 | Description of the building model |
| Line 2 | Area en m². Defined in the models |
| Line 3 | Factor of the consumption dependent on area of the unit. |
| Line 4 | Partial electricity consumption (kWh/month) dependent to constructed area |
| Line 5 | Number of habitants of the unit. Defined in the models. |
| Line 6 | Factor of the consumption dependent of the number of habitants of the unit. |
| Line 7 | Partial electricity consumption (kWh/month) dependent from the number of habitants of the unit. |
| Line 8 | Income of the unit in multiples of minimum income (MI). Defined in the models. |
| Line 9 | Factor of the consumption dependent from the family income of the unit. |
| Line 10 | Partial electricity consumption (kWh/month) dependent from family income of the unit. |
| Line 11 | Electricity consumption per final use of equipments (kWh/month). Average consumption of a,h,i. result of equation |
| Line 12 | Factor of the relation of electricity consumption with cooking energy consumption, conform with table |
| Line 13 | Cooking energy (kWh/month). Result of equation |
| Line 14 | Sum of electricity and cooking energy consumption per building type per year (kWh/ m²/year) |
| Line 16 | Sum of electricity and cooking energy consumption per building type per square meter (kWh/ m²/year) |

Source: Elaboration of author

**Table 56:** Results of the projected energy consumption for the building stock before calibration

| | Unit | Urban SFH | Rural SFH | Small MFH | Large MFH | weighted average | statistic value | deviation |
|---|---|---|---|---|---|---|---|---|
| Family income[1] | [x MI] | 4,9 | 2 | 3 | 12 | 4,5 | 4,9 | -9% |
| Number of inhabitants[2] | [number] | 3,3 | 4 | 3 | 3 | 3,15 | 3,3 | -4% |
| Calculated electricity consumption per household | [kWh/ month] | 120 | 93 | 93 | 192 | 115 | 131 | -12,0% |
| Correlation factor | Cf | 1,3[3] | 4,0 | 1,0 | 1,0 | 1,7 | 1,8 | -7,0% |
| Calculated cooking energy consumption per household | [kWh/ month] | 156 | 372 | 93 | 192 | 157 | 231 | -32,0% |
| Calculated electricity consumption of building stock | [GWh/a] | 60.739 | 9.542 | 5.725 | 2.627 | 78.633 | 83.199 | -5% |

[1] The base of this estimation was the size (and assumed income level of the inhabitants of the building). The income of the USFH was assumed to be the average value of Brazil. The weighted average from the values of the other building types was validated with the total average from Brazil.
[2] The average inhabitant of the USFH was assumed to be the average value of Brazil. Due to higher average inhabitants in rural areas, the average number was assumed to be 4. The average inhabitants in multi family houses is slightly above three, therefore the values was set to three.
[3] weighted average value of the cooking scenarios (only gas stove, in 65% of households and gas and firewood stove, in 20% of households)
Source: Calculation on base of (Abreu de Queiroz and Tramontano, 2009; EMBRAESP, 2008; EPE, 2009; IBGE, 2009; PROCEL/Eletrobrás, 2007).

**Table 57:** Table of calibration

| New Building type | SFH urban | SFH rural | MFH small | MFH large | GWh | 10^3 toe | deviation |
|---|---|---|---|---|---|---|---|
| Occurence | **74,1%** | **15,0%** | **8,7%** | **2,2%** | | | 100,0% |
| Income [mutliply minimal salary] | **4,9** | **2,0** | **3,0** | **12,0** | | | |
| Electricity | 138 | 94 | 94 | 285 | | | |
| Factor | 1,3 | 6 | 1 | 1 | | | |
| Cooking total | 187 | 562 | 94 | 285 | | | |
| percentage firewoood | 65,0% | 100,0% | 0,0% | 0,0% | | | |
| percentage gas | 35,0% | 0,0% | 100,0% | 100,0% | | | |
| Cooking Firewood | 52 | 562 | 0 | 0 | | | |
| Cooking Gas | 134 | 0 | 94 | 285 | | | |
| **total** | 325 | 655 | 188 | 570 | | | |
| projection energy consumption [GWh] | 153.379 | 62.850 | 10.457 | 7.919 | 234.605 | 20.176 | -8,2 |
| Total all, BEN [GWh] | | | | | 253.807 | 21.827 | |
| correction factor | | | | | 108,18% | | |
| All [GWh] | 165.933 | 67.994 | 11.312 | 8.567 | | | |
| Projection electricity [GWh] | 65.268 | 8.979 | 5.228 | 3.960 | 83.435 | 7.175 | 0,3 |
| Total electricity, BEN [GWh] | | | | | 83.199 | 7.155 | |
| correction factor | | | | | 99,72% | | |
| Electricity [GWh] | 65.084 | 8.953 | 5.214 | 3.948 | | | |
| Projection cooking energy [GWh] | 88.111 | 53.871 | 5.228 | 3.960 | 151.170 | 13.000 | -12,9 |
| Total cooking, BEN | | | | | 170.607 | 14.672 | |
| correction factor | | | | | 112,86% | | |
| Cooking [GWh] | 99.440 | 60.798 | 5.901 | 4.469 | | | |
| Projection firewood [GWh] | 24.746 | 53.871 | 0 | 0 | 78.617 | 6.761 | -29,4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total firewood, BEN | | | | | 101.769 | 8.752 | |
| correction factor | | | | | 129,45% | | |
| Firewood[GWh] | 32.033 | 69.735 | 0 | 0 | | | |
| Projection gas [GWh] | 63.365 | 0 | 5.228 | 3.960 | 72.553 | 6239,452769 | 5,1 |
| Total gas, BEN | | | | | 68.838 | 5.920 | |
| correction factor | | | | | 94,88% | | |
| Gas [GWh] | 60.121 | 0 | 4.961 | 3.757 | | | |
| Total | 157.238 | 78.688 | 10.174 | 7.705 | 253.806 | 21.827 | |

Source: Elaboration of author

**Table 58:** Building type, number of buildings

| | Unit | Urban - SFH | Rural SFH | SMFH | LMFH | Average reference house | Source |
|---|---|---|---|---|---|---|---|
| Number of dwellings | Mio | 42,61 | 8,67 | 5,02 | 1,25 | | PNAD |
| Floor area | Mio m² | 3.187 | 486 | 281 | 172 | | PROCEL, PNAD |

Source: Elaboration of author

## Annex D - Reference buildings

**Table 59:** Power of air condition

| Power of air condition [1000 units] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Consumption range | | | | | | | |
| | | **1** | **2** | **3** | **4** | **5** | **6** | **Total** | **total %** |
| KBTU/h | 6000 | 42.100 | 29.990 | 165.120 | 128.870 | 149.870 | 115.170 | 631.120 | 18,3 |
| | 7000 | 25.260 | 59.970 | 86.910 | 48.330 | 53.180 | 47.750 | 321.400 | 9,3 |
| | 7500 | 42.100 | 89.960 | 330.250 | 510.120 | 546.300 | 342.710 | 1.861.440 | 53,8 |
| | 8300 | 0 | 0 | 0 | 0 | 4.830 | 0 | 4.830 | 0,1 |
| | 9000 | 0 | 0 | 34.760 | 10.740 | 29.010 | 33.710 | 108.220 | 3,1 |
| | 10000 | 0 | 39.980 | 95.600 | 64.440 | 82.190 | 58.990 | 341.190 | 9,9 |
| | 10500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,0 |
| | 12000 | 8.420 | 10.000 | 34.760 | 21.480 | 38.680 | 25.280 | 138.610 | 4,0 |
| | 18000 | 0 | 0 | 0 | 10.740 | 0 | 8.430 | 19.170 | 0,6 |
| | 21000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,0 |
| | 23000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,0 |
| | 30000 | 0 | 0 | 8.690 | 5.370 | 14.500 | 2.810 | 31.370 | 0,9 |
| | Total | 117.870 | 229.890 | 756.090 | 800.090 | 918.560 | 634.860 | 3.457.350 | 100,0 |

Source: Elaboration of author

**Table 60:** Power of shower

| Power of shower [%] | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Consumption range | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| Power of shower | 2,5 kW | 6,81 | 5,39 | 4,25 | 4,06 | 3,01 | 5,18 |
| | 3 kW | 6,28 | 12,28 | 11,27 | 15,71 | 14,23 | 11,59 |
| | 3,5 kW | 24,35 | 16,02 | 17,07 | 11,78 | 11 | 9 |
| | 4,2 kW | 0,79 | 1,2 | 2,34 | 1,31 | 3 | 1 |
| | 4,4 kW | 57,07 | 60,33 | 56,15 | 52,23 | 55 | 53 |
| | 4,8 kW | 0,79 | 0,6 | 0,87 | 1,57 | 1 | 2 |
| | 5 kW | 0,79 | 1,65 | 3,38 | 5,89 | 4 | 7 |
| | 5,2 kW | 0,52 | 0,45 | 1,13 | 1,83 | 2 | 4 |
| | 5,4 kW | 1,83 | 1,35 | 2,25 | 4,06 | 5 | 6 |
| | 6,4 kW | 0,52 | 0,45 | 0,26 | 0,39 | 1 | 0 |
| | 6,5 kW | 0,26 | 0,15 | 0,61 | 0,79 | 0 | 1 |
| | 7,5 kW | 0 | 0,15 | 0,43 | 0,39 | 0,2 | 1,22 |
| | 8,8 kW | 0 | 0 | 0 | 0 | 0 | 0 |

Source: Elaboration of author

**Table 61:** Power of lamps

| Average ownership per consumption range | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Consumption range | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | average |
| Type of lamp | Inc. 25W | 0,06 | 0,1 | 0,11 | 0,1 | 0,11 | 0,19 | 0,10 |
| | Inc. 40W | 0,46 | 0,43 | 0,35 | 0,34 | 0,34 | 0,56 | 0,40 |
| | Inc. 60W | 2,41 | 2,6 | 3,05 | 3,3 | 3,71 | 3,9 | 3,00 |
| | Inc. 100W | 0,17 | 0,29 | 0,49 | 0,79 | 0,72 | 0,73 | 0,47 |
| | Inc. 150W | 0,01 | 0,03 | 0,02 | 0,03 | 0,01 | 0,01 | 0,02 |
| | Fluor. 20W | 0,39 | 0,29 | 0,46 | 0,6 | 0,88 | 1,18 | 0,51 |
| | Fluor. 40W | 0,37 | 0,46 | 0,67 | 0,75 | 1,06 | 2,92 | 0,76 |
| | Fluor. Comp. até 15W | 0,74 | 0,84 | 1,01 | 1,26 | 2 | 3,12 | 1,18 |
| | Fluor. Comp. >15W | 0,61 | 0,87 | 1,28 | 1,77 | 2,57 | 3,37 | 1,40 |
| | Fluor. Circul. | 0,04 | 0,08 | 0,11 | 0,25 | 0,25 | 0,21 | 0,13 |
| | Dicróica | 0,02 | 0,01 | 0,03 | 0,1 | 0,15 | 0,29 | 0,06 |
| | Outro | 0,02 | 0,02 | 0,03 | 0,04 | 0,05 | 0,28 | 0,04 |

Source: Elaboration of author

**Table 62:** Calculation of reference houses

| End uses | Share in the stock | Calculated values | Total consumption [GWh] |
|---|---|---|---|
| Shower | 24% | | 89.594 |
| Refrigerator | 22% | | |
| A/C | 20% | | |
| Lighting | 14% | | |

Source: Elaboration of author

**Table 63:** Calculation sheet for operation time of appliances - Shower

| Shower | | SFH | SFH | SMFH | LMFH | averages | PROCEL |
|---|---|---|---|---|---|---|---|
| **occurrence of building type** | **%** | **74,1%** | **15,0%** | **8,7%** | **2,2%** | | |
| Nominal power | [kW] | 4,5 | 3 | 3 | 5,5 | 4,17 | 4,17 |
| Average operation time | [h/year] | 92 | | | | | |
| ownership | | 0,89 | 0,8 | 0,8 | 1,9 | 0,89 | 0,89 |
| Total electricity consumption | [GWh] | 15.620 | 2.149 | 1.251 | 948 | 19.968 | |
| total installed nominal power | GW | 171 | 21 | 12 | 13 | 217 | |

Source: Elaboration of author

**Table 64:** Calculation sheet for operation time of appliances – HVAC system

| HVAC System | | SFH | SFH | SMFH | LMFH | averages | PROCEL |
|---|---|---|---|---|---|---|---|
| **occurrence of building type** | **%** | **74,1%** | **15,0%** | **8,7%** | **2,2%** | | |
| Nominal power | kW | 0,90 | 0,90 | 0,90 | 1,13 | 0,91 | |
| Cooling capacity | kW | 2,2 | 1,8 | 2,2 | 2,9 | 2,15 | 2,12 |
| Efficiency | COP | 2,44 | 1,95 | 2,44 | 2,59 | 2,37 | 2,28 |
| Consumption per year/hh | [kWh] | 305 | 206 | 208 | 630 | 289 | |
| average operation time | [h/year] | 2.016 | | | | | |
| ownership rate | | 16% | 8% | 8% | 80% | 0,16 | |
| total nominal power in stock | GW | 6,3 | 0,6 | 0,4 | 1 | 8,3 | |
| Total consumption | [GWh] | 13.017 | 1.791 | 1.043 | 790 | 16.640 | |

Source: Elaboration of author

**Table 65:** Calculation sheet for operation time of appliances - Lighting

| **Lighting** | **%** | **74,1%** | **15,0%** | **8,7%** | **2,2%** | |
|---|---|---|---|---|---|---|
| Nominal power, incandescent | [W] | 60 | 60 | 60 | 60 | |
| # of devices inefficient | [unit] | 4 | 4 | 4 | 4 | |
| nominal power efficient | [W] | 15 | 15 | 15 | 15 | |
| Efficiency | [%] | 20 | 20 | 20 | 20 | |
| # of devices efficient | [unit] | 2 | 2 | 2 | 2 | |
| | | | | | | |
| # of devices fluorescent tubular | | 2 | 2 | 2 | 2 | |
| Nominal power, fluorescent tubular and compact installed | [W] | 30 | 30 | 30 | 30 | |
| total installed capacity | GW | 12,8 | 2,6 | 1,5 | 0,4 | 17,3 |
| Consumption per year/hh | [kWh] | 214 | 145 | 146 | 441 | 202 |
| Total electricity consumption | [GWh] | 9.112 | 1.253 | 730 | 553 | 11.648 |
| average operation time | h/year | 674,6 | | | | |

Source: Elaboration of author

**Table 66:** Electricity consumption by end use per building type

| | **Fraction of total electricity consumption [%]** | **SFH urban** | **SFH rural** | **MFH small** | **MFH large** | **Total** |
|---|---|---|---|---|---|---|
| Occurrence [%] | - | 74,1 | 15,0 | 8,7 | 2,2 | 100 |
| Total electricity consumption [GWh] | - | 65.084 | 8.953 | 5.214 | 3.948 | 83.199 |
| Shower [GWh] | 24 | 15.620 | 2.149 | 1.251 | 948 | 19.968 |
| Air condition [GWh] | 20 | 13.017 | 1.791 | 1.043 | 790 | 16.641 |
| Refrigeration [GWh] | 22 | 14.318 | 1.970 | 1.147 | 869 | 18.304 |
| Lighting [GWh] | 14 | 9.112 | 1.253 | 730 | 553 | 11.648 |
| Other appliances [GWh]* | 20 | 13.017 | 1.791 | 1.043 | 790 | 16.641 |

* calculated as difference of total electricity consumption minus the sum of the four main appliances (shower, lighting, refrigeration, air condition)

Source: Elaboration of author on base of data from (IBGE, 2009; PROCEL/Eletrobrás, 2007)

# Annex E - Scenarios

**Table 67:** GDP and building stock forecast

| Year | Floor area per house type (PROCEL, PNAD) | | | | | GDP WEO, 451 | | | | | Income per type of house | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SFH-u [mio m²] | SFH-r [mio m²] | SMFH [mio m²] | LMFH [mio m²] | total [mio m²] | growth rate WEO, 2006 | total [10^9 $], Weltbank 2008 | per household/ month [1000] | per capita (PPP) [1000$] | growth rate per capita | SFH-u [minimum income factor] | SFH-r [minimum income factor] | SMFH [minimum income factor] | LMFH [minimum income factor] |
| 2005 | 3.010 | 458 | 209 | 128 | 3.805 | 3,3% | $1.978 | $3,1 | $10,7 | 2,08% | 5 | 2 | 3 | 12 |
| 2006 | 3.083 | 465 | 227 | 139 | 3.914 | 3,3% | $1.979 | $3,0 | $10,6 | 2,08% | 5,1 | 2,0 | 3,1 | 12,2 |
| 2007 | 3.160 | 475 | 244 | 149 | 4.029 | 3,3% | $1.980 | $2,9 | $10,5 | 2,08% | 5,2 | 2,1 | 3,1 | 12,5 |
| 2008 | 3.187 | 486 | 281 | 172 | 4.125 | 3,3% | $1.981 | $2,9 | $10,4 | 2,08% | 5,3 | 2,1 | 3,2 | 12,8 |
| 2009 | 3.282 | 485 | 294 | 202 | 4.263 | 3,3% | $2.046 | $2,9 | $10,7 | 2,08% | 5,4 | 2,2 | 3,3 | 13,0 |
| 2010 | 3.377 | 485 | 307 | 232 | 4.402 | 3,3% | $2.114 | $2,9 | $10,9 | 2,08% | 5,5 | 2,2 | 3,3 | 13,3 |
| 2011 | 3.472 | 485 | 320 | 263 | 4.540 | 3,3% | $2.184 | $2,9 | $11,1 | 2,08% | 5,7 | 2,3 | 3,4 | 13,6 |
| 2012 | 3.568 | 484 | 333 | 293 | 4.679 | 3,3% | $2.256 | $2,9 | $11,3 | 2,08% | 5,8 | 2,3 | 3,5 | 13,9 |
| 2013 | 3.663 | 484 | 346 | 324 | 4.817 | 3,3% | $2.330 | $2,9 | $11,6 | 2,08% | 5,9 | 2,4 | 3,5 | 14,1 |
| 2014 | 3.758 | 484 | 360 | 354 | 4.955 | 3,3% | $2.407 | $3,0 | $11,8 | 2,08% | 6,0 | 2,4 | 3,6 | 14,4 |
| 2015 | 3.853 | 484 | 373 | 384 | 5.094 | 3,3% | $2.486 | $3,0 | $12,1 | 2,08% | 6,1 | 2,5 | 3,7 | 14,7 |
| 2016 | 3.949 | 483 | 386 | 415 | 5.232 | 2,8% | $2.556 | $3,0 | $12,3 | 1,98% | 6,3 | 2,5 | 3,8 | 15,0 |
| 2017 | 4.044 | 483 | 399 | 445 | 5.371 | 2,8% | $2.628 | $3,0 | $12,5 | 1,98% | 6,4 | 2,6 | 3,8 | 15,3 |
| 2018 | 4.139 | 483 | 412 | 475 | 5.509 | 2,8% | $2.701 | $3,0 | $12,8 | 1,98% | 6,5 | 2,6 | 3,9 | 15,6 |
| 2019 | 4.234 | 482 | 425 | 506 | 5.647 | 2,8% | $2.777 | $3,0 | $13,1 | 1,98% | 6,6 | 2,7 | 4,0 | 16,0 |
| 2020 | 4.330 | 482 | 438 | 536 | 5.786 | 2,8% | $2.855 | $3,0 | $13,3 | 1,98% | 6,8 | 2,7 | 4,1 | 16,3 |

Source: Elaboration of author

**Table 68:** building stock forecast unit 2020

| Year | | | Share [%] per house type | | | | share of house by situation [#] | | # of buildings per house type | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SFH total | MFH total | SFH u | SFH r | SMFH | LMFH | urban | rural | SFH-u [#] | SFH-r [#] | SMFH [#] | LMFH [#] | total [#²] |
| 2005 | 91,2% | 8,8% | 75,8% | 15,4% | 7,0% | 1,8% | 45 | 8 | 40 | 8 | 4 | 1 | 53,1 |
| 2006 | 90,7% | 9,3% | 75,5% | 15,2% | 7,4% | 1,9% | 46 | 8 | 41 | 8 | 4 | 1 | 54,6 |
| 2007 | 90,3% | 9,7% | 75,2% | 15,1% | 7,8% | 1,9% | 48 | 8 | 42 | 8 | 4 | 1 | 56,2 |
| 2008 | 89,1% | 10,9% | 74,1% | 15,0% | 8,7% | 2,2% | 49 | 9 | 43 | 9 | 5 | 1 | 57,6 |
| 2009 | 88,8% | 11,2% | 74,1% | 14,7% | 8,8% | 2,4% | 51 | 9 | 44 | 9 | 5 | 1 | 59 |
| 2010 | 88,4% | 11,6% | 74,1% | 14,3% | 8,9% | 2,7% | 52 | 9 | 45 | 9 | 5 | 2 | 61 |
| 2011 | 88,1% | 11,9% | 74,1% | 14,0% | 9,0% | 2,9% | 54 | 9 | 46 | 9 | 6 | 2 | 63 |
| 2012 | 87,7% | 12,3% | 74,1% | 13,7% | 9,1% | 3,1% | 56 | 9 | 48 | 9 | 6 | 2 | 64 |
| 2013 | 87,4% | 12,6% | 74,1% | 13,3% | 9,2% | 3,4% | 58 | 9 | 49 | 9 | 6 | 2 | 66 |
| 2014 | 87,1% | 13,0% | 74,1% | 13,0% | 9,4% | 3,6% | 59 | 9 | 50 | 9 | 6 | 3 | 68 |
| 2015 | 86,7% | 13,3% | 74,0% | 12,7% | 9,5% | 3,8% | 61 | 9 | 52 | 9 | 7 | 3 | 70 |
| 2016 | 86,4% | 13,6% | 74,0% | 12,3% | 9,6% | 4,1% | 63 | 9 | 53 | 9 | 7 | 3 | 71 |
| 2017 | 86,0% | 14,0% | 74,0% | 12,0% | 9,7% | 4,3% | 64 | 9 | 54 | 9 | 7 | 3 | 73 |
| 2018 | 85,7% | 14,3% | 74,0% | 11,7% | 9,8% | 4,5% | 66 | 9 | 55 | 9 | 7 | 3 | 75 |
| 2019 | 85,3% | 14,7% | 74,0% | 11,3% | 9,9% | 4,8% | 68 | 9 | 57 | 9 | 8 | 4 | 76 |
| 2020 | 85,0% | 15% | 74,0% | 11,0% | 10,0% | 5,0% | 70 | 9 | 58 | 9 | 8 | 4 | 78 |

Source: Elaboration of author

**Table 69:** Forecast of end uses and ownership rates

| Refrigerator | | | | Shower | | | | | A/C | | | | | | Cooking factor (cf) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1999 | 0,89 | linear | langsam | 0,89 | 0,73 | linear | langsam | 0,73 | 0,08 | linear | langsamer | 0,08 | schneller | 0,08 | 0,3453 | | |
| 2000 | 0,91 | 2,1% | 2,0% | 0,91 | 0,76 | 3,6% | 3,6% | 0,76 | 0,09 | 17% | 17,2% | 0,09 | 17,3% | 0,09 | 0,361 | 5% | 7% |
| 2001 | 0,92 | 2,0% | 1,9% | 0,92 | 0,79 | 3,5% | 3,5% | 0,79 | 0,10 | 15% | 14,6% | 0,10 | 14,8% | 0,10 | 0,3767 | 4% | 6% |
| 2002 | 0,94 | 2,0% | 1,8% | 0,94 | 0,81 | 3,4% | 3,2% | 0,81 | 0,12 | 13% | 12,6% | 0,12 | 12,9% | 0,12 | 0,3924 | 4% | 6% |
| 2003 | 0,96 | 1,9% | 1,9% | 0,96 | 0,84 | 3,3% | 3,1% | 0,84 | 0,13 | 11% | 11,1% | 0,13 | 11,5% | 0,13 | 0,4081 | 4% | 6% |
| 2004 | 0,98 | 1,9% | 1,7% | 0,97 | 0,87 | 3,2% | 2,9% | 0,86 | 0,14 | 10% | 9,9% | 0,14 | 10,4% | 0,15 | 0,4238 | 4% | 6% |
| 2005 | 1,00 | 2% | 1,6% | 0,99 | 0,89 | 3,1% | 2,8% | 0,88 | 0,16 | 9% | 8,9% | 0,16 | 9,5% | 0,16 | 0,4395 | 4% | 6% |
| 2006 | 1,02 | 1,8% | 1,5% | 1,00 | 0,92 | 3,0% | 2,6% | 0,91 | 0,17 | 8% | 8,1% | 0,17 | 8,8% | 0,17 | 0,4552 | 4% | 6% |
| 2007 | 1,03 | 1,8% | 1,4% | 1,02 | 0,95 | 2,9% | 2,5% | 0,93 | 0,18 | 8% | 7,4% | 0,18 | 8,2% | 0,19 | 0,4709 | 3% | 5% |
| 2008 | 1,05 | 1,8% | 1,3% | 1,03 | 0,97 | 2,8% | 2,4% | 0,95 | 0,20 | 7% | 6,8% | 0,19 | 7,7% | 0,20 | 0,4866 | 3% | 5% |
| 2009 | 1,07 | 1,7% | 1,2% | 1,04 | 1,00 | 2,7% | 2,2% | 0,97 | 0,21 | 7% | 6,2% | 0,21 | 7,2% | 0,22 | 0,5023 | 3% | 5% |
| 2010 | 1,09 | 1,7% | 1,2% | 1,06 | 1,03 | 2,7% | 2,1% | 0,99 | 0,22 | 6% | 5,8% | 0,22 | 6,9% | 0,23 | 0,518 | 3% | 5% |
| 2011 | 1,11 | 1,7% | 1,1% | 1,07 | 1,05 | 2,6% | 2,0% | 1,01 | 0,24 | 6% | 5,3% | 0,23 | 6,5% | 0,25 | 0,5337 | 3% | 5% |
| 2012 | 1,13 | 1,6% | 1,0% | 1,08 | 1,08 | 2,5% | 1,9% | 1,03 | 0,25 | 6% | 4,9% | 0,24 | 6,2% | 0,26 | 0,5494 | 3% | 5% |
| 2013 | 1,14 | 1,6% | 0,9% | 1,09 | 1,11 | 2,5% | 1,8% | 1,05 | 0,26 | 5% | 4,6% | 0,25 | 4,6% | 0,27 | 0,5651 | 3% | 5% |
| 2014 | 1,16 | 1,6% | 0,8% | 1,10 | 1,13 | 2,4% | 1,6% | 1,07 | 0,28 | 5% | 4,3% | 0,26 | 5,8% | 0,29 | 0,5808 | 3% | 5% |
| 2015 | 1,18 | 1,6% | 0,8% | 1,11 | 1,16 | 2,3% | 1,5% | 1,08 | 0,29 | 5% | 4,0% | 0,27 | 5,6% | 0,31 | 0,5965 | 3% | 5% |
| 2016 | 1,20 | 1,5% | 0,7% | 1,11 | 1,18 | 2,3% | 1,4% | 1,10 | 0,30 | 5% | 3,7% | 0,28 | 5,4% | 0,32 | 0,6122 | 3% | 5% |
| 2017 | 1,22 | 1,5% | 0,6% | 1,12 | 1,21 | 2,2% | 1,3% | 1,11 | 0,32 | 4% | 3,5% | 0,29 | 5,3% | 0,34 | 0,6279 | 3% | 5% |
| 2018 | 1,23 | 1,5% | 0,5% | 1,13 | 1,24 | 2,2% | 1,2% | 1,13 | 0,33 | 4% | 3,2% | 0,30 | 5,1% | 0,36 | 0,6436 | 3% | 5% |
| 2019 | 1,25 | 1,5% | 0,5% | 1,13 | 1,26 | 2,1% | 1,1% | 1,14 | 0,34 | 4% | 3,0% | 0,31 | 5,0% | 0,37 | 0,6593 | 2% | 4% |
| 2020 | 1,27 | 1,5% | 0,3% | 1,13 | 1,29 | 2,1% | 0,6% | 1,15 | 0,36 | 4% | 2,4% | 0,32 | 5,4% | 0,39 | 0,675 | 2% | 4% |

Source: Elaboration of author

**Table 70:** Unit energy consumption of the appliances in the future - Cooking energy

| Year | Cooking energy consumption/housetyp, substitution | | | | | Cooking energy consumption/housetyp, higher subsitution, efficiency | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Urban SHF | Rural SFH | SMFH | LMFH | **cf** | Urban SHF | Rural SFH | SMFH | LMFH | **cf** |
| | factor | factor | factor | factor | cf change | factor | factor | factor | factor | cf change |
| 2005 | 1,3 | 9,0 | 1,0 | 1,0 | 3% | 1,3 | 9,0 | 1,0 | 1,0 | 7% |
| 2006 | | | | | 4% | | | | | 6% |
| 2007 | 1,3 | 8,7 | 1,0 | 1,0 | 3% | 1,3 | 8,4 | 0,9 | 0,9 | 6% |
| 2008 | 1,2 | 8,4 | 0,9 | 0,9 | 3% | 1,2 | 8,4 | 0,9 | 0,9 | 6% |
| 2009 | 1,2 | 8,1 | 0,9 | 0,9 | 3% | 1,1 | 8,2 | 0,8 | 0,8 | 6% |
| 2010 | 1,2 | 7,9 | 0,9 | 0,9 | 3% | 1,0 | 7,9 | 0,8 | 0,8 | 6% |
| 2011 | 1,1 | 7,6 | 0,8 | 0,8 | 3% | 1,0 | 7,6 | 0,7 | 0,7 | 6% |
| 2012 | 1,1 | 7,4 | 0,8 | 0,8 | 3% | 0,9 | 7,4 | 0,7 | 0,7 | 5% |
| 2013 | 1,1 | 7,2 | 0,8 | 0,8 | 3% | 0,9 | 7,2 | 0,7 | 0,7 | 5% |
| 2014 | 1,0 | 7,0 | 0,8 | 0,8 | 3% | 0,8 | 7,0 | 0,6 | 0,6 | 5% |
| 2015 | 1,0 | 6,8 | 0,8 | 0,8 | 3% | 0,8 | 6,8 | 0,6 | 0,6 | 5% |
| 2016 | 1,0 | 6,6 | 0,7 | 0,7 | 3% | 0,8 | 6,6 | 0,6 | 0,6 | 5% |
| 2017 | 1,0 | 6,4 | 0,7 | 0,7 | 3% | 0,7 | 6,4 | 0,5 | 0,5 | 5% |
| 2018 | 0,9 | 6,3 | 0,7 | 0,7 | 3% | 0,7 | 6,3 | 0,5 | 0,5 | 5% |
| 2019 | 0,9 | 6,1 | 0,7 | 0,7 | 2% | 0,6 | 6,1 | 0,5 | 0,5 | 5% |
| 2020 | 0,9 | 6,0 | 0,7 | 0,7 | 2% | 0,6 | 6,0 | 0,5 | 0,5 | 5% |

Source: Elaboration of author

**Table 71:** BAU projection of shower, air condition and refrigerator

| year | SHOWER | | | | | AIR CONDITON | | | | | REFRIGERATOR | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Urban SFH** | **Rural SFH** | **SMFH** | **LMFH** | **Total** | **Urban SHF** | **Rural SFH** | **SMFH** | **LMFH** | **Total** | **Urban SHF** | **Rural SFH** | **SMFH** | **LMFH** | **Total** |
| | Electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Total electr. Consu. Wh/a] | Electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Total electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Electr. Consu.[ TWh/a] | Total electr. Consu.[ TWh/a] |
| 2005 | 13,1 | 1,8 | 0,8 | 0,8 | 16,6 | 11,5 | 1,2 | 0,5 | 1,7 | 14,9 | 20,0 | 3,3 | 1,9 | 0,7 | 25,9 |
| 2006 | 13,7 | 1,9 | 0,9 | 0,9 | 17,5 | 12,1 | 1,3 | 0,6 | 1,8 | 15,9 | 20,7 | 3,4 | 2,0 | 0,8 | 26,9 |
| 2007 | 14,4 | 2,0 | 1,0 | 1,0 | 18,4 | 13,3 | 1,5 | 0,8 | 2,0 | 17,5 | 21,5 | 3,5 | 2,2 | 0,8 | 28,1 |
| 2008 | 14,8 | 2,1 | 1,2 | 1,1 | 19,2 | 14,3 | 1,7 | 1,0 | 2,2 | 19,2 | 21,9 | 3,7 | 2,6 | 1,0 | 29,1 |
| 2009 | 16,5 | 2,2 | 1,4 | 1,5 | 21,6 | 15,5 | 1,8 | 1,1 | 2,6 | 21,0 | 22,4 | 3,7 | 2,7 | 1,2 | 30,0 |
| 2010 | 18,2 | 2,4 | 1,5 | 1,9 | 24,0 | 16,8 | 2,0 | 1,2 | 3,1 | 23,1 | 22,9 | 3,7 | 2,8 | 1,4 | 30,8 |
| 2011 | 19,9 | 2,5 | 1,7 | 2,3 | 26,5 | 18,2 | 2,1 | 1,4 | 3,6 | 25,3 | 23,4 | 3,7 | 2,9 | 1,7 | 31,7 |
| 2012 | 21,8 | 2,6 | 1,9 | 2,8 | 29,1 | 19,6 | 2,3 | 1,5 | 4,1 | 27,5 | 24,0 | 3,7 | 2,9 | 1,9 | 32,6 |
| 2013 | 23,6 | 2,8 | 2,1 | 3,2 | 31,7 | 21,1 | 2,4 | 1,7 | 4,6 | 29,8 | 24,5 | 3,7 | 3,0 | 2,2 | 33,5 |
| 2014 | 25,5 | 2,9 | 2,3 | 3,7 | 34,5 | 22,6 | 2,6 | 1,9 | 5,1 | 32,1 | 25,1 | 3,8 | 3,1 | 2,5 | 34,4 |
| 2015 | 27,5 | 3,1 | 2,5 | 4,2 | 37,3 | 24,2 | 2,7 | 2,1 | 5,7 | 34,6 | 25,7 | 3,8 | 3,2 | 2,7 | 35,4 |
| 2016 | 29,6 | 3,2 | 2,7 | 4,7 | 40,2 | 25,9 | 2,9 | 2,3 | 6,2 | 37,4 | 26,3 | 3,8 | 3,3 | 3,0 | 36,4 |
| 2017 | 31,7 | 3,4 | 3,0 | 5,3 | 43,3 | 27,7 | 3,1 | 2,5 | 6,8 | 40,1 | 27,0 | 3,8 | 3,5 | 3,2 | 37,5 |
| 2018 | 33,8 | 3,5 | 3,2 | 6,0 | 46,5 | 29,6 | 3,3 | 2,8 | 7,4 | 43,0 | 27,9 | 3,9 | 3,6 | 3,5 | 38,8 |
| 2019 | 36,0 | 3,7 | 3,4 | 6,8 | 49,9 | 31,5 | 3,4 | 3,0 | 8,0 | 45,9 | 29,1 | 4,0 | 3,8 | 3,7 | 40,6 |
| 2020 | 39,0 | 3,8 | 3,8 | 7,6 | 54,3 | 33,5 | 3,6 | 3,3 | 8,6 | 48,9 | 30,4 | 4,1 | 4,0 | 3,9 | 42,4 |

Source: Elaboration of author

**Table 72:** BAU projection of lighting, other appliances

| year | Lighting | | | | | Other appliances | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Urban SHF** | **Rural SFH** | **SMFH** | **LMFH** | **Total** | **Urban SHF** | **Rural SFH** | **SMFH** | **LMFH** | **Total** |
| | Electr. Consu. [TWh/a] | Electr. Consu. [TWh/a] | Electr. Consu. [TWh/a] | Electr. Consu. [TWh/a] | Total electr. Consu. [TWh/a] | Electr. Consu. [TWh/a] | Electr. Consu. [TWh/a] | Electr. Consu. [TWh/a] | Electr. Consu. [TWh/a] | Total electr. Consu. [TWh/a] |
| 2005 | 8,1 | 1,7 | 0,8 | 0,2 | 10,7 | 13,0 | 1,8 | 1,0 | 0,8 | 16,6 |
| 2006 | 8,4 | 1,7 | 0,8 | 0,2 | 11,1 | 13,4 | 1,8 | 1,1 | 0,8 | 17,2 |
| 2007 | 8,6 | 1,7 | 0,9 | 0,2 | 11,4 | 13,9 | 1,9 | 1,1 | 0,8 | 17,8 |
| 2008 | 8,7 | 1,8 | 1,0 | 0,5 | 11,9 | 14,3 | 2,0 | 1,1 | 0,9 | 18,3 |
| 2009 | 8,5 | 1,7 | 1,0 | 0,3 | 11,5 | 14,8 | 2,0 | 1,2 | 0,9 | 18,9 |
| 2010 | 8,4 | 1,6 | 1,0 | 0,3 | 11,3 | 15,3 | 2,1 | 1,2 | 0,9 | 19,6 |
| 2011 | 8,2 | 1,5 | 1,0 | 0,4 | 11,1 | 15,8 | 2,2 | 1,3 | 1,0 | 20,2 |
| 2012 | 8,1 | 1,4 | 1,0 | 0,4 | 10,9 | 16,3 | 2,2 | 1,3 | 1,0 | 20,9 |
| 2013 | 7,9 | 1,3 | 1,0 | 0,4 | 10,7 | 16,9 | 2,3 | 1,4 | 1,0 | 21,6 |
| 2014 | 7,7 | 1,3 | 1,0 | 0,4 | 10,4 | 17,4 | 2,4 | 1,4 | 1,1 | 22,3 |
| 2015 | 7,5 | 1,2 | 1,0 | 0,5 | 10,1 | 18,0 | 2,5 | 1,4 | 1,1 | 23,0 |
| 2016 | 7,3 | 1,1 | 1,0 | 0,5 | 9,8 | 18,6 | 2,6 | 1,5 | 1,1 | 23,8 |
| 2017 | 7,1 | 1,0 | 1,0 | 0,5 | 9,5 | 19,1 | 2,6 | 1,5 | 1,2 | 24,4 |
| 2018 | 6,8 | 0,9 | 0,9 | 0,5 | 9,2 | 19,7 | 2,7 | 1,6 | 1,2 | 25,1 |
| 2019 | 6,6 | 0,8 | 0,9 | 0,5 | 8,9 | 20,2 | 2,8 | 1,6 | 1,2 | 25,8 |
| 2020 | 6,3 | 0,8 | 0,9 | 0,5 | 8,5 | 20,8 | 2,9 | 1,7 | 1,3 | 26,6 |

Source: Elaboration of author

**Table 73:** BAU – Projection of cooking energy

| year | Cooking energy consumption/house type | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Urban SHF** | | | **Rural SFH** | | | **SMFH** | | | **LMFH** | | |
| | gas [TWH/a] | firewood [TWH/a] | total [TWH/a] | gas [TWH/a] | firewood [TWH/a] | total [TWH/a] | gas [TWH/a] | firewood [TWH/a] | total [TWH/a] | gas [TWH/a] | firewood [TWH/a] | total [TWH/a] |
| 2005 | 60 | 32 | 92 | 0 | 70 | 70 | 5 | | 5 | 4 | | 4 |
| 2006 | 61 | 32 | 93 | 0 | 71 | 71 | 5 | | 5 | 4 | | 4 |
| 2007 | 62 | 33 | 95 | 0 | 71 | 71 | 5 | | 5 | 4 | | 4 |
| 2008 | 63 | 33 | 96 | 0 | 73 | 73 | 5 | | 5 | 4 | | 4 |
| 2009 | 64 | 33 | 98 | 0 | 73 | 73 | 5 | | 5 | 4 | | 4 |
| 2010 | 66 | 33 | 100 | 0 | 73 | 73 | 5 | | 5 | 4 | | 4 |
| 2011 | 68 | 33 | 101 | 0 | 73 | 73 | 6 | | 6 | 4 | | 4 |
| 2012 | 70 | 33 | 103 | 0 | 73 | 73 | 6 | | 6 | 4 | | 4 |
| 2013 | 72 | 33 | 105 | 0 | 73 | 73 | 6 | | 6 | 4 | | 4 |
| 2014 | 74 | 33 | 107 | 0 | 73 | 73 | 6 | | 6 | 5 | | 5 |
| 2015 | 76 | 33 | 109 | 0 | 73 | 73 | 6 | | 6 | 5 | | 5 |
| 2016 | 78 | 33 | 111 | 0 | 73 | 73 | 6 | | 6 | 5 | | 5 |
| 2017 | 80 | 33 | 113 | 0 | 73 | 73 | 7 | | 7 | 5 | | 5 |
| 2018 | 82 | 33 | 115 | 0 | 73 | 73 | 7 | | 7 | 5 | | 5 |
| 2019 | 84 | 33 | 117 | 0 | 73 | 73 | 7 | | 7 | 5 | | 5 |
| 2020 | 86 | 33 | 119 | 0 | 73 | 73 | 7 | | 7 | 5 | | 5 |

Source: Elaboration of author

**Table 74:** Efficiency scenario - projection of electricity consumption of shower, air condition and refrigerator

| year | Shower | | | | | Air condition | | | | | Refrigerator | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Urban SHF | Rural SFH | SMFH | LMFH | Total | Urban SHF | Rural SFH | SMFH | LMFH | Total | Urban SHF | Rural SFH | SMFH | LMFH | Total |
| | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Total electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Total electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Total electr. Consu. [GWh/a] |
| 2005 | 13 | 2 | 1 | 1 | 17 | 12 | 1 | 1 | 2 | 15 | 18 | 3,0 | 2 | 1 | 23 |
| 2006 | 13 | 2 | 1 | 1 | 17 | 12 | 1 | 1 | 2 | 16 | 19 | 3 | 2 | 1 | 24 |
| 2007 | 14 | 2 | 1 | 1 | 18 | 13 | 1 | 1 | 2 | 17 | 19 | 3 | 2 | 1 | 25 |
| 2008 | 14 | 2 | 1 | 1 | 18 | 14 | 2 | 1 | 2 | 19 | 20 | 3 | 2 | 1 | 26 |
| 2009 | 15 | 2 | 1 | 1 | 19 | 15 | 2 | 1 | 3 | 20 | 20 | 3 | 2 | 1 | 26 |
| 2010 | 17 | 2 | 1 | 1 | 21 | 16 | 2 | 1 | 3 | 22 | 19 | 3 | 2 | 1 | 26 |
| 2011 | 18 | 2 | 1 | 1 | 22 | 17 | 2 | 1 | 4 | 24 | 19 | 3 | 2 | 1 | 26 |
| 2012 | 19 | 2 | 1 | 1 | 24 | 18 | 2 | 1 | 4 | 26 | 19 | 3 | 2 | 1 | 25 |
| 2013 | 21 | 3 | 1 | 1 | 25 | 20 | 2 | 2 | 5 | 28 | 19 | 3 | 2 | 1 | 25 |
| 2014 | 22 | 3 | 1 | 1 | 27 | 21 | 2 | 2 | 5 | 30 | 18 | 3 | 2 | 2 | 25 |
| 2015 | 23 | 3 | 1 | 1 | 29 | 22 | 2 | 2 | 6 | 32 | 18 | 3 | 2 | 2 | 25 |
| 2016 | 25 | 3 | 1 | 1 | 30 | 24 | 3 | 2 | 6 | 35 | 18 | 3 | 2 | 2 | 24 |
| 2017 | 26 | 3 | 1 | 1 | 32 | 26 | 3 | 2 | 7 | 37 | 17 | 3 | 2 | 2 | 24 |
| 2018 | 27 | 3 | 1 | 1 | 33 | 27 | 3 | 2 | 7 | 40 | 18 | 3 | 2 | 2 | 25 |
| 2019 | 29 | 3 | 2 | 1 | 35 | 29 | 3 | 3 | 8 | 43 | 18 | 2 | 2 | 2 | 26 |
| 2020 | 30 | 4 | 2 | 1 | 37 | 31 | 3 | 3 | 9 | 46 | 19 | 3 | 3 | 2 | 27 |

Source: Elaboration of author

**Table 75:** Efficiency scenario – projection of lighting and other appliances consumption

| Year | Lighting | | | | | other appliances | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Urban SHF | Rural SFH | SMFH | LMFH | Total | Urban SHF | Rural SFH | SMFH | LMFH | Total |
| | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Total electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Electr. Consu. [GWh/a] | Total electr. Consu. [GWh/a] |
| 2005 | 8 | 2 | 1 | 0 | 10 | 13 | 2 | 1 | 1 | 17 |
| 2006 | 8 | 2 | 1 | 0 | 11 | 13 | 2 | 1 | 1 | 17 |
| 2007 | 8 | 2 | 1 | 0 | 11 | 14 | 2 | 1 | 1 | 17 |
| 2008 | 8 | 2 | 1 | 0 | 12 | 14 | 2 | 1 | 1 | 18 |
| 2009 | 8 | 2 | 1 | 0 | 10 | 14 | 2 | 1 | 1 | 18 |
| 2010 | 7 | 1 | 1 | 0 | 10 | 15 | 2 | 1 | 1 | 19 |
| 2011 | 6 | 1 | 1 | 0 | 9 | 15 | 2 | 1 | 1 | 20 |
| 2012 | 6 | 1 | 1 | 0 | 8 | 16 | 2 | 1 | 1 | 20 |
| 2013 | 5 | 1 | 1 | 0 | 6 | 16 | 2 | 1 | 1 | 21 |
| 2014 | 4 | 1 | 1 | 0 | 5 | 17 | 2 | 1 | 1 | 21 |
| 2015 | 3 | 0 | 0 | 0 | 4 | 17 | 2 | 1 | 1 | 22 |
| 2016 | 3 | 0 | 0 | 0 | 4 | 17 | 2 | 1 | 1 | 22 |
| 2017 | 3 | 1 | 0 | 0 | 4 | 18 | 2 | 1 | 1 | 23 |
| 2018 | 3 | 1 | 0 | 0 | 4 | 18 | 3 | 1 | 1 | 23 |
| 2019 | 4 | 1 | 0 | 0 | 5 | 19 | 3 | 1 | 1 | 24 |
| 2020 | 4 | 1 | 1 | 0 | 5 | 19 | 3 | 2 | 1 | 24 |

Source: Elaboration of author

**Table 76:** Efficiency scenario – projection of cooking energy (USFH and RSFH)

| Year | Cooking energy consumption | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Urban SHF | | | | | Rural SFH | | | |
| | gas | wood | total [GWH/a] | sensitivity, gas (2% refurbish) | sensitivity, wood (2% refurbish) | gas | wood | total [GWH/a] | sensitivity, 2% refurbish |
| 2005 | 60 | 32 | 92 | | | 0 | 70 | 70 | |
| 2006 | 61 | 32 | 93 | | | 0 | 71 | 71 | |
| 2007 | 62 | 33 | 95 | | | 0 | 71 | 71 | |
| 2008 | 63 | 33 | 96 | | | 0 | 73 | 73 | |
| 2009 | 64 | 33 | 96 | | | 0 | 72 | 72 | |
| 2010 | 64 | 32 | 97 | | | 0 | 71 | 71 | |
| 2011 | 65 | 32 | 97 | | | 0 | 70 | 70 | |
| 2012 | 66 | 32 | 98 | | | 0 | 69 | 69 | |
| 2013 | 67 | 31 | 98 | | | 0 | 68 | 68 | |
| 2014 | 68 | 31 | 99 | | | 0 | 67 | 67 | |
| 2015 | 69 | 30 | 99 | | | 0 | 66 | 66 | |
| 2016 | 70 | 30 | 99 | | | 0 | 65 | 65 | |
| 2017 | 70 | 29 | 100 | | | 0 | 64 | 64 | |
| 2018 | 71 | 29 | 100 | | | 0 | 63 | 63 | |
| 2019 | 72 | 29 | 100 | | | 0 | 62 | 62 | |
| 2020 | 72 | 28 | 100 | | | 0 | 61 | 61 | |

Source: Elaboration of author

**Table 77:** Efficiency scenario – projection of cooking energy (SMFH and LMFH)

| Year | Cooking | | | | | | Total cooking | | |
|---|---|---|---|---|---|---|---|---|---|
| | SMFH | | | LMFH | | | Total | | |
| | gas | wood | total [GWH/a] | gas | wood | total [GWH/a] | gas | wood | sum [GWH/a] |
| 2005 | 5 | | 5 | 4 | | 4 | 69 | 102 | 171 |
| 2006 | 5 | | 5 | 4 | | 4 | 70 | 103 | 173 |
| 2007 | 5 | | 5 | 4 | | 4 | 71 | 104 | 175 |
| 2008 | 5 | | 5 | 4 | | 4 | 72 | 106 | 178 |
| 2009 | 5 | | 5 | 4 | | 4 | 73 | 105 | 177 |
| 2010 | 5 | | 5 | 4 | | 4 | 74 | 103 | 177 |
| 2011 | 5 | | 5 | 4 | | 4 | 75 | 102 | 176 |
| 2012 | 5 | | 5 | 4 | | 4 | 76 | 100 | 176 |
| 2013 | 6 | | 6 | 4 | | 4 | 77 | 99 | 176 |
| 2014 | 6 | | 6 | 4 | | 4 | 78 | 97 | 175 |
| 2015 | 6 | | 6 | 4 | | 4 | 79 | 96 | 175 |
| 2016 | 6 | | 6 | 4 | | 4 | 80 | 95 | 174 |
| 2017 | 6 | | 6 | 4 | | 4 | 80 | 93 | 174 |
| 2018 | 6 | | 6 | 4 | | 4 | 81 | 92 | 173 |
| 2019 | 6 | | 6 | 4 | | 4 | 82 | 91 | 173 |
| 2020 | 6 | | 6 | 5 | | 5 | 83 | 90 | 172 |

Source: Elaboration of author

# Annex F – Diagrams BAU and ES

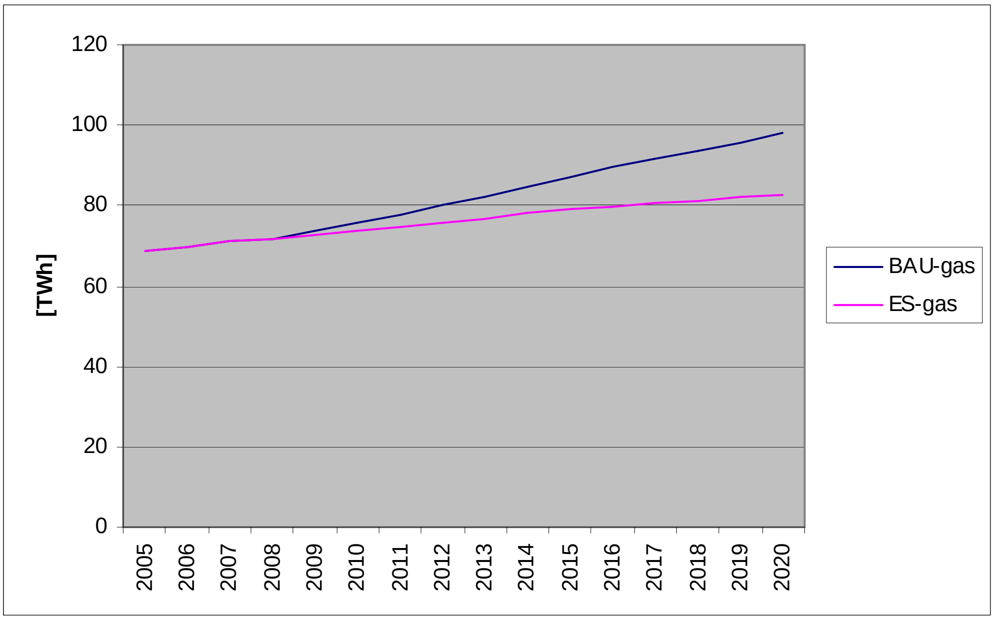


**Figure 78:** BAU and ES -Gas
Source: Elaboration of author

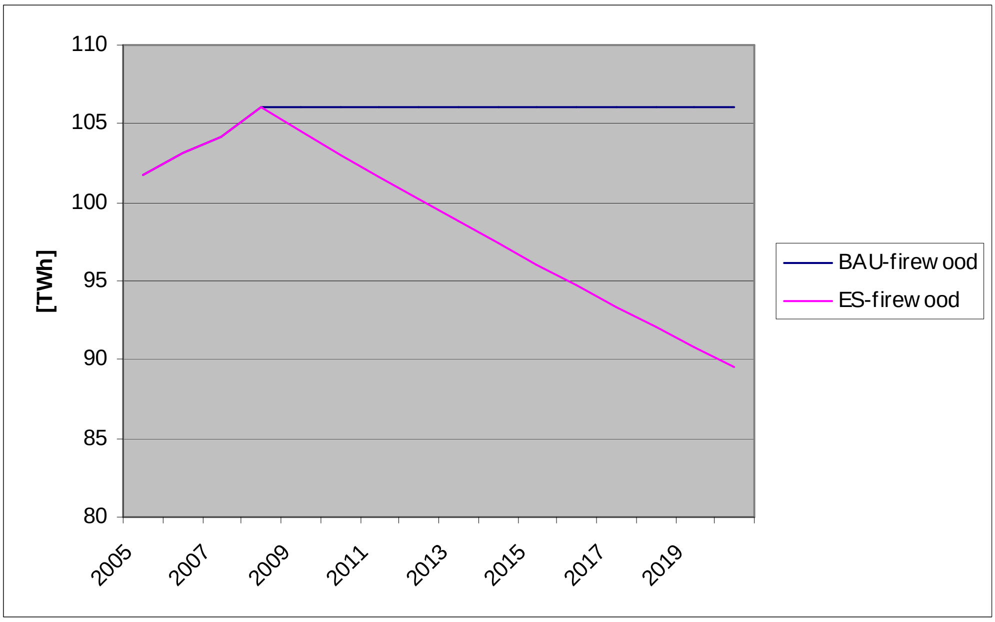


**Figure 79:** BAU and ES Cooking (firewood)
Source: Elaboration of author

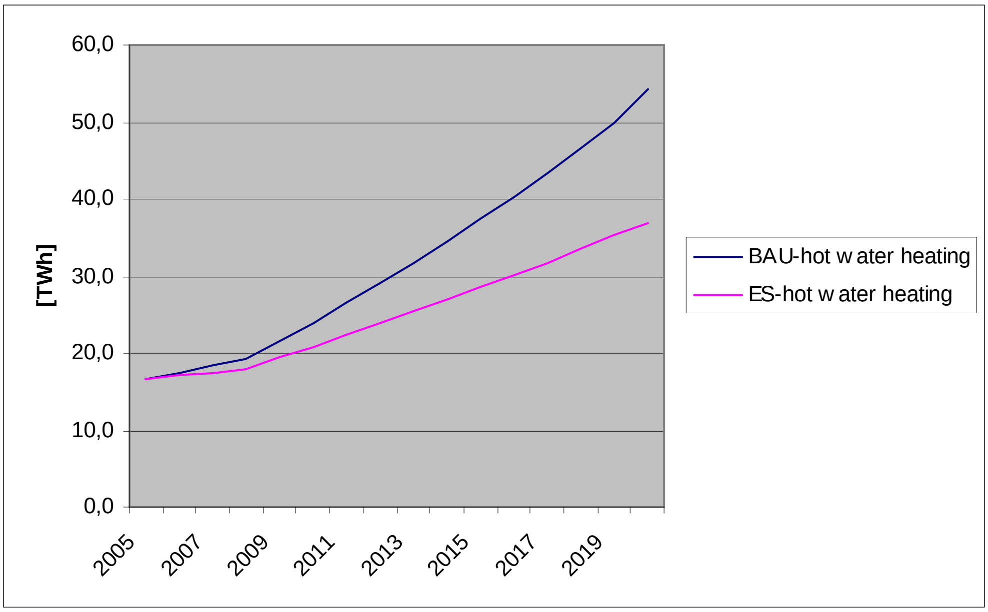


**Figure 80:** BAU and ES – Water heating
Source: Elaboration of author

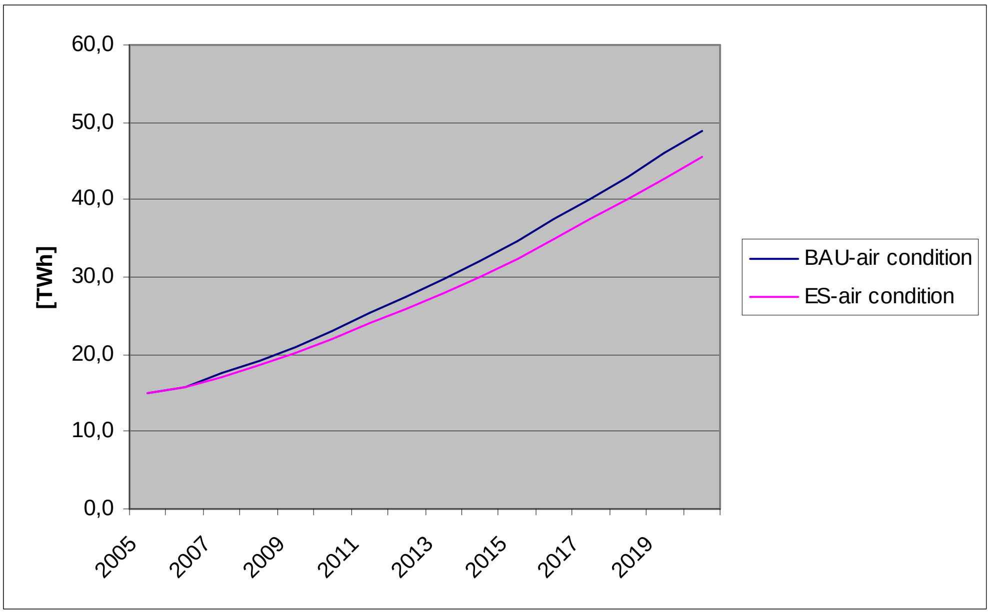


**Figure 81:** BAU and ES – Air condition
Source: Elaboration of author

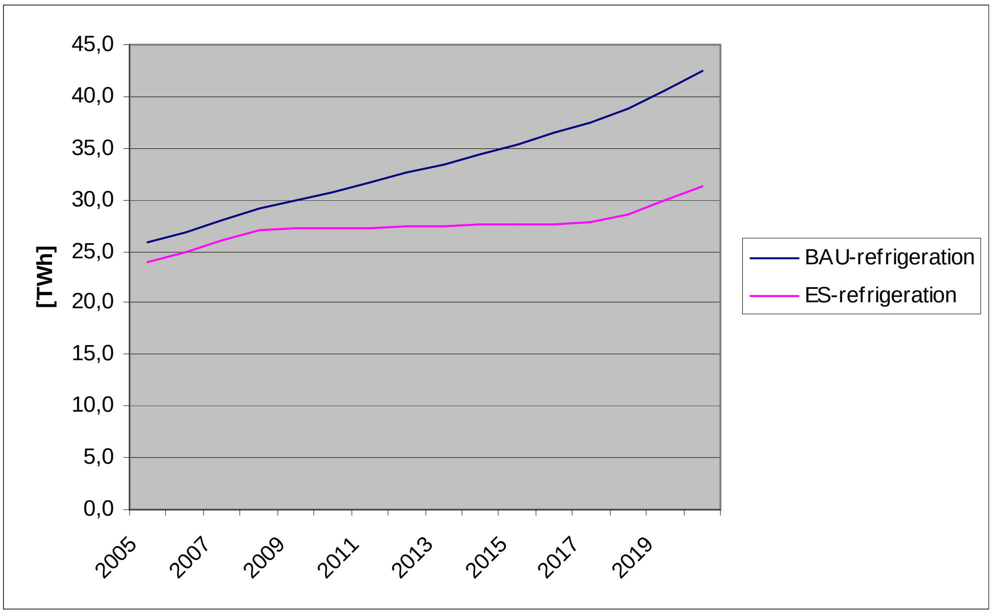


**Figure 82:** BAU and ES – Refrigeration
Source: Elaboration of author

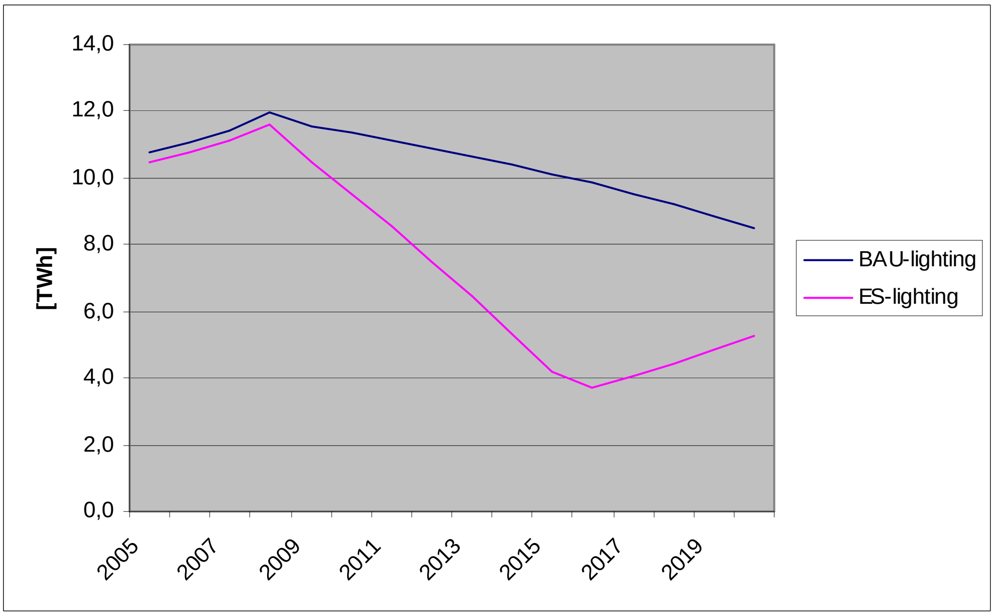


**Figure 83:** BAU and ES – Lighting
Source: Elaboration of author

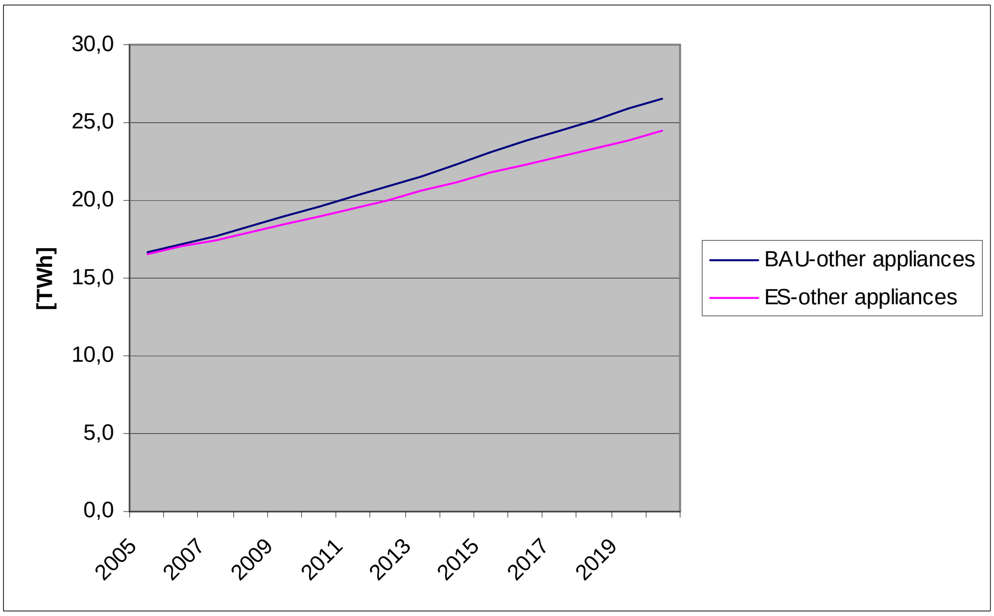


**Figure 84:** BAU and ES – Other appliances
Source: Elaboration of author

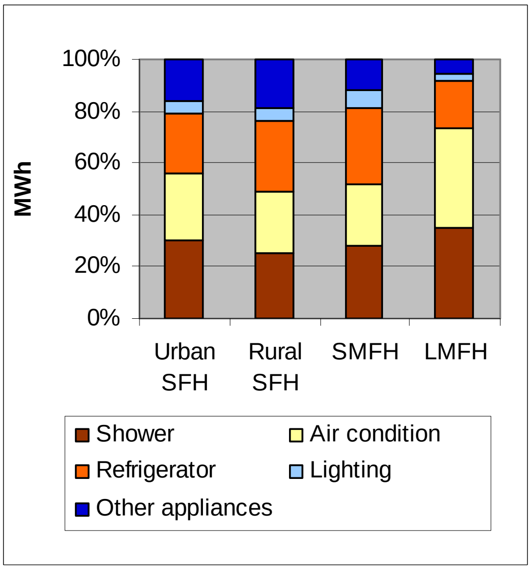


**Figure 85:** Share of electricity mix by building type under the BAU scenario by 2020
Source: Elaboration of author

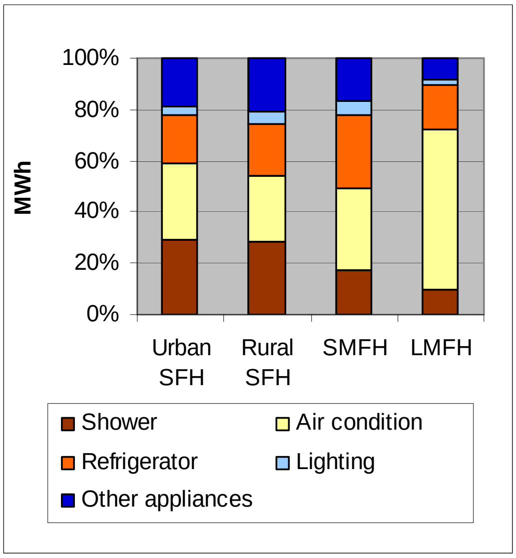


**Figure 86:** Share of electricity mix by building type under the ES scenario by 2020
Source: Elaboration of author