# A Life-Cycle Cost Analysis (LCCA) for Setting Energy-Efficiency Standards in Brazil: The Case of Residential Refrigerators

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**ABSTRACT**

The Brazilian law 10.295/2001 set the principles for the "National Energy Conservation Policy and Rational Use of Energy". The law requires the development of energy standards for all of energy consuming equipment commercialized in the country. This paper presents the impacts of introducing cost-effective improvements in domestic refrigerators that were determined by means of a LCCA analysis. The analytical approach and computer simulation tool used in the study are the ones employed for the US DOE as well as the European Commission.

The results were used to estimate the impacts of efficiency standards on new refrigerators up to year 2020 assuming two hypothetical cases. Case A assumes that all new refrigerators sold have the efficiency innovations proposed here, Case B assumes that part of these innovations would be included in a first mandatory standard enforced in year 2005 and in 2010 a second mandatory standard would consider all the innovations analyzed.

The electricity consumption per refrigerator in *Case A* can be reduced by 43% (in 2005) with currently known and available technologies. The payback time to the consumer (12% interest rate) is calculated to be 7 years (lower than the 16 years average life time). Over 2005-2020 period, Brazil would save around 80 TWh, Brazilian consumers would save more than 12 Billion R$ on their electricity bills and the nation would save 38,000 $GgCO_2$ (due to avoided $CO_2$ emissions from natural gas power plants).

In *Case B*, we assume two mandatory standards, one enforced in year 2005 that yields a 24% reduction. A second mandatory standard set in 2010 reduces by 48% (compared to the base year 2000 refrigerator consumption). The payback time was calculated as 7 and 12 years, respectively. Over 2005-2020 period, Brazil would save 70 TWh, the consumers would save 9 billion R$ and the nation would save 34,000 $GgCO_2$.

## Introduction

In Brazil until recently the labels were used on a voluntary basis. However, the Brazilian government has introduced compulsory legislation to introduce minimum efficiency standards, which should be mandatory in the next years.

The main objective of this study is the application of the LCCA methodology as a tool to propose efficiency standards for the Brazilian residential refrigerators. Some assumptions were adopted in order to allow the construction of all methodological stages. In some cases it was necessary to rely on numerical estimates to supply missing data. For instance, as it will be seen, the choice of the 2 cases (Case A and Case B) was based on sales of the two most popular refrigerators manufacturer brands in the country (both represent 93% of the market[1]).

The CLASP (2001) manual "Energy Efficiency Labels and Standard - a guidebook for appliances, equipment and lighting" presents three approaches/analysis for the establishment of minimum efficiency standards. A statistical approach is one option for analyzing the desirable level of a proposed standard. For each refrigerator model, energy use is plotted as a function of adjusted volume[2] and a linear regression analysis is performed. The two other approaches are engineering/economic and LCCA/payback (consumer, industry, national, and environmental impacts). In the case of the methodology using the statistical approach, the criteria for minimum appliance efficiency is recommended to be based on the possibilities of technical improvements for the whole stock of refrigerators, or at least a significant portion of them. In this study, it was used the economic/engineering and LCCA/payback approaches to create the % energy saving lines based in two models improvements, reducing substantially the number of necessary simulations for the establishment of efficiency criteria. Whenever data on production costs were missing, we based our estimates based on literature or information from North American refrigerator industry.

Due to lack of good statistical information on all models sold in Brazil, the study considers only two refrigerators models (the most sold model from each one of the two main manufacturers). These models were used to simulate two representative situations for the entire refrigerator stock described later in the paper. The LCCA methodology, proposed in CLASP (2001) manual, IEA (2000) and DOE (1995), has been considered here for evaluating some possible technical innovations with regards to their impacts in the economy and environment. The choice of the LCCA methodology is a contribution to the on going discussions to implement compulsory minimum efficiency standards in the country.

## The Brazilian Electricity Market: General Issues

In year 2000, a total of 306.3 TWh of electricity was produced in Brazil, 43% of this was consumed by the industrial sector, 27% by the residential and 15% by the commercial sector (BEN, 2001). The residential refrigerator is the largest user of electricity in the residential sector (32% of residential consumption), according to the National Program of Electric Power Conservation (PROCEL, 1998).

## Main Characteristics of Brazilian Refrigerators

The most sold refrigerators in the country are popular models suited to the lower purchasing power of the population. They are one-door models with a self-contained small freezer compartment (*congelador)* inside the refrigerator. They have a single cooling cycle,

[1] Statistics on market share sales by refrigerator models are not available in Brazil. The percentages presented in this report refer to manufacturers participation in total annual sales. This report assumes that manufacturers' one-door model maintain these proportions.

[2] Adjusted volume = Refrigerator Volume +1.42 *Congelador* Volume. *Congelador* is a small freezer compartment placed inside the refrigerator and present in Brazilian one-door models.

where the evaporator and the condenser operate by natural convection. In general, most of these models do not have complex controls or accessories; however, this has been changing recently as new manufacturers are competing in the domestic market. The average electricity consumption of these popular models is about 1kWh per day.

INMETRO (National Institute of Metrology, Standards and Industry Quality), in partnership with PROCEL (National Program of Electric Power Conservation), has a labeling energy efficiency program that now has the voluntary participation of a single-door refrigerator models. This program is further described in the Internet site of INMETRO (www.inmetro.gov.br).

Table 1 presents the mains characteristics of one-door refrigerators as analyzed by INMETRO.

**Table 1. Single-Door Refrigerators Analyzed by INMETRO/Procel Label**

| | | VOLUMES | | | | |
|---|---|---|---|---|---|---|
| **Brand** | **Model** | Refrige-rator | Freezer | Adjusted volume = Refrigerator +1.42 *Congelador* | Electricity consumption (kWh/month) | **Procel Label** |
| BOSCH | RB 31 | 297 | 00 | 297 | 24.5 | A |
| BOSCH | RB 38 | 367 | 00 | 367 | 27.0 | A |
| BRASTEMP | BRA31A | 253 | 33 | 300 | 32.0 | C |
| BRASTEMP | BRA35A | 296 | 33 | 343 | 36.0 | C |
| BRASTEMP | BRB35A | 329 | 00 | 329 | 36.5 | D |
| BRASTEMP | BRF36A | 330 | 00 | 330 | 29.5 | A |
| CCE | R31L | 263 | 30 | 306 | 30.0 | B |
| CCE | R32SL | 268 | 30 | 311 | 30.0 | B |
| CCE | R26L | 224 | 30 | 267 | 32.0 | D |
| BLUE SKY | R31L | 263 | 30 | 306 | 30.0 | B |
| HOUSTON | R31L | 263 | 30 | 306 | 30.0 | B |
| CONSUL | CRB23B | 223 | 00 | 223 | 32.0 | F |
| CONSUL | CRC24B | 191 | 22 | 222 | 30.5 | F |
| CONSUL | CRA32A | 272 | 31 | 316 | 26.6 | A |
| CONSUL | CRA32B | 272 | 30 | 315 | 24.9 | A |
| CONSUL | CRC32A | 272 | 31 | 316 | 28.8 | A |
| CONSUL | CRA36A | 312 | 30 | 355 | 31.5 | A |
| CONTINENTAL | RC 27 | 223 | 29 | 264 | 23.7 | A |
| CONTINENTAL | RC 30 | 257 | 29 | 298 | 27.0 | A |
| CONTINENTAL | RC 37 | 324 | 33 | 371 | 33.0 | A |
| ELECTROLUX | R250 | 214 | 26 | 251 | 24.6 | B |
| ELECTROLUX | R280 | 237 | 26 | 274 | 25.0 | A |
| ELECTROLUX | R310 | 263 | 31 | 307 | 30.0 | B |
| ELECTROLUX | R330 | 286 | 31 | 330 | 30.2 | A |
| ELECTROLUX | R360 | 312 | 31 | 356 | 32.4 | A |
| ESMALTEC | RG3100E | 283 | 27 | 321 | 34.8 | B |
| GE | GE310A | 263 | 31 | 307 | 30.0 | B |

Source: INMETRO, 2001.

It is important to recognize that there are autonomous energy efficiency improvements in the industry. It is possible to verify by the annual update in the INMETRO/Procel Label (see new electricity consumption by refrigerator model in the site www.inmetro.gov.br). It is also possible to verify by the laboratory tests that will be presented in the EEDAL (third International Conference on Energy Efficiency in Domestic Appliances and Lighting – EEDAL 2003) that shows an actual 340 kWh/year base case consumption, around 5% more efficient that the 360 kWh/year presented here). The LCCA method as applied here has not considered autonomous energy efficiency improvements in the scenarios calculation.

## Methodology

### The Choice of the Two Refrigerator Models and the LCCA Method

In order to choose refrigerator models as base-cases, or references, for this study, we observed the market share of the various existing models. As explained previously, available Brazilian statistical information suggested that the refrigerator model that is currently the market leader (53% of annual sales) already incorporates several technological innovations and is quite efficient from its competitors. The choice of a refrigerator that already had several innovations could not be a representative case to illustrate the LCCA method used. The second best selling model chosen has 29% of the current market and is less efficient than the market leader, but it allows illustrating the impacts of technological innovations and the LCCA method. This model is also more representative of other one-door refrigerators.

The analysis for the whole stock of refrigerators is based on these two models and considered two scenarios, namely Case A and Case B.

### The Cases Considered

Case A scenario (100% of the market is taken by the less efficient model) assumes that all refrigerators in the one-door category sold in the country are the same as the second model described.

Case B scenario (53% is taken up by the more efficient model and 47% by the less efficient model) is more realistic and assumes that improvements suggested are applicable only to 47% of the existing market; and therefore the standard is set at a lower efficiency level as the one considered in Case A, as will be presented later. At a later stage further improvements are enforced to all refrigerators. Case B therefore simulates the application of two standards over time.

Therefore, the analysis presented is based on the first and the second best selling model, as of year 2000.

### LCC Method

We follow the methodological itinerary proposed by the CLASP (2001) manual, as detailed in the Chapter 6 – "Analyzing and Setting Standards". The results presented here were obtained from the application of the methodology there described. The two approaches adopted in this study are an engineering/economic and LCCA/payback analysis. An engineering/economic analysis shows the extra manufacturing costs that accompany increases in energy efficiency. These must be weighted against the target reductions in energy costs. The engineering/economic approach does not prescribe that manufacturers meet the standard using the technical options used in the analysis. It simply ensures that there is at least one practical way to meet the standard. Once the engineering/economic analysis is completed, it is customary to analyze the economic impact of potential efficiency improvements on consumers by analyzing consumer payback period and life cycle cost (LCC). There are separate methodologies for estimating consumer LCC and payback period, national energy savings and economic impact, manufacturer impact, energy supply impacts, and environmental impacts.

Another support document which was relied on, especially with regards to the format of presenting our results, was "Technical Support Document: Energy Efficiency Standards for consumer products: Refrigerators, Refrigerator-Freezers, & Freezers" of DOE (1995).

The LCC is the sum of the purchase cost (P) and the annual operating costs (O) discounted over the lifetime (N, in years) of the appliance (see Box 1). Compared to the payback period, LCC includes consideration of two additional factors: lifetime of the appliance and consumer discount rate.

**Box 1. Calculating LCC and Payback Period**

The equation for LCC is a function of price (P) and annual operating cost (O):

$$LCC = P + \sum_{t=1}^{N} \frac{O_t}{(1+r)^t}$$

P = retail price to the consumers (R$); O = operating costs (electricity tariff etc.);
r = discount rate (real to the consumers); N = life time (years);
t = time (years) from the base case (appliance acquisition)
If operating expenses are constant over time, the above equation reduces to:
LCC = P + PWF * O
where the PWF (present worth factor) equals:

$$PWF = \sum_{t=1}^{N} \frac{1}{(1+r)^t} = \frac{1}{r}\left[1 - \frac{1}{(1+r)^N}\right]$$

Payback period (PAY) is found by solving the equation:

$$\Delta P + \sum_{1}^{PAY} \Delta O_t = 0$$

for PAY. The Delta signifies the difference from the base case to the standards case. Delta P is an increase in price and Delta O is a decrease in operating costs. In general, PAY is found by interpolating between the two years when the above expression changes sign. If the operating cost (O) is constant over time (t), the equation has the simple solution:

$$PAY = -\frac{\Delta P}{\Delta O}$$

Source: (CLASP 2001; Biermayer 2001).

# Results

## Costs and Performance Analysis

**Technical alternatives.** Based on the INMETRO data, manufacturers and literature, simulations of technical improvements were analyzed using the software ERA/EPA. The Brazilian refrigerator used in Case A was a model of 330 liters of adjusted volume and 360 kWh/year of electric power consumption. In Case B, a 320-liter model of adjusted volume and 320 kWh/year of electric power consumption was analyzed. The technical innovations chosen for the analysis are presented in Table 2.

**Table 2. Efficiency, Consumption, Standard, and Cost of the Technological Innovations**

| Description | | % Energy Savings (a) | | Payback (Years) | | Cost |
|---|---|---|---|---|---|---|
| | | Case A | Case B | Case A | Case B | (R$) |
| Base-case (C0) | Existing voluntary Procel label A set as a Mandatory Efficiency Standard | 4.0 % | 4.0 % | 0 | 0 | 0 |
| Innovation 1 (C1) | Base-case + more efficient compressor | 20.7 % | 16.1 % | 4 | 6 | 60 |
| Innovation 2 (C2) | Innovation 1 + increase of the door insulating thermal thickness - 1,27cm | 3.8 % | 3.9 % | 5 | 7 | 20 |
| Innovation 3 (C3) | Innovation 2 + increase of the wall insulating thermal thickness - 1,27cm | 14.0 % | 12.0 % | 7 | 9 | 67 |
| Innovation 4 (C4) | Innovation 3 + increase of the door insulating thermal thickness - 2,54cm | 2.8 % | 2.9 % | 8 | 10 | 18 |
| Innovation 5 (C5) | Innovation 4 + increase of the wall insulating thermal thickness - 2,54cm | 10.0 % | 9.2 % | 9 | 12 | 53 |

Source: innovations costs in dollars using the exchange of 21/august/2002 US$ 1.00 = R$ 3,30 (DOE 1995).
(a) Efficiency values were estimated using the simulation software ERA/EPA (Merrian, Verone & Feng nd).

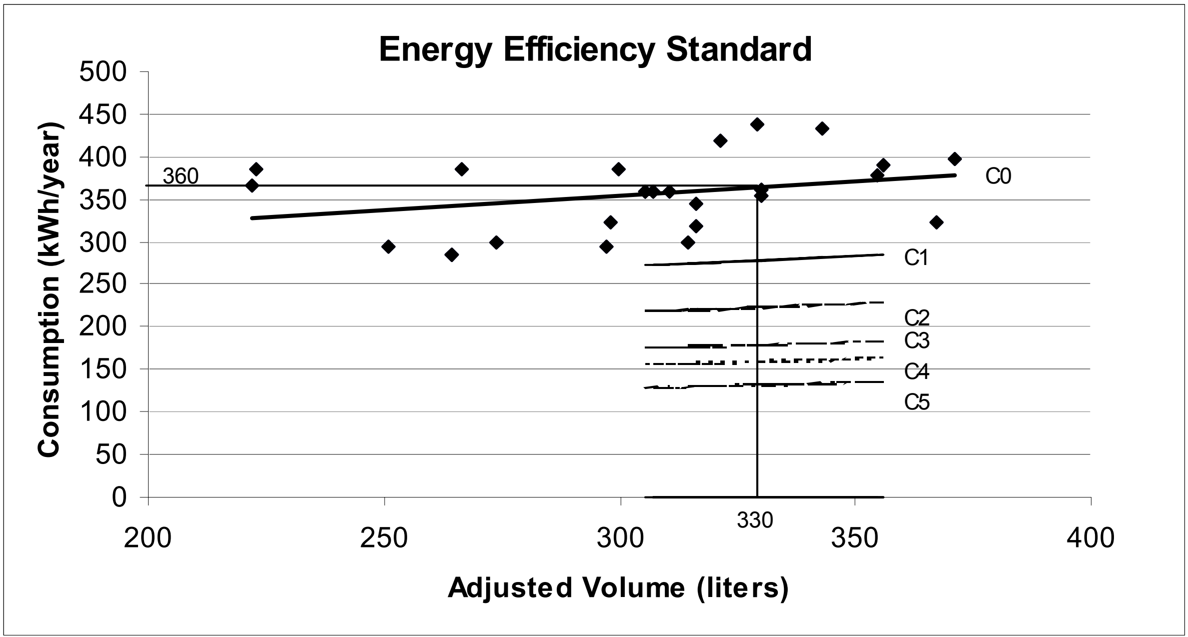
## LCCA Results

**Statistical method.** Data presented in Table 1 was used to fit a liner regression given by:

***Consumption (KWh/month) = 21.1678 + 0.0279 x adjusted volume***

Figure 1 presents the INMETRO data and the regression results. The refrigerator model used in the calculations is also represented on the graph, together with the results obtained introducing the technical improvements.

**Figure 1. Linear Regression Using INMETRO Refrigerators (Table 1) Data, and Possible Technological Innovations – Case A**




These statistical regressions performed using INMETRO data can be converted into standards recommendations for minimum energy consumption of energy. All the curves (C1, C2 etc.) are results of the new linear regressions that substitute the real models by the more efficient models in accordance with the suggested innovations (described in C1, C2, etc) in case A and case B (weighted efficiency index).

The C0 line regression, suggested that it is possible to get 4%[3] reduction if the Procel label A is a mandatory standard (all less efficient models - represented by the points above the solid line - will be forced to come down to the mandatory standard line). The second refrigerator model used as base-case (Case B hypothesis) lies exactly on the segment of straight line of the regression (C0).

According to the statistical methodology, in order to use regression results as recommendation for minimum standards, we should perform new simulations for each set of technical innovations for all models and then run a new regression based on the simulation results. These calculations are displayed as lines C1, C2, .., C5, where 1,2,..5 represent the innovations presented in Table 2.

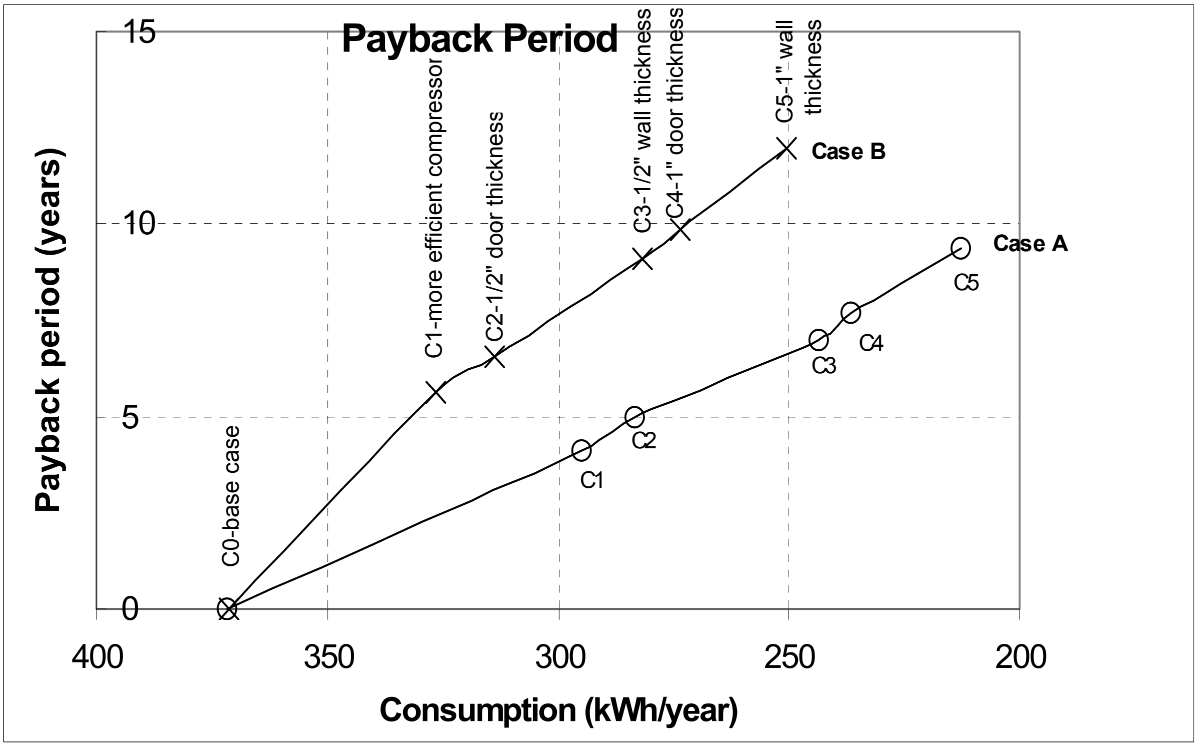
Table 2 presents the simulations results obtained using the ERA computer model[4] and available cost data. The percentage energy savings represent the average values per refrigerator for cases A and B.

[3] This is the arithmetic average of the reduction in electricity consumption of all the models above the regression line. We have not considered the market share participation of each model.

[4] The ERA model was adapted to incorporate as close as possible the technical characteristics of Brazilian refrigerators considered.

**Engineering/Economic Analysis.** Assuming a retail price of R$ 699.00 (14 August 2002) for a 330 and 320 liter refrigerator, the innovations costs described as in the Table 2, and the factor 2.42 - the Brazilian markup factor (consumer cost / manufacturer cost of refrigerators) - it is possible; assuming a 12% per year discount rate, to calculate the Payback Period curve (Figure 2), and to build the curve for the engineering/economic analysis (Figure 3) of refrigerator efficiency standards.

**Figure 2. Payback Period Analysis**

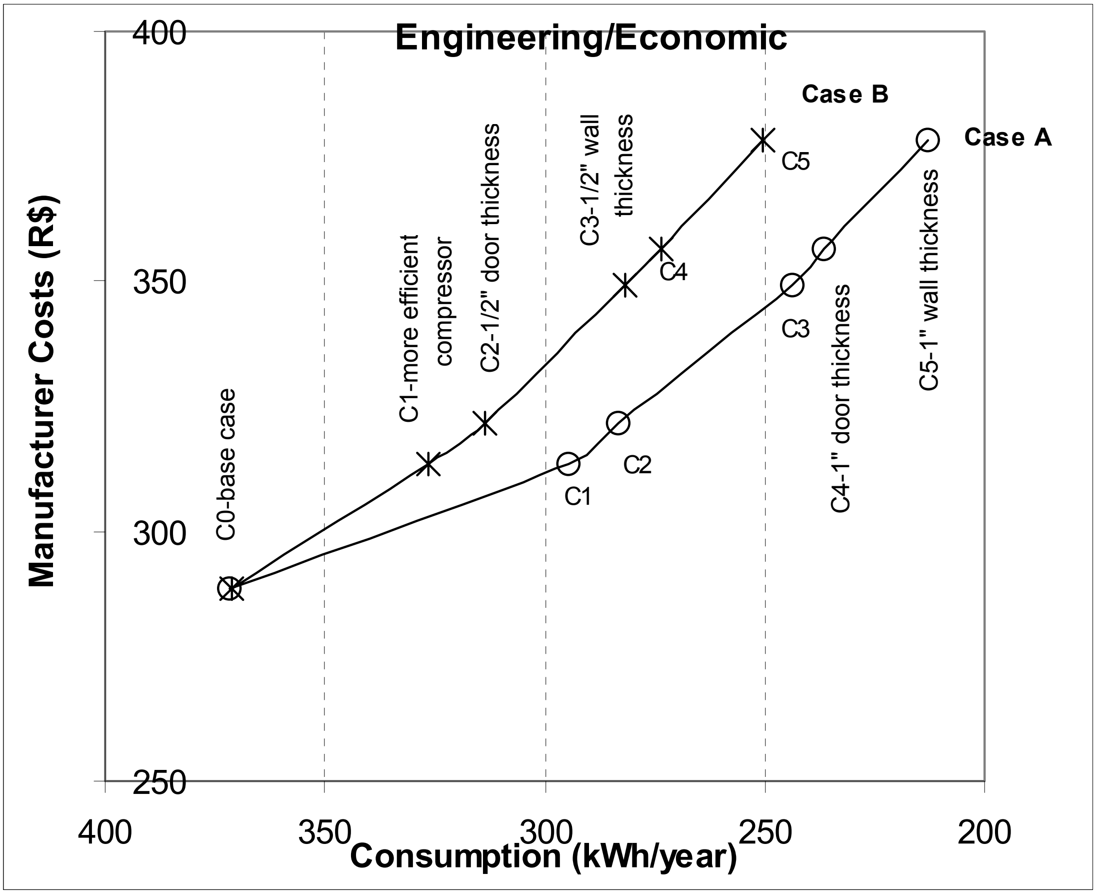



As expected, manufacturer's costs increases as innovations are introduced and electricity consumption is reduced (Figure 3). When all innovations are considered the total payback period rises to 12 years approximately, which is high, but less than the expected 16 years of useful refrigerator lifetime assumed by manufacturers (Figure 2).

**Life cycle cost (LCC) method for the consumer.** Assuming a 16-year useful lifetime for the refrigerator model, a 12% return rate and the electricity price 252 R$/MWh, including the 18%[5] of tax on the tariff of Agência Nacional de Energia Elétrica (ANEEL 2002), it is possible to construct Figure 4 of LCC for the consumer.

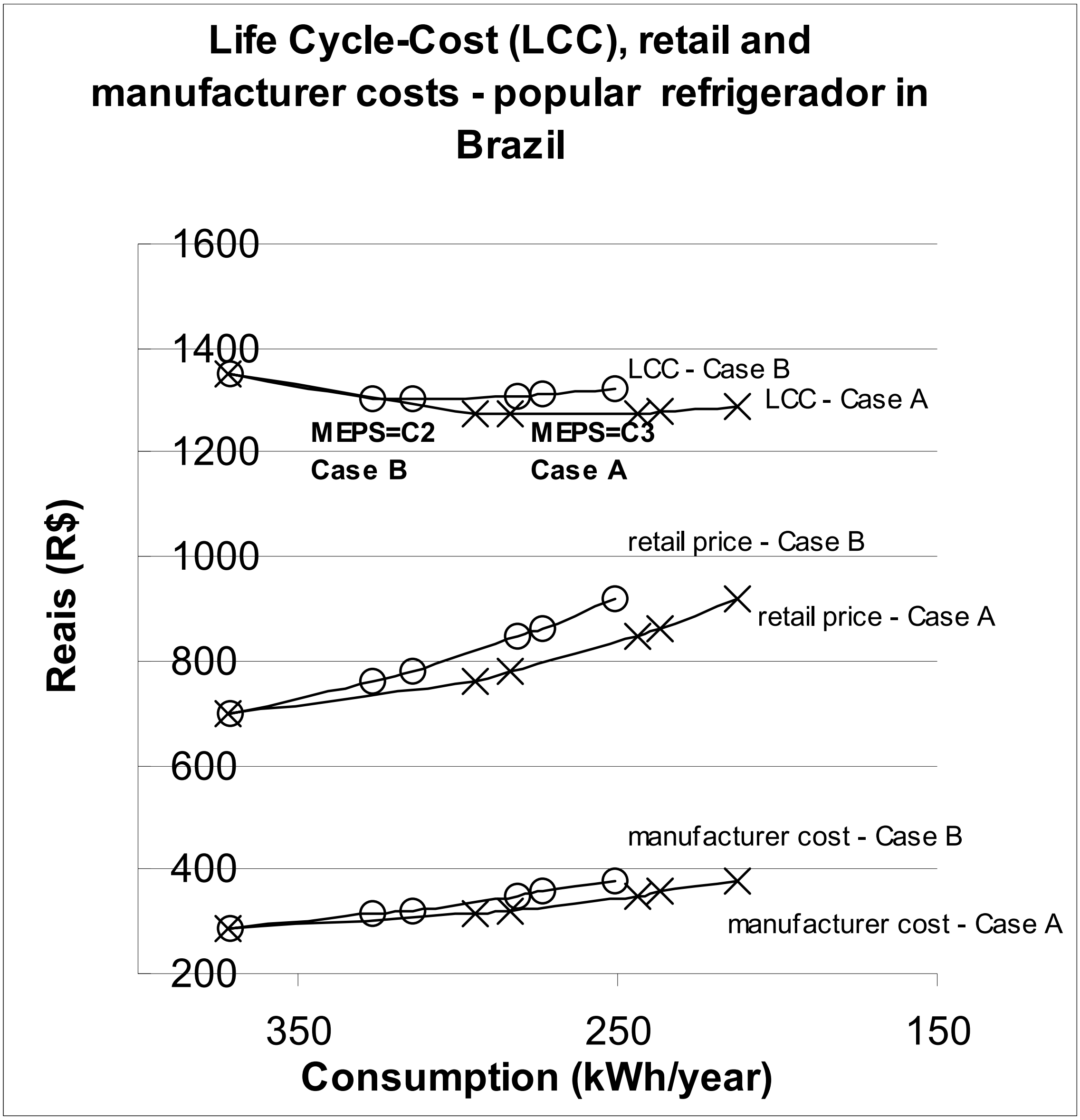
[5] It is assumed tax of 18% as a national average, because there are different estate taxes in Brazil.

**Figure 3. Engineering/Economic Calculations**




The life-cycle cost analysis performed for Case A (Figure 5) which considered the popular Brazilian one-door refrigerator model suggests that the standard has to be set at the C3 (MEPS - *minimum energy performance standards* of 43%) level. MEPS is the point of the lowest LCC to consumers and has, in this case, a 7 years payback period. However, with a sensitivity analysis (changing the USA costs of improvements to a better change/exchange rate – 1U$ = 2 R$), it is possible to propose a mandatory standard of 55% (C5) to 2005 (that maintains a LCC to the consumer lower than the base-case LCC).

**Figure 4. Life Cycle Cost (LCC) - Popular Brazilian Refrigerators**




In the Case B Life Cycle Cost Analysis it was used the same structure of the linear regression of the refrigerator units sold in Brazil (with the lifetime calculation of the refrigerators based on these vintages and the household penetration too).

The Case B hypothesis incorporates in the analysis the 4% obtained from the mandatory standard based on the existing Procel label A (innovation C0 in Table 2) and 20% from innovations C1 and C2 (Table 2), totalizing 24% (MEPS = C2) for a first standard in 2005. The second standard would be 48% assuming all improvements (Table 3).

**Figure 5. LCC Sensitivity Analysis – Case A - Popular Brazilian Model**

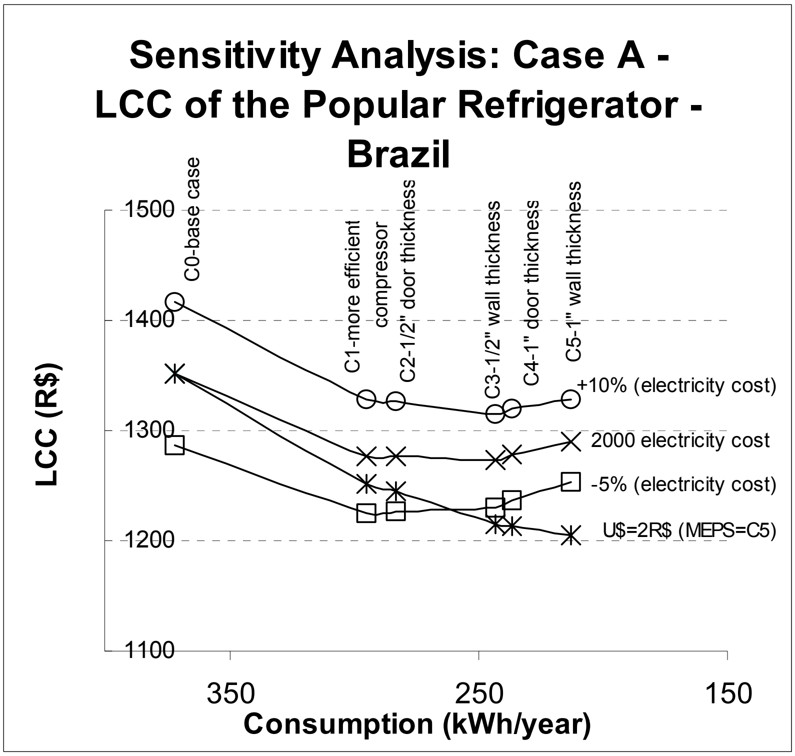



**Table 3. Summary Results**

| Indicators | Case A | Case B |
|---|---|---|
| Mandatory Standards (energy reduction) | 43% (year 2005) (*) | 24% (first standard in 2005)(*)<br>48% (second standard in 2010)(*) |
| Payback Period | 7 years | 7 years (first standard)/12 years (second standard) |
| Improvements | - Voluntary Procel label A like a mandatory standard, new compressor, increase of the door and walls insulating thermal thickness - ½". | - Voluntary Procel label A like a mandatory standard, new compressor, increase of the door insulating thermal thickness - ½" (first standard);<br>- All improvements analyzed (second standard). |
| Energy saved (TWh) | 12 (until year 2010) 80 (until year 2020) | 7 (until year 2010) 70 (until year 2020) |
| $CO_2$ Conservation (Gg) | 38,160 (2005-2020 period) | 33,759 (2005-2020 period) |
| Billion R$ saved on the electricity bill | 12 (2005-2020 period) | 9 (2005-2020 period) |

Notes: It was assumed a coefficient 0.48 kg CO2/kWh (emission from Natural gas fuelled thermoelectric plant). All values were calculated in R$ (2000). (*) compared to the 2000 refrigerator model.

## Conclusions

The use of tools and methods that simulate the refrigerator performance according to proposed technical innovations and the use of life cycle cost analysis show that it is possible to obtain significant reductions in electricity consumption in Brazilian refrigerators.

The results represent important inputs to subsidy further discussion with manufacturers in the process of setting-up efficiency standards for Brazilian refrigerators.

The paper suggests that the amount of savings can be in the range of 24-43% in year 2005 if the MEPS are adopted. The improvements are the implementation of the mandatory standard, more efficient compressors and increase of the door and walls insulating thermal thickness (1/2"), all cost effective with a payback period of 7 years. Over 2005-2020 period, the amount of energy savings can be in the range of 70-80 TWh, the amount of $CO_2$ conservation can be in the range of 34,000-38,000 Gg and the Brazilian consumers would save around 9-12 billion R$ (reais).

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