A life-cycle cost analysis for setting energy-efficiency standards in Brazil:

The case of residential refrigerators.

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Preface

This report presents the study performed during August-Dember/2002 in order to illustrate the application of the life-cycle cost analysis to help the discussions in setting-up technical and economical parameters for energy-efficiency standards.

We used the example of residential refrigerators, which are responsible for about one third of the residential electricity bill.

As our results show, significant savings can be achieved cost-effectively in this appliance, and these estimates should be regarded as inputs to further discussions with government officials, manufacturers and civil society. Brazil has a law that requires the establishment of minimum energy efficiency standards and a steering committee (CGIEE – Comitê Gestor de Indicadores de Eficiência Energética) that is responsible for implementing these standards. It is hoped that work such as this one can help the CGIEE and others in the process.

We received several inputs and support to carry out the analysis, but none of the partners, institutions or individuals, are responsible for the analysis and opinions presented. Comments or questions are welcome and should be directed to me.

Campinas 23 December 2002.

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SUMMARY

The Brazilian federal 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 report presents calculations made on the impacts of introducing cost-effective improvements in domestic refrigerators that will represent important energy saving to Brazilian consumers. Case A assumes that all new refrigerators sold have the high efficiency innovations proposed here, Case B assumes that these high efficiency would be applicable to 47% of the existing market share, which corresponds to the market share of less efficient refrigerators currently sold in the country.

A detailed cost-engineering analysis is performed on a single-door domestic refrigerator representing the average model found on the Brazilian market. The electricity consumption in *Case A* can be reduced by more than 43% with currently known and available technologies. The extra cost associated with the technical improvements is offset by the electricity savings: the payback time to the consumer (12% interest rate) is calculated to be 7 years, lower than the average life time of such appliance in Brazil, estimated at 16 years. The analytical approach and computer simulation tool used in the study are the ones employed in similar analysis done for the US Department of Energy as well as the European Commission. If the forthcoming energy efficiency standards under the new federal law 10.295 are set to the level assessed through the life cycle cost analysis just described, Brazil would save around 12 TWh until 2010, or 80 TWh until 2020, if the standard is enforced in year 2005. Over the 2005-2020 period, Brazilian consumers would save more than 12 Billion R$ on their electricity bills and the nation would save 38,000

Gg CO_2 (due to savings in thermoelectricity generation using natural gas).

The average electricity consumption per refrigerator in *Case B* can be reduced by 24% in a first moment and by 48% in a second moment with all currently known and available technologies (these reductions were calculated assuming that 47% of the market share would get the high efficiency innovations and the others 53% of the market share would have lower efficiency improvements due to the existing more efficient model). The extra cost associated with the technical improvements is also offset by the electricity savings: the payback time to Brazil is calculated to be 7 and 12 years for the first and second mandatory standard (24% reduction in 2005 and 48% in 2010 based in the 2000 level at 12% interest rate), lower than the average life time of such appliance in Brazil, estimated to be 16 years. If the forthcoming energy efficiency standards under the new federal law 10.295 are set to the level assessed through the life cycle cost analysis just described, Brazil would save around 7 TWh until 2010, 70 TWh until 2020 if the standards are enforced as off 2005 and 2010. Over the period 2005-2020, Brazilian consumers would save more than 9 billion R$ on their electricity bill and the nation would save 33,000 Gg CO_2.

This project discusses the international experience on the subject, and relies on life cycle cost analysis (LCCA) for supporting the process of setting Brazilian energy efficiency standards for appliances and equipment. A case study was proposed to study single-door domestic refrigerators with a small freezer (called *congelador*) inside the fresh food refrigerator space. This is the most popular model in Brazil. A numeric refrigeration simulation model (ERA software - Environmental Protection Agency – EPA/USA) was used to evaluate technical improvements for the life cycle cost model. The economic and technical data for this study were obtained among manufacturers, government, literature and laboratory tests. The analysis provides useful technical support as inputs to the process of setting up energy efficiency standards. Laboratory measurements were performed and the results obtained supported the reduction in electricity consumption estimated in the present work.

A full report is available in Portuguese with more details of the work, and presents the experimental results as well.

INTRODUCTION

Since the main objective of this study is the application of the methodology for the Brazilian context, some assumptions were adopted to allow the construction of all methodological stages. In some cases it was necessary to rely on numerical estimates in order to supply lack of 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 in the country (both represent 93% of the market). 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, new thresholds were created by these 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.

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.

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 (Figure 1).

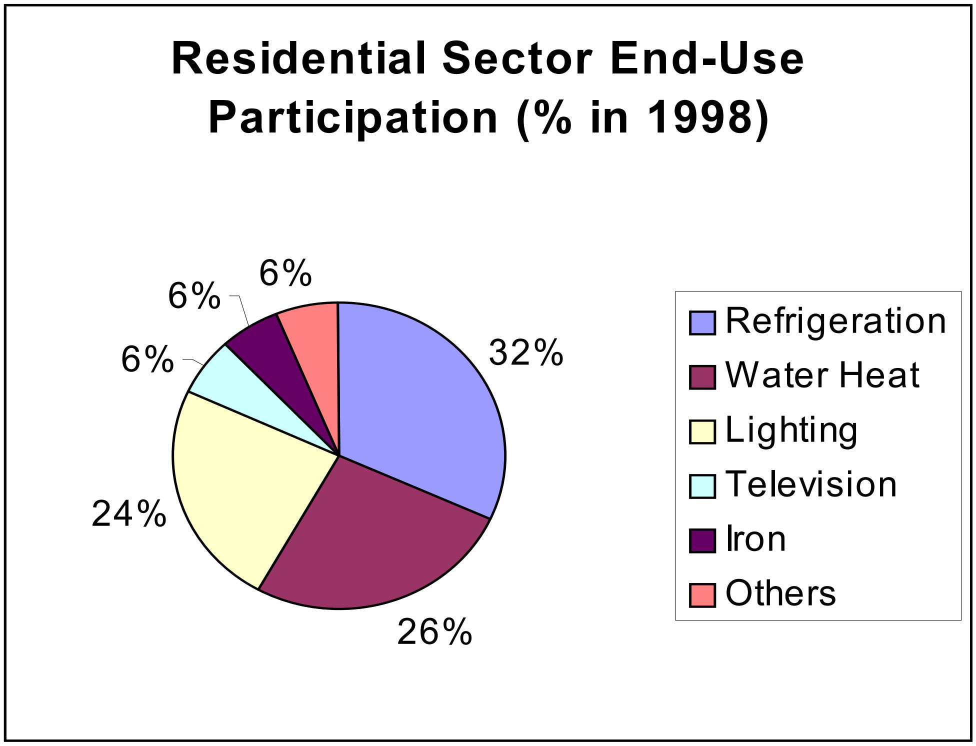

Figure 1 - Brazilian residential sector: end-use participation (%).

Source: (BEN, 2001; PROCEL, 1998).

The national electricity system is mainly based on hydroelectricity. It consists of two different grid systems: the interconnected national system and the isolated system. The former consists of two subsystems that are operated independently: South/Southwest/Center-west and North-northeast. Both systems are interconnected.

The interconnected grid system supplies most of the national market, and responds for great part of the installed capacity (~96% - 62.463 MW), while approximately the 4% (2.287 MW) remaining refer to the isolated system, which included more than 330 electrically areas isolated one of the other, most in the Northern Area. Regarding the supply base, the installed capacity of the interconnected system is practically all based on hydroelectricity, while the isolated system is largely thermal (ELETROBRÁS, 2000).

Main characteristics of Brazilian refrigerators

The refrigerators most sold in the country are popular models suited to the lower purchasing power of the population. They consist of a one-door refrigerator and a self-contained small freezer (*congelador)* inside the refrigerator. It has a single cooling cycle, 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 is 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, in partnership with PROCEL, 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	Refrigerator (Refr.)	Freezer	Adjusted volume = Refr. +1.42 Congelador	**Electricity consumption (kWh/month)**	Procel Label
BOSCH	RB 31	297	0	297	24.5	A
BOSCH	RB 38	367	0	367	27.0	A
BRASTEMP	BRA31A	253	33	300	32.0	C
BRASTEMP	BRA35A	296	33	343	36.0	C
BRASTEMP	BRB35A	329	0	329	36.5	D
BRASTEMP	BRF36A	330	0	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	0	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.

METHODOLOGY

The choice of the two refrigerator models LCCA method

In order to choose models as base-cases for this study, it was observed the market share of the various existing models. The refrigerator model that is currently the market leader (53%)[1] already

[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

incorporates several technological innovations and is quite efficient. The choice of a refrigerator that already had several innovations could not be a representative case to illustrate the method used. The second model chosen has 29% of the current market share and is less efficient than the market leader, but it allows for better illustrate 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 Base Cases considered

Case A scenario assumes that all refrigerators in the one-door category sold in the country are the same as the second model described.

Case B scenario is more realistic and assumies that improvements sugested are applicable only to 47% of the existing market, at a later stage further improvents are enforced to all refrigerators. Case B therefore simulates the application of two standards over time. Then, for this exercise it was used the first and the second best selling model.

<u>RESULTS</u>

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 was a model of 330 liters of adjusted volume and 360 kWh/year of electric power

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total annual sales. This report assumes that manufacturers' one-door model maintain these proportions.

consumption. Observe the consumption and the efficiencies estimated in Table 1. The technical innovations chosen for the analysis are presented in Table 2.

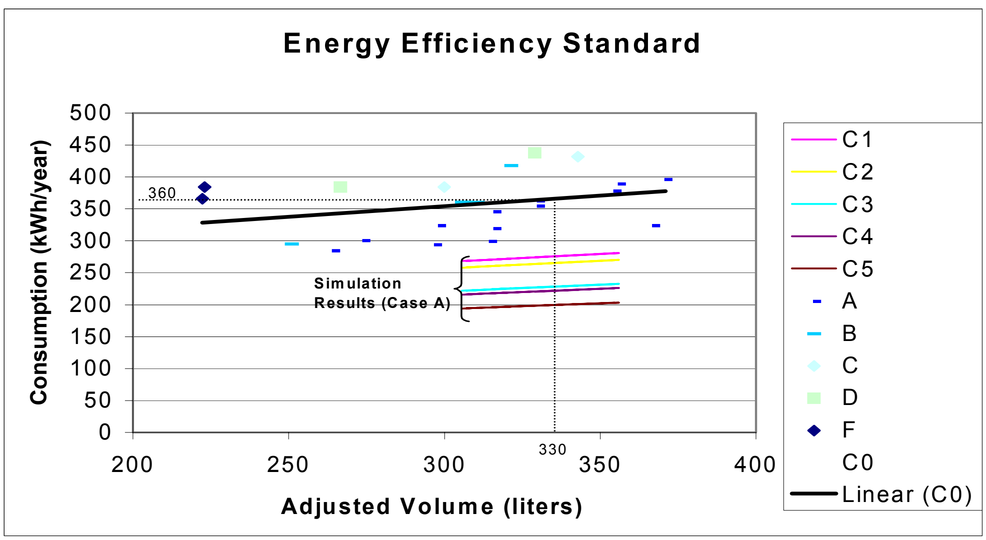
LCCA Results

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

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



Graph 1 - Statistical treatment with INMETRO refrigerators population linear regression, and the possible technological innovations – (case A)

These statistical regressions performed using INMETRO data can be converted into standards recommendations for minimum energy consumption of energy.

This regression, suggested that it is possible to get 4% reduction if the Procel label A is a mandatory standard. (xx) The second refrigerator model used as base-case (Case A hypothesis) lies exactly on the segment of straight line of the regression (the larger line on Graph 1). According to the statistical methodology, in order to use regression results as recommendation for minimum standards, we should perform new simulations of the set of technical innovations for all models and then run a new regression based on the simulation results.

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

Table 2: Efficiency, consumption, standard and cost of the technological innovations.

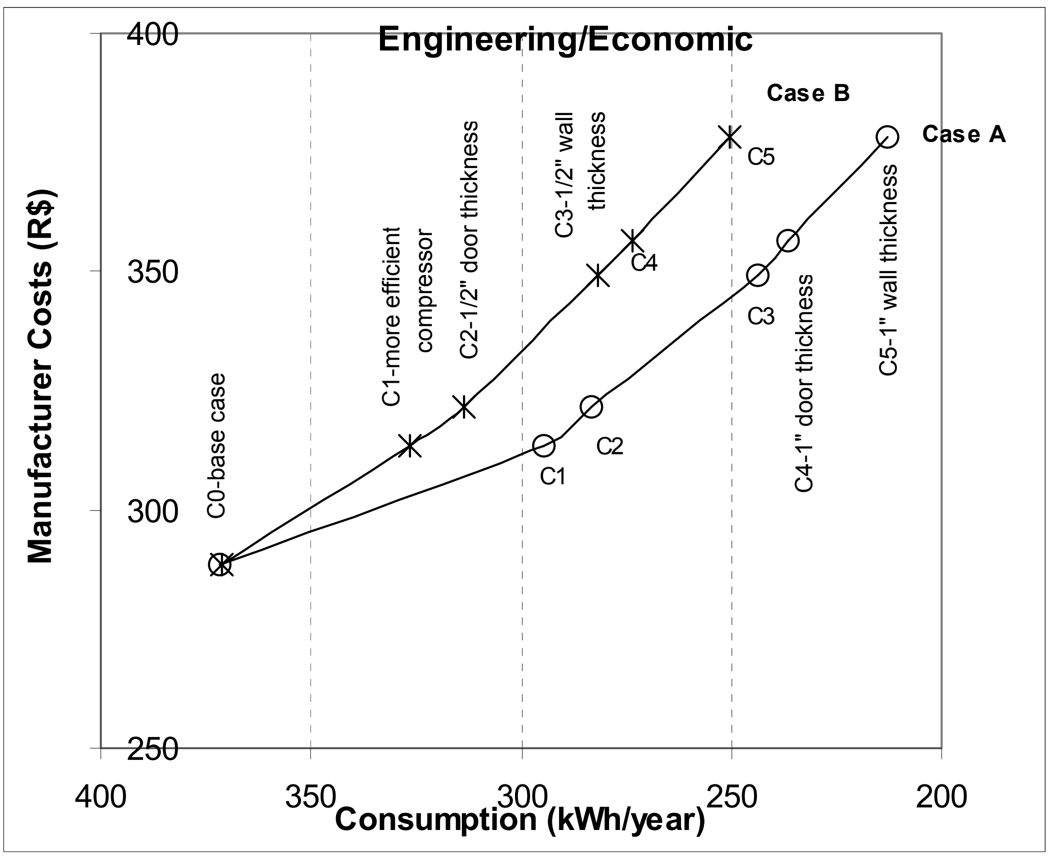
Description		% Energy Savings (a)		Payback (Years)		Costs
		Case A	Case B	Case A	Case B	(R$)
Base-case (C0)	Voluntary Procel label A as Mandatory Standard	4.0 %	4.0 %	0	0	0
Innovation 1 (C1)	Base-case + more efficient compressor	20.7 %	16.1 %	4	6	60
Innovation 2 (C2)	Innovation 1 + increase of the door 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.

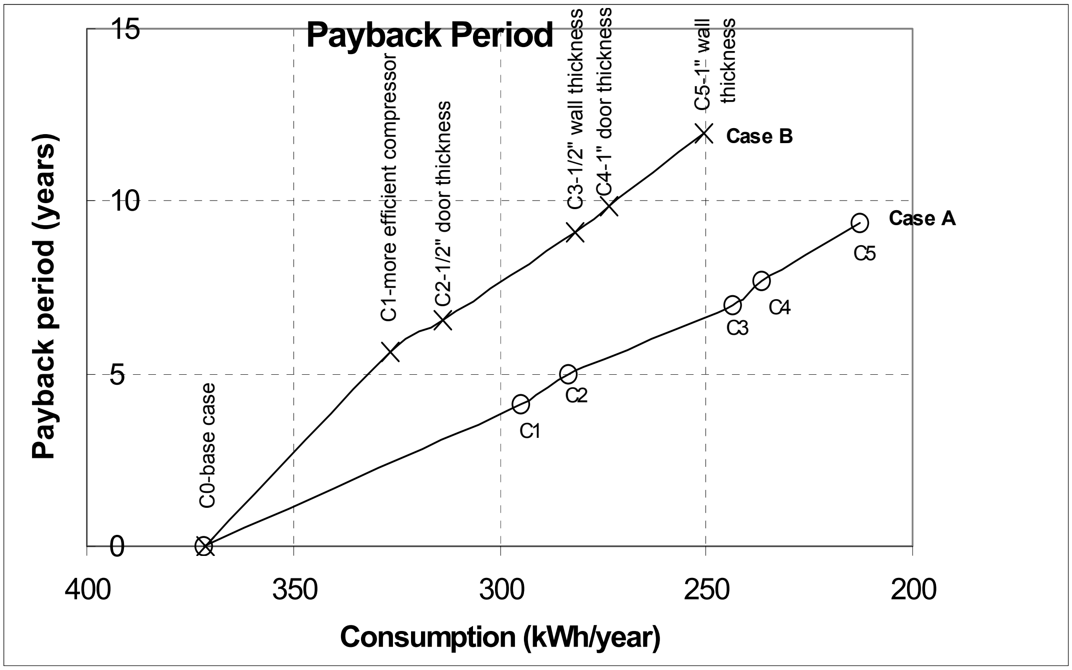
(a) Efficiency values were estimated using the simulation software ERA (EPA).

Engineering/Economic Analysis

Assuming a retail price of R$ 699.00 (14 August 2002) for a 330 liter refrigerator and the innovations costs described as in the Table2; and the factor 2.42 - the Brazil markup factor (consumer cost / manufacturer cost of refrigerators) - it is possible to build the curve for the engineering/economic analysis (Graph 2) and; assuming a 12% per year discount rate to calculate the Payback Period curve (Graph 3).



Graph 2: Engineering/Economic calculations.

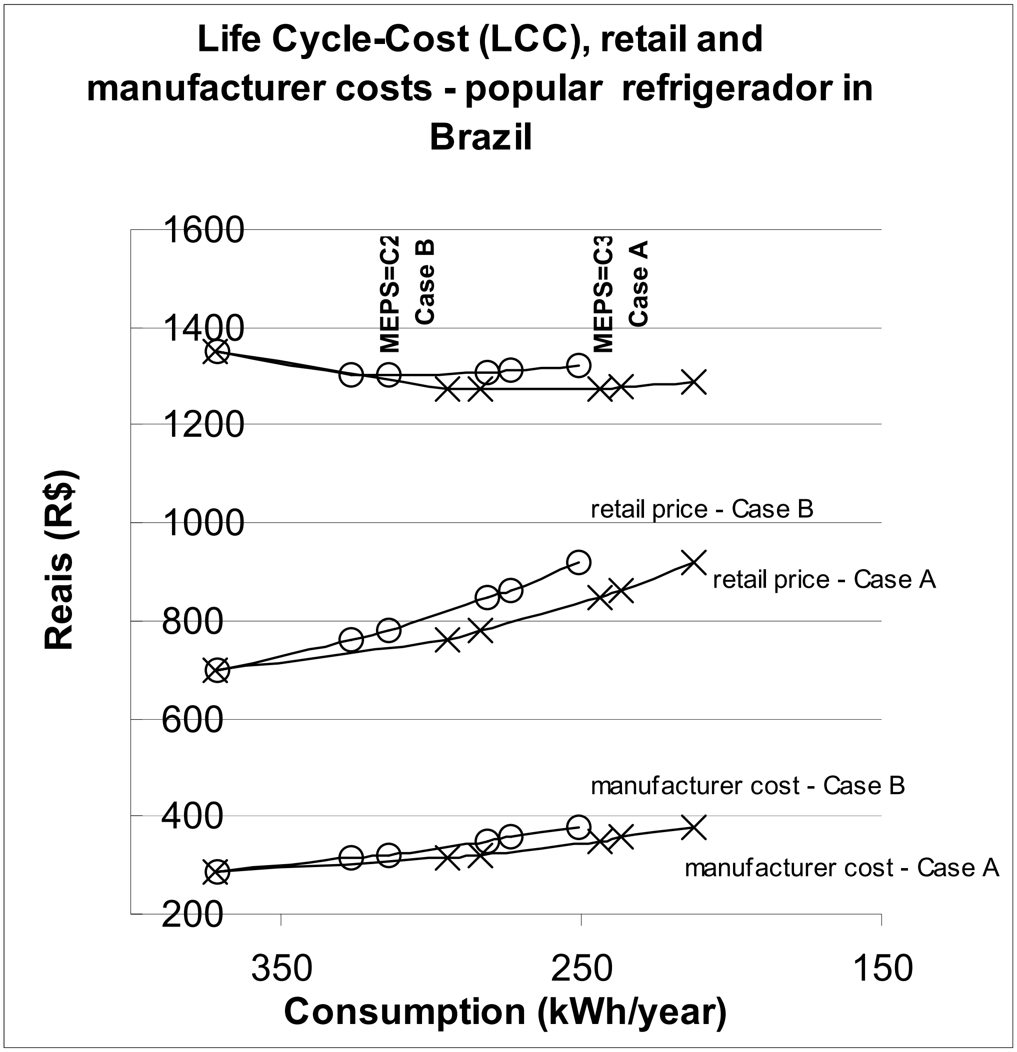


Graph 3: **Payback Period Analysis.**

The manufacturer's costs increases as innovations are introduced and electricity consumption is reduced (Graph 2). 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 (Graph 3).

Life cycle cost (LCC) Method

Assuming a 16-year useful lifetime for the refrigerator model, a 12% return rate and the electricity price 252 R$/MWh (including the 18% of tax in the tariff of ANEEL – *Agência Nacional de Energia Elétrica*), it is possible to construct the Graph 4 of LCC for the consumer:



Graph 4 – Life Cycle Cost (LCC), retail and manufacturer costs - Popular Brazilian Refrigerators.

The CLASP manual "Energy Efficiency Labels and Standard - a guidebook for appliances, equipment and lighting" presents the diversity of approaches for the establishment of minimum patterns of efficiency and suggests one approach, which was adopted in this study. We follow the methodological itinerary proposed by the CLASP manual, detailed in the Chapter 6 – "Analyzing and Setting Standards". The results presented here were obtained from the application of the methodology there described. Another support document which we relied, 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 the North American Department of Energy, of july/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).

Box 1 - Calculating LCC and Payback Period.

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

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

P = retail price to the consumers (R$)

O = operating costs (electricity tariff etc.)

r = discount rate (real to the consumers)

t = time (years) from the base case (appliance acquisition)

N = life time (years)

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:

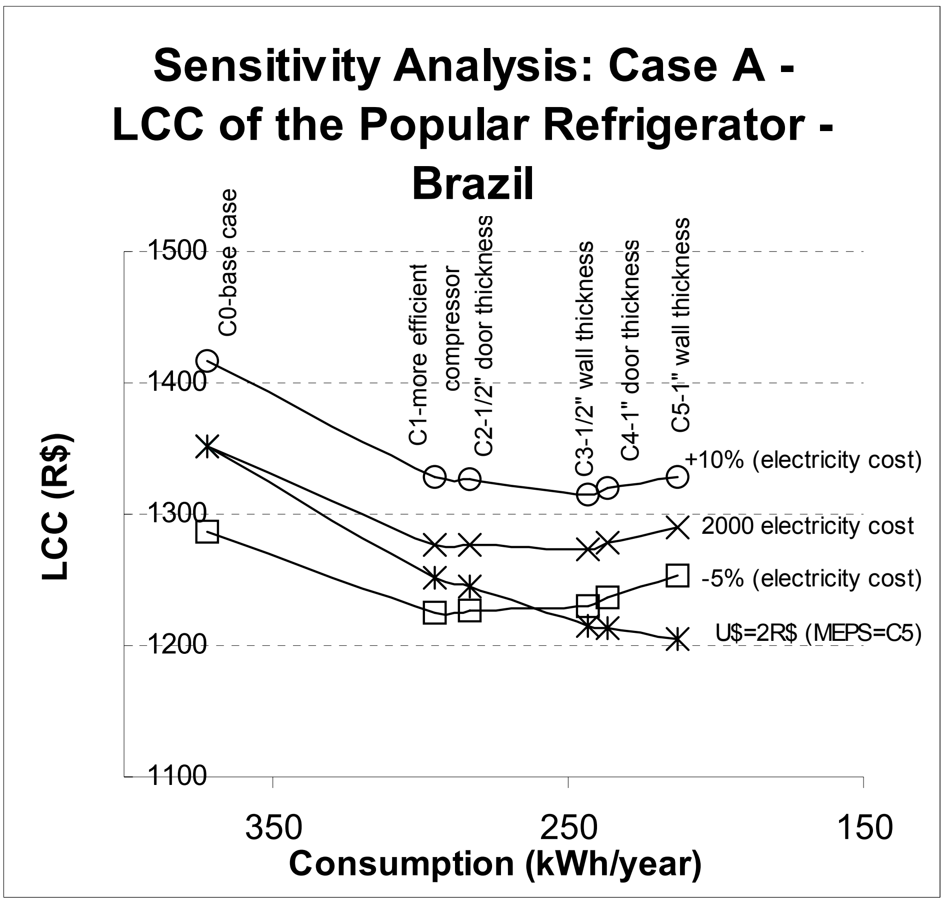
$$PAY = -\frac{\Delta P}{\Delta O}$$

Source: (CLASP, 2001).

Compared to the payback period, LCC includes consideration of two additional factors: lifetime of the appliance and consumer discount rate.

CONCLUSIONS

The life-cycle cost analysis performed for Case A (Graph 5) which considered the popular Brazilian one-door refrigerator model suggests that the standard is set at the C3 (43%) level. This is the point of the lowest LCC to consumers and has 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).



Graph 5 – LCC Sensitivity Analysis – Case A - Popular Brazilian model.

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 (Annex 1 – that shows 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% for a first standard in 2005 The second standard would be 48% assuming all improvements.

Table 3 presents the summary results of the calculations performed.

Table 3 – Summary Results:

Indicators	**Case A**	**Case B**
Mandatory Standards	43% (year 2005)	24% (first standard in 2005) 48% (second standard in 2010)
Payback Period	7 years	7 years (first standard) 12 years (second standard)
Improvements	- Voluntary Procel label A as 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); - All improvements analyzed (second standard).
Energy Conservation (TWh)	12 (until year 2010) 80 (until year 2020)	7 (until year 2010) 70 (until year 2020)
CO_2 Avoided (Gg)	38,160	33,759
Billion R$ (reais) saved on the electricity bill	12	9

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).

BIBLIOGRAPHY

LEI 10.295. Dispõe sobre a Política Nacional de Conservação e Uso Racional de Energia e dá outras providências. Subsecretaria de Informações do Senado Federal, 17 de outubro de 2001.

Choi, J. Y. *Requirements and Procedures for Refrigerator and Freezers Testing in Korea*, APEC Workshop on Setting Up and Running an Energy Performance Testing Laboratory, Filipinas, Julho, 1999.

CLASP. *Energy-Efficiency Labels and Standards: A Guidebook for Appliances, Equipment, and Lighting*. Lead authors: Stephen Wiel and James E. McMahon, Collaborative Labeling and Appliance Standards Program (CLASP), 205p., February, 2001.

DECRETO 4.059. Regulamenta a Lei nº 10.295, de 17 de outubro de 2001, que dispõe sobre a Política Nacional de Conservação e Uso Racional de Energia, e dá outras providências. Subchefia para Assuntos Jurídicos da Casa Civil da Presidência da República, 19 de dezembro de 2001.

Hirschfeld, H. Engenharia Econômica e análise de custos.1998 6ª. Edição, Editora Atlas, São Paulo, 407 p.

Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (INMETRO) http://www.inmetro.gov.br/consumidor/prodEtiquetados.asp#pbe, acesso em 08 de agosto de 2002.

Turiel, I. Present status of residential appliance energy efficiency standards - an international review. Energy and Building Journal, pp. 5-15, vol. 26, ed. 1. Elsevier Sciences, 1997.

Meier, A. K.; Hill, J. E. *Energy Test Procedures for Appliances*. Energy and Buildings Journal, pp. 23-33, vol 26, ed. 1. Elsevier Sciences, 1997.

BEN. Balanço Energético Nacional – ano base 2000. Disponível na www.mme.gov.br, 2002.

PROCEL. *Resultados de 1998*. Programa Nacional de Conservação de Energia (PROCEL/Eletrobrás). Disponível em: http://www.eletrobras.gov.br/procel/1.htm. Acesso em 4 de julho de 2001, 1998.

IEA. *International Energy Agency*. Terms of Reference for a Life-Cycle Cost Analysis on appliance energy efficiency in Brazil, proposta/projeto para Prof. Dr. Jannuzzi e equipe (UNICAMP), 2002.

IEA. *Energy Labels & Standards: energy efficiency policy profile.* International Energy Agency, OECD (Organization for Economic Co-operation and Development), 194 pgs., 2000.

LBL. *Lawrence Berkeley National Laboratory*. Palestra do Dr. Alan Meier no MME (Ministério de Minas e Energia) sobre Eficientização Energética em 06 de maio de 2002.

Meier, A. K., *Energy test procedures for appliances.* Energy and buildings, V26, (1997) pp23-33. Elsevier

Merrian, R.; Verone, A.; Feng, H. *EPA refrigerator Analysis (ERA) program: User's manual,* version 1.2E, Cambridge, Mass: Arthur D. Little, Inc.

Biermayer, P. J. *Life-Cycle Cost Analysis: Refrigerators*. Ernest Orlando Lawrence Berkeley National aboratory (LBNL), second regional workshop on energy efficiency standards and labels, IRAM, Buenos Aires, 23 march, 2001.

Acknowledgments:

This is the report of the work performed during August and December/2002 with the objective of applying the method of Life cycle cost analysis to help in setting up minimum standard levels for domestic refrigerators in Brazil.

This work has been performed by the International Energy Initiative (IEI - Latin American Office) under its program on energy efficiency, in co-operation with the University of Campinas (UNICAMP - Brazil). The team received support from the International Energy Agency (IEA), Climate Technology Initiative (CTI/IEA/OECD), Collaborative Labeling Standards Program (CLASP), Environmental Protection Agency (EPA/USA) and Lawrence National Berkeley Laboratory (LBNL/USA).

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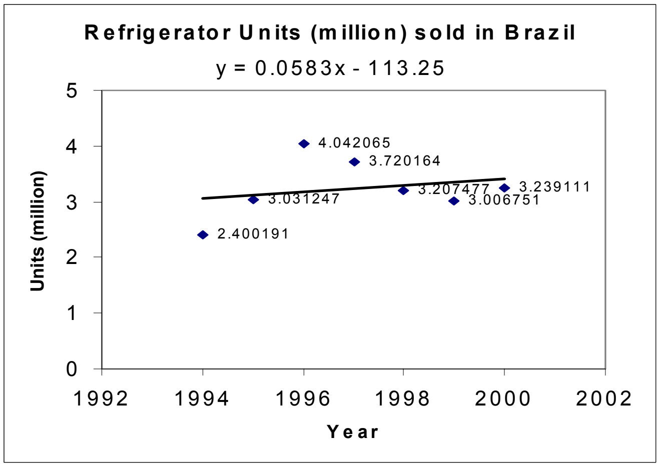
We also would like to thank the assistance received from Multibrás and the Refrigerator Testing Laboratory from PUC-Paraná.

ANNEX 1



Graph – Refrigerators sold in Brazil.

Table – Refrigerator Vintage.

Age	1	2	3	4	5	6	7
Fraction Retired	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Fraction Surviving	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Surviving rate by vintage	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Age	8	9	10	11	12	13	14
Fraction Retired	0,000	0,000	0,000	0,010	0,040	0,067	0,124
Fraction Surviving	1,000	1,000	1,000	0,990	0,950	0,884	0,760
Surviving rate by vintage	1,000	1,000	1,000	0,990	0,960	0,930	0,860
Age	15	16	17	18	19	20	Lifetime
Fraction Retired	0,175	0,217	0,199	0,122	0,040	0,007	16
Fraction Surviving	0,585	0,369	0,170	0,047	0,007	0,000	Years
Surviving rate by vintage	0,770	0,630	0,460	0,280	0,150	0,000	

Then, the Brazilian refrigerator lifetime is assumed to be 16 years.

Table – Household penetration.

Year	households	% households with refrigerator	Total refrigerators in Brazil
1999	43859738	82.80%	36315863
2001	46507196	85.10%	39577624

Source: (IBGE, 2002)