The manufacturer economics and national benefits of cooling efficiency for air conditioners in Brazil

Virginie E. Letschert, Nihan Karali, Won Young Park & Nihar Shah
International Energy Analysis Department
Lawrence Berkeley National Laboratory
Berkeley, California 94720
USA
VLetschert@lbl.gov
NKarali@lbl.gov
wypark@lbl.gov
nkshah@lbl.gov

Gilberto Jannuzzi
Mechanical Engineering School
Energy Systems Planning
University of Campinas UNICAMP
Brazil
jannuzzi@fem.unicamp.br

Fernando Costa
International Energy Initiative Brasil
Campinas, São Paulo
Brazil
fernando@iei-brasil.org

Roberto Lamberts
Laboratory for Energy Efficiency in Buildings
Federal University of Santa Catarina
Brazil
Roberto.lamberts@ufsc.br

Kamyla Borges
& Suely Machado Carvalho
Instituto Clima e Sociedade
Rio de Janeiro
Brazil
kamyla@climaesociedade.org
suelymmc@gmail.com

Keywords

appliances, engineering estimates, air conditioning, cost benefit, multiple benefits, bottom-up analysis

Abstract

The revision of Brazil's minimum energy performance standards (MEPS) for air conditioners (ACs) – which are currently set to a modest level compared with international standards – represents a major energy-saving opportunity. We analyze the technical requirements, manufacturer economics, and broader benefits of strengthening Brazil's MEPS policies. First, we develop a cost-versus-efficiency curve based on more than 300 configurations of mini-split ACs rated at 1.0 refrigeration ton (3.5 kW). We use this curve and economic modeling to estimate the manufacturer costs and industry net present value (INPV) of higher MEPS levels. The change in INPV is highly positive and increasing for higher-efficiency variable-speed ACs, indicating that manufacturers will benefit most by switching their production to the variable-speed (inverter) technology. Achieving more modest efficiency levels require similar investments, which manufacturers do not recover through future revenues. Higher MEPS also provide larger consumer and national benefits. At the highest level analyzed (i.e., at the estimated technical potential), Brazilian consumers save R$27 billion through 2035, and the power sector avoids 4.5 GW of demand (worth an additional R$30 billion) – representing R$400 in consumer/national benefits for every R$1 invested in manufacturing high-efficiency ACs. In addition, higher MEPS result in substantial national CO_2 reductions, which could be increased further by simultaneously and cost-effectively transitioning to refrigerants with low global warming potential (GWP) in accordance with the goals of the Kigali Amendment to the Montreal Protocol; our manufacturing analysis is applicable to ACs that use low-GWP refrigerants. Although we focus on MEPS, our analysis can also inform the design of complementary policies that promote high-efficiency ACs in Brazil. We offer several policy recommendations based on our findings.

Introduction

Rising incomes in warm climates are driving unprecedented growth in space cooling demand. Space cooling electricity demand could more than triple by 2050 if energy-efficiency issues are not addressed (IEA, 2018). Brazil's Energy Research Office (EPE, 2018) estimates that 60 % of Brazilian households will have at least one air conditioner (AC) in 2030. AC already accounts for 14 % of electricity consumption in Brazil's residential sector, and this demand is growing by 5.4 % each year (EPE, 2018). In addition, the time of AC use coincides with peak load hours, demanding power generation from the most polluting and expensive fossil fuel thermal power plants. Moreover, Brazilian ACs still use hydrofluorocarbons (HFCs), which are refrigerants with high global warming potential (GWP).

The Kigali Amendment to the Montreal Protocol, which entered into effect in January 2019, aims to phase down HFCs as a way to mitigate climate change. Lawrence Berkeley National Laboratory (LBNL) research has shown that transitioning to low-GWP refrigerants and higher AC energy efficiency in concert could double the impact of the Kigali Amendment (Shah et al., 2015). Brazil could benefit from this opportunity, not only because it is one of the largest AC markets, but also because it has great potential to improve AC energy efficiency

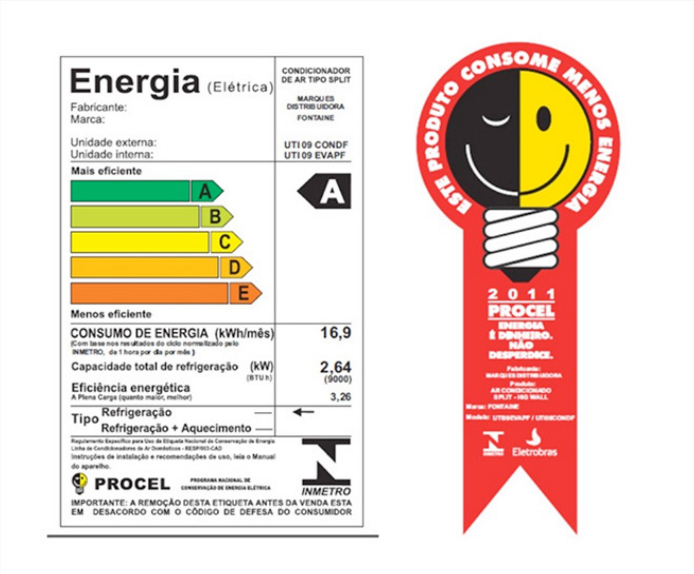

Figure 1. INMETRO label and PROCEL seal for mini-split ACs.

(EPE, 2018). The Kigali Cooling Efficiency Program (K-CEP) is implementing a project aimed at establishing state-of-the-art energy-efficiency standards and labeling in Brazil's AC sector and encouraging the transition to low-GWP refrigerants.

This paper provides key technical analyses, also known as regulatory impact analysis, that will support Brazilian policy actions. The analyses focus on revised AC minimum energy performance standards (MEPS) that could be implemented in conjunction with projects promoting the transition to low-GWP refrigerants. Because MEPS are a mandatory measure to eliminate inefficient products from the market, it is essential to demonstrate that the MEPS are technically feasible and economically justifiable. The following analyses support the development of regulations that meet those criteria. The results could also be used to inform the design of complementary programs – such as bulk procurement, rebate programs, and buyers' clubs – targeting high-efficiency ACs.

Regulatory and Analytical Framework

In 2001, the Brazilian National Congress approved the "National Energy Conservation Policy and Rational Use of Energy" law, which requires minimum energy-efficiency performance standards for energy-consuming equipment commercialized in Brazil (Brazilian law no. 10.295/2001). These MEPS are set by a committee (CGIEE) headed by the Ministry of Energy and Mines, with two representatives from civil society (one from academia and one technical expert), two regulators (from the electricity and oil and gas sectors), and representatives from the Ministry of Economy. Currently, 10 categories of electrical equipment have MEPS, including ACs. These MEPS are reviewed periodically by CGIEE, and the existing process includes a technical appraisal prepared by appointed technical groups currently coordinated by ELETROBRAS/PROCEL and later submitted to public review before being enacted by the government. This paper contributes to the efforts of ELETROBRAS/PROCEL in assisting CGIEE by introducing new parameters and indicators for analysing the impact of new MEPS.

Prior to ELETROBRAS/PROCEL, INMETRO was the technical body responsible for advising CGIEE. INMETRO also coordinates the National Energy Labeling Program (PBE) responsible for classifying energy-using equipment including electrical appliances, buildings, vehicles, solar water heating panels, and others. Brazil's labeling system is also an important market instrument, especially for public auctions and governmental purchases and for the initiatives undertaken by the National Energy Efficiency Programs PROCEL and CONPET, because those initiatives help to promote label A equipment. The analysis presented in this paper can also inform the design of such programs.

The first mandatory label for ACs was established in 2006 (Figure 1). Since then, the label has been reviewed three times, most recently in 2013 (EPE, 2018). The level "A," which identifies the most efficient appliances, applies to energy efficiency ratios (EERs) of 3.23 W/W or above – this is considered a modest top efficiency level (EL), because it is roughly equivalent to the 2010 Chinese MEPS for fixed-speed AC units. Moreover, the labeling test method does not consider variable-speed operation or seasonal metrics, because it is still based on International Organization for Standardization (ISO) Standard 5151, which focuses on the determination of EER ratings.[1]

The INMETRO label is one of the oldest energy-efficiency programs in Brazil, and consumers know it very well. A market analysis undertaken by Mitsidi Projetos (2018) shows that 80 % of the ACs on Brazil's market are labeled A (most efficient). Thus, the label has become inadequate for helping consumers identify the most efficient ACs.

Brazil's first AC MEPS were established in 2007, and they were revised in 2011 and 2018 (EPE, 2018). The current MEPS are set at level B, 3.02 EER, which is relatively low by international standards. Many large economies with markets similar to Brazil's have either set higher MEPS or set similar levels several years ago and are currently considering revising those upwards.

Considering the scope of the current regulation, our analysis focuses on the most common type of ACs found in the Brazilian market: mini-split ACs, with a representative cooling capacity of 1 refrigeration ton (RT, equivalent to 12,000 Btu/hr or 3.5 kW). Based on the most recent information about Brazil's MEPS regulation schedule, we consider MEPS implemented in 2021, with impacts forecasted to 2035.

Field Energy Use and Efficiency Metrics

In the 1990s and early 2000s, most countries adopted the EER metric – the ratio of total cooling capacity to effective power input to the device at any given set of rating conditions – for rating AC performance based on ISO Standard 5151. Since the mid-2000s, as variable-speed (also known as inverter-driven) ACs have been increasingly adopted, seasonal energy-efficiency metrics have been designed to estimate AC performance under regional climatic conditions that affect the amount of time ACs operate at part or full load, and these metrics are increasingly used as an alternative to the EER to set standards and labeling requirements for ACs and heat pumps (Park et

1. The ISO 5151 standard specifies performance testing, standard conditions, and test methods for determining the capacity and efficiency ratings of air-cooled ACs and air-to-air heat pumps.

Table 1. ISO CSPF and Energy Use for 1-RT (3.5-kW) ACs by Efficiency Level.

Efficiency Level (EL)	Comparable EER	Seasonal Efficiency in CSPF[a]		Unit Energy Consumption (UEC)[b]			
				Residential		Commercial	
		Fixed-speed unit	Variable-speed unit	Fixed-speed unit	Variable-speed unit	Fixed-speed unit	Variable-speed unit
	W/W	W/W	W/W	kWh/year	kWh/year	kWh/year	kWh/year
INMETRO Label B	3.02	3.21	4.31	498	371	627	467
INMETRO Label A	3.23	3.43	4.61	466	347	586	437
Intermediate Level #1	3.44	3.65	5.14	439	314	552	395
Intermediate Level #2	3.50	3.72	5.34	431	302	542	380
Intermediate Level #3	3.98	4.23	6.83	368	234	464	294
Highest Level	4.80	NA[c]	8.65	NA	184	NA	231

[a] We estimated CSPF for each case based on the performance data and ISO CSPF in accordance with ISO 16358, for two 1-RT fixed-speed models and three 1-RT variable-speed models.

[b] We adjusted UECs based on ACs being used 3.1 hours per day in the residential sector and 3.9 hours in the commercial sector (Mitsidi Projetos, 2018), from UEC results in accordance with the ISO 16538 method based on 1,817 hours per year (about 5 hours per day).

[c] There are no commercially available fixed-speed units that achieve EER 4.5 or above.

al., 2017). Accurately characterizing the energy consumption of ACs in the field is a key element of regulatory-impact analysis. Our analysis considers a seasonal energy-efficiency metric to support revision of the INMETRO label based on ISO 16358.[2]

FINDINGS FROM THE FIELD

Güths (2018) performed a field experiment at Federal University of Santa Catarina. A mini-split AC system was installed in each of two rooms, which had the same area and orientation: one AC was a fixed-speed unit, the other was a variable-speed unit, and both had the same capacity. Experiments were performed with different periods of operation (24 hours, 12 hours during days, and 12 hours during nights) and different internal load densities. The variable-speed unit demonstrated energy savings of 20 % at full load capacity, 40 % during daytime partial-load operation, and 60 % during nighttime partial-load operation. Such field measurement results based on different ambient temperatures can be used to estimate savings potential in ACs by different climatic regions in Brazil. To evaluate the actual field energy use of ACs, further work should focus on defining representative times of use and the conditions corresponding to different local climatic regions.

SEASONAL ENERGY EFFICIENCY

Seasonal efficiency metrics consider the impact of variations in outdoor temperature on cooling load and energy consumption, requiring multiple test points to compute a seasonally weighted average efficiency. They are intended to represent how ACs would perform over a typical cooling season in a representative building type with typical operating characteristics (Econoler et al., 2011). The seasonal efficiency metrics used in Asian countries such as India and Japan are consistent with ISO 16358:2013-defined metrics, including cooling seasonal performance factor (CSPF), except they use their region-specific climatic conditions and minor adjustments.

The CSPF calculation for variable-speed units requires two sets of test data – measurement of performance (capacity and power input) at full- and half-capacity operation at an outdoor dry bulb temperature of 35 °C – and then performance at 29 °C can be calculated by ISO 16358-determined equations. In this analysis, we calculate or estimate ISO CSPF based on performance data (measured according to ISO 5151 and 16358 standards) from commercially available 1-RT (3.5-kW) fixed-speed units that achieve EER 3.2 and 3.6 as well as 1-RT variable-speed units that achieve EER 3.3, 4.0, and 4.8, by using the ISO 16358 reference outdoor temperature bin hours – totaling 1,817 hours of data in the range of 21–35 °C (15 bins, 1 °C per bin). Further research will develop a Brazil-specific temperature profile that better represents AC energy consumption in Brazil.

Table 1 shows the results of ISO CSPF calculated for 1-RT (3.5-kW) cooling-capacity units that have efficiencies comparable to EERs defined by the INMETRO label and higher ELs.

Engineering Analysis

Our engineering analysis estimates the costs of efficiency improvement by assessing the energy performance of various design configurations of more efficient components and their associated incremental costs.

METHODOLOGY

Several combinations of technologies can be used to increase the efficiency of mini-split ACs. These technologies – both on the market and in development – fall into one of four categories:

- Compressors

2. The ISO 16358:2013 standards specify the calculations for evaluating the seasonal performance factor – defined as CSPF (ISO 16358-1:2013), heating seasonal performance factor (HSPF, ISO 16358-2:2013), and annual performance factor (APF, ISO 16358-3:2013, which considers both cooling and heating efficiency for heat pumps) – of equipment with testing covered by ISO 5151, ISO 13253, and ISO 15042.

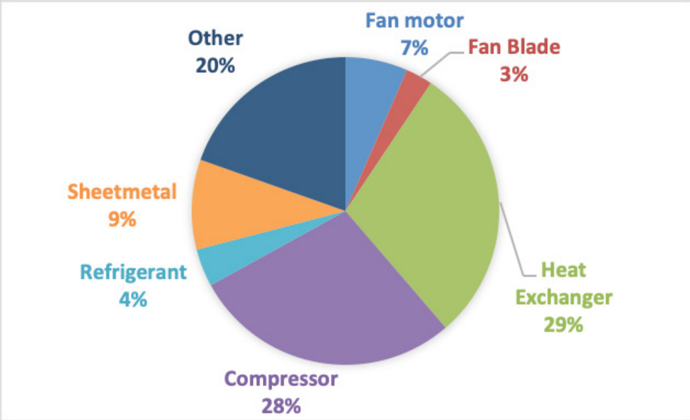

Figure 2. Baseline manufacturing cost estimates for a 1.0-RT mini-split room AC in Brazil, excluding markups.

- Heat exchangers
- Variable-speed drives (VSDs)
- Expansion valves

By combining these different technologies, we developed a total of 306 AC engineering designs and estimated the lowest-cost design able to achieve given ELs, from which we developed a cost curve for efficiency improvement. The simulated performance of the efficient components used in this study was verified via actual performance data on efficient ACs (Riviere et al. 2009) as well as by testing performed at LBNL for related projects. The manufacturing costs of baseline components, except compressors, are based on an LBNL study that estimated the economic benefits and costs of improving the efficiency of mini-split room ACs to determine cost-effective levels of AC energy-efficiency improvements in China (Shah et al., 2019). Compressor cost is based on data collected from local manufacturers as part of the analysis. For the other components, we could not collect cost data owing to confidentiality issues. Because China manufactures over 70 % of room ACs in the global market (Shah et al., 2017), we believe using China cost data for the rest of the components is a reasonable proxy. The baseline and incremental manufacturing cost estimates of more efficient components in China were developed in collaboration with the China National Institute of Standardization using market research and interviews with appliance and component manufacturers in China. Our research has found no significant impact of refrigerant choice on the cost of components.[3] Previous research (Park et al., 2017) showed that ACs using low-GWP refrigerants are available at retail prices comparable to ACs using conventional high-GWP hydrochlorofluorocarbon (HCFC) or HFC refrigerants, further confirming our findings. Thus, our manufacturing analysis of energy-efficiency improvement is applicable to ACs that use low-GWP refrigerants.

The total incremental manufacturing production cost (MPC), manufacturer selling price (MSP), and retail price (P) of the design combination *m* are calculated as follows:

$$MPC(m) = \sum_i cost_m(i) \tag{1}$$

$$P(m) = MPC(m) \times MM \times DM = MSP \times DM \tag{2}$$

Where:
$cost_m(i)$ is the cost of component *i* used in the design combination *m*, MM is the manufacturer markup rate, and DM is the distribution channel markup. An AC-model database of retail prices and efficiency from a recent assessment of the Brazilian AC market and manufacturer surveys is used to calibrate the markup rates and validate the analysis results (Mitsidi Projetos, 2018).

The overall percentage savings of the design combination *m*, *Total Energy Saving* (*m*), compared to the baseline model, is calculated as follows:

$$Total\ Energy\ Saving(m) = 1 - \prod_i (1 - energy\ saving_m(i)) \tag{3}$$

Where:
$energy\ saving_m\ (i)$ is the percentage energy savings gained from component *i* used in the design combination *m* compared to the baseline component. The power demand of the design combination *m*, *input*(*m*), is shown in the following equation:

$$input(m) = \frac{Capacity}{Efficiency\ Rating(m) * (1 - total\ \ energy\ saving(m))} \tag{4}$$

Where:
capacity refers to the capacity of the mini-split room AC, and *Efficiency Rating*(*m*) is the efficiency rating of the design combination *m*.

BRAZILIAN CONTEXT

The baseline room AC uses a fixed-speed drive (FSD) and is based on the minimum efficiency standard that will be required in 2019: EER 3.02 (INMETRO label Level B). The baseline manufacturing cost of a 1.0-RT mini-split room AC used in this study, excluding any markup, is R$648 (roughly equivalent to US$180).[4] Because 1.0-RT room ACs constitute the majority of the Brazilian AC market, 1.0 RT is used as the representative capacity for Brazil in this study. The share of component costs is presented in Figure 2. Higher levels of efficiency are generated by combining the components presented in Table 2.

In this analysis, we account for the Brazilian regulation on "processo produtivo básico" or PPB, which mandates 30 % minimum local manufactured content for FSD AC compressors as well as a 3 % mandatory investment in research and development for producing variable-speed ACs.

SUMMARY OF INPUTS

Table 3 presents the key data inputs to the engineering analysis.

3. The incremental costs due to refrigerant changes for A5 economies such as Brazil include manufacturing conversion and capital costs that are covered by the Multilateral Fund for the Implementation of the Montreal Protocol.

4. We use an exchange rate of 0.28 US$ per R$.

Table 2. Incremental Cost and Efficiency Improvement Considered for 1.0-RT Mini-split Room ACs.

	Component	Incremental Manufacturing Cost	Energy Savings from Baseline
Compressor 1	3.0 EER compressor with FSD	4 %	5.5 %
Compressor 2	3.2 EER compressor with FSD	19 %	10.5 %
Compressor 3	3.4 EER compressor with FSD	35 %	15.0 %
Compressor 4	3.6 EER compressor with FSD	85 %	20.0 %
Inverter AC	Alternating current compressor with VSD	49 %	23.5 %
Inverter DC	Direct current compressor with VSD	89 %	25.5 %
All DC	VSD for fans and compressor	126 %	29.0 %
Heat Exchanger 1	UA of both heat exchangers increased 20 %	14 %	7.5 %
Heat Exchanger 2	UA of both heat exchangers increased 40 %	54 %	13.5 %
Heat Exchanger 3	UA of both heat exchangers increased 60 %	92 %	18.0 %
Heat Exchanger 4	UA of both heat exchangers increased 80 %	105 %	21.0 %
Heat Exchanger 5	UA of both heat exchangers increased 100 %	163 %	24.0 %
TXV	Thermostatic expansion valve	37 %	5.0 %
EXV	Electronic expansion valve	63 %	9.0 %

Note 1: UA value is a heat exchanger coefficient defined as the product of the overall heat transfer coefficient and the heat transfer area.

Table 3. Key Data Inputs for Engineering Analysis.

Input	Description	Value	Source
Component costs	Includes labor costs, material costs, factory overhead, and depreciation	Table 2	LBNL estimates
MPC	Sum of all component costs, including labor costs, material costs, factory overhead, and depreciation	Baseline R$648 (or US$180)	Calculation
MSP	Includes MPC and MM	Baseline R$875 (or US$245)	Calculation
P	Retail price	Baseline R$1,330 (or US$370)	Calculation
MM	Manufacturer markups covering per-unit research and development expenses; selling, general, and administrative expenses; interest; and profit	35%	Manufacturer interviews
DM	Markups in distribution channels	52% (includes a 17 % value-added tax)	tradingeconomics.com + calibration

RESULTS

Figure 3 shows our results for manufacturing costs and retail prices versus efficiency for 1.0-RT ACs in Brazil. It also presents actual retail prices of FSD and VSD room ACs in the Brazilian market to validate our price predictions based on a 35 % manufacturer markup and 52 % distribution channel markup. Current market prices appear to show bundling of features other than efficiency, because prices at the same EL vary by over 100 %. When considering the actual costs of components, we find minimal costs associated with achieving modest efficiency improvements: for example, 10 % incremental cost to reach a CSPF of 4.1. Super-efficient levels not yet available on the Brazilian market can be reached with more significant increases in price. These price increases are expected to decline as the market reaches economies of scale (Taylor et al., 2015). Although the results in this section focus primarily on 1.0-RT room ACs, the trends are likely to be the same across various capacities.

We use the specific ELs defined in Table 1 to calculate the retail price of ACs based on the cost curve. We then convert the EERs from the retail model database developed by Mitsidi Projetos (2018) to calculate the current mix of ELs in the market in CSPF-equivalent. By applying these market shares

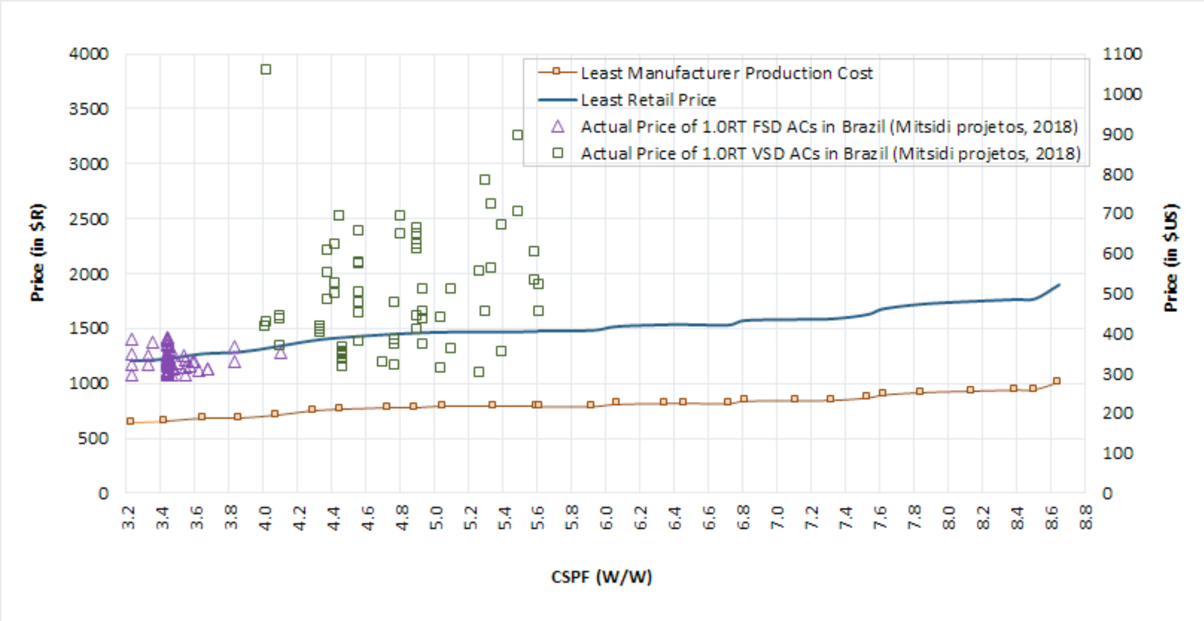

Figure 3. Cost curve (price/cost vs. efficiency) for 1.0-RT mini-split room ACs in Brazil. Note 1: Manufacturing cost estimates listed, except for compressors, are LBNL's current best estimates for 1.0-RT mini-split room ACs in Brazil.

Table 4. Estimated Market Penetration of ACs at Various Efficiency Levels and Market-Average Efficiency, Price, and UEC under BAU and Higher-MEPS Scenarios.

		Scenario					
	Efficiency Level (EL)	BAU	MEPS at CSPF = 3.43	MEPS at CSPF = 3.65	MEPS at CSPF = 5.34	MEPS at CSPF = 6.83	MEPS at CSPF = 8.65
Percentage of All Market ACs at Given EL	INMETRO Label B	17 %					
	INMETRO Label A	41 %	58 %				
	Intermediate Level #1	37 %	37 %	95 %			
	Intermediate Level #2	4 %	4 %	4 %	99 %		
	Intermediate Level #3	0 %	0 %	0 %	0 %	100 %	
	Highest Level	0 %	0 %	0 %	0 %	0 %	100 %
	Market-Average CSPF Efficiency	3.60	3.64	3.77	5.36	6.84	8.65
	Average Price (R$)	$1,258	$1,261	$1,289	$1,474	$1,578	$1,897
	Average UEC (kWh/year)	469	463	447	313	243	191

to efficiencies and UECs from Table 1, and to the retail prices given by the cost curve, we calculate average market-weighted CSPF efficiency, UEC, and price under business as usual (BAU) and higher-MEPS scenarios (Table 4). In the BAU scenario, we assume that the current market shares by EL remain the same in the future. In each higher-MEPS scenario, all models that do not comply with the MEPS "roll up" to the MEPS level.

Manufacturer Impact Analysis

The goal of our manufacturer impact analysis is to evaluate the impact of MEPS on local AC manufacturers in Brazil, which supply 90 % of the national AC market. The analysis is based on a cash-flow model adapted for Brazil and the AC industry, in the style of the analysis performed for U.S. appliance efficiency standards (USDOE, 2016). The model evaluates how MEPS can impact local manufacturers in terms of investments, production costs per unit, and revenues resulting from changes in prices.

METHODOLOGY

Revenue Forecast

Manufacturer revenues represent the sum of the MSPs, calculated in the engineering analysis, associated with the sales in a specific year:

$$Revenues = \sum_{sales} MSP \tag{5}$$

Sales are calculated using a combination of data from Euromonitor (Euromonitor, 2018) and the Policy Analysis Modelling System (PAMS) saturation model for ACs and stock turnover analysis (McNeil et al., 2007). Based on the macroeconomic forecast of AC adoption and population growth for Brazil, we calculate a growth rate of 4.7 % per year. The data and results are shown in Figure 4.

Net Operating Profits After Taxes

One important input to the industry net present value (INPV) calculation is the net operating profit after taxes (NOPAT), calculated as follows:

$$NOPAT = EBIT \times (1 - Tax\ rate) \quad (6)$$

Where earnings before interest and taxes (EBIT) is equal to:

$$EBIT = Revenues - \left(\frac{Revenues}{MM}\right) - Overheads - Equipment\ conversion\ costs \quad (7)$$

The *Overheads* represent the selling, general, and administrative (SG&A) and research and development expenses, which are taken from the engineering analysis.

The *Equipment conversion costs* represent the one-time investments in research, product development, testing, certification, and marketing. They represent the non-capital investments that are needed before the effective date of the standard and after its announcement. They are equal to zero in the BAU scenario and typically increase with the MEPS stringency. Other costs that may be associated with efficiency standards are "stranded assets," which represent the tooling and equipment made obsolete by MEPS (equal to zero in the BAU scenario). For the AC industry, these costs are expected to be very low.

Free Cash Flow

Another intermediate calculation for the INPV is the determination of the free cash flow (FCF):

$$FCF = CF - Capital\ expenditures - Capital\ conversion\ costs \quad (8)$$

Where:

$$CF = NOPAT - Change\ in\ working\ capital \quad (9)$$

The model calculates the *Capital expenditures* as a percentage of revenues using a default value. These represent the one-time expenses incurred on the purchase of plant, property, and equipment used in the production of ACs. The *Capital conversion costs* – estimated based on LBNL research – represent the one-time investments in plant, property, and equipment resulting from setting MEPS. The *Change in working capital* represents the change in current assets less current liabilities between a given year and the previous year. The model calculates the working capital as a percentage of the revenues based on a default value.

Industry Net Present Value

The INPV in the BAU scenario and in each higher MEPS scenario is calculated as:

$$INPV = FCF \times \left(\frac{1}{1 + Discount\ rate}\right)^{(yr-y0)} + Terminal\ value \quad (10)$$

The terminal value represents the present value at a future point in time of all future cash flows considering stable growth rates.

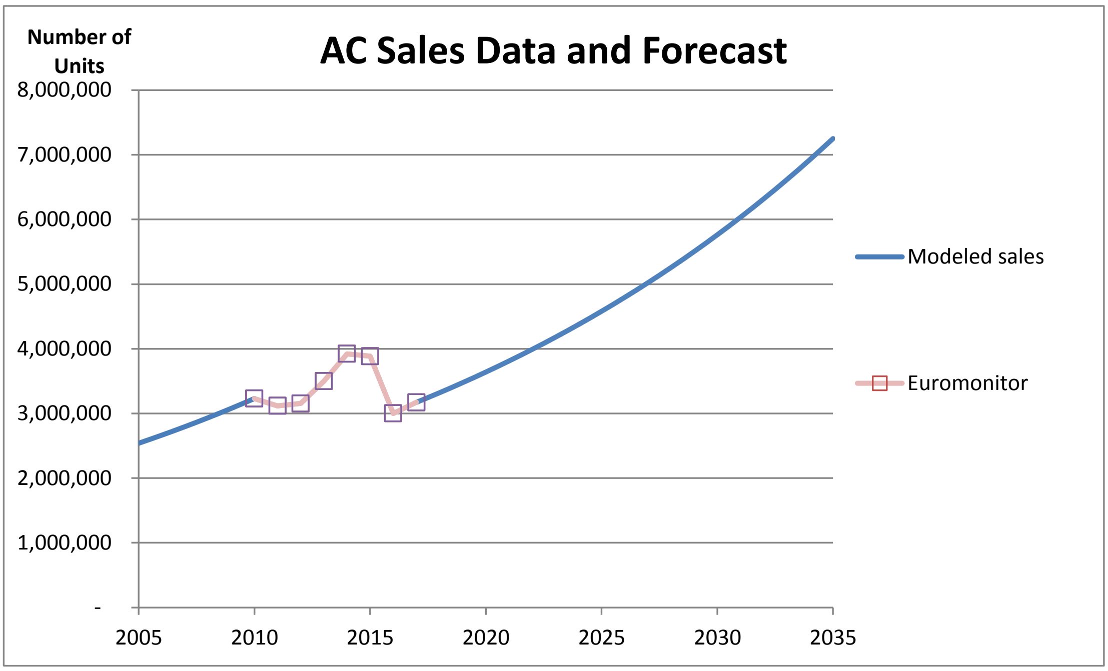

Figure 4. Brazilian market mini-split AC unit sales data and forecast.

SUMMARY OF INPUTS

Table 5 presents the key data inputs to the manufacturer analysis.

RESULTS

Table 6 presents the results for the INPV under different efficiency scenarios compared to the BAU scenario. The change in INPV is highly positive and increasing for MEPS set at CSPF 5.34 and above, indicating that manufacturers will benefit most by switching their production to high-efficiency variable-speed ACs. Modest incremental improvements in efficiency imply similar investment costs that manufacturers will not recover in their future revenues.

Figure 5 presents the annual FCF from 2018 through 2035 for the BAU and higher-MEPS scenarios. It is important to note the short-term changes in cash flow in the years preceding the regulation (which is implemented in 2021). In the higher-MEPS scenarios, investments in conversion costs increase between the announcement date and the date of compliance (2018–2021) to prepare for the new regulation. As a result of these investments, industry cash flow declines during those years (as revenue increase is only driven by sales). In the years after the standards (2021–2035), revenues and hence cash flow increase compared to the BAU scenario owing to the higher price of more efficient ACs.

Additional Impacts Analyses

Our regulatory analysis is implemented using LBNL's PAMS model, a spreadsheet tool that performs consumer and national impact analysis, following U.S. Department of Energy standard-setting methods (McNeil et al., 2007). Table 7 summarizes the consumer impact analysis from PAMS. All design options are very cost-effective to the consumer, with life cycle cost savings and payback periods of less than 1 year up to 3.5 years. Maximum consumer benefits are found for ACs with a market-weighted CSPF of 6.84.

At the national level, the technical potential for ACs (i.e., at MEPS of 8.65 CSPF) translates into the following benefits:

Table 5. Key Data Inputs for Manufacturer Impact Analysis.

Inputs	Description	Value	Source
Tax Rate	Corporate effective income tax paid (percentage of earning before taxes)	8.5 %	tradingeconomics.com
Discount Rate	Weighted average cost of capital	10 %	waccexpert.com
Working Capital	Current assets less current liabilities (percentage of revenues)	10 %	USDOE (2016)
SG&A	Selling, general, and administrative expenses (percentage of revenues)	14 %	USDOE (2016)
Research and Development	Research and development expenses (percentage of revenues)	1 % 3 % for VSDs	Stakeholder feedback
Capital Expenditures	Cash expenditure to acquire or improve capital assets (percentage of revenues)	2 %	USDOE (2016)
Depreciation	Amortization of fixed assets (percentage of revenues)	2 %	USDOE (2016)
Equipment Conversion Costs	One-time investments in research and development, testing, certification, and marketing	Constant at all ELs, scales with production capacity	LBNL estimates
Capital Conversion Costs	One-time investments in plant, property, and equipment process resulting from the MEPS		LBNL estimates
Stranded Assets	Assets replaced before the end of their useful lives as a direct result of the MEPS		LBNL estimates

Table 6. Manufacturer Impact Analysis Results.

	MEPS at CSPF = 3.43	MEPS at CSPF = 3.65	MEPS at CSPF = 5.34	MEPS at CSPF = 6.83	MEPS at CSPF = 8.65
Product Conversion Cost (million R$)	7.7	26.6	43.7	45.7	45.7
Capital Conversion Cost (million R$)	16.3	56.2	73.9	86.6	86.6
Total Investment Required (million R$)	24.1	82.8	117.6	132.4	132.4
Change in INPV (million R$)	-18.3	-26.6	245.3	400.3	921.8

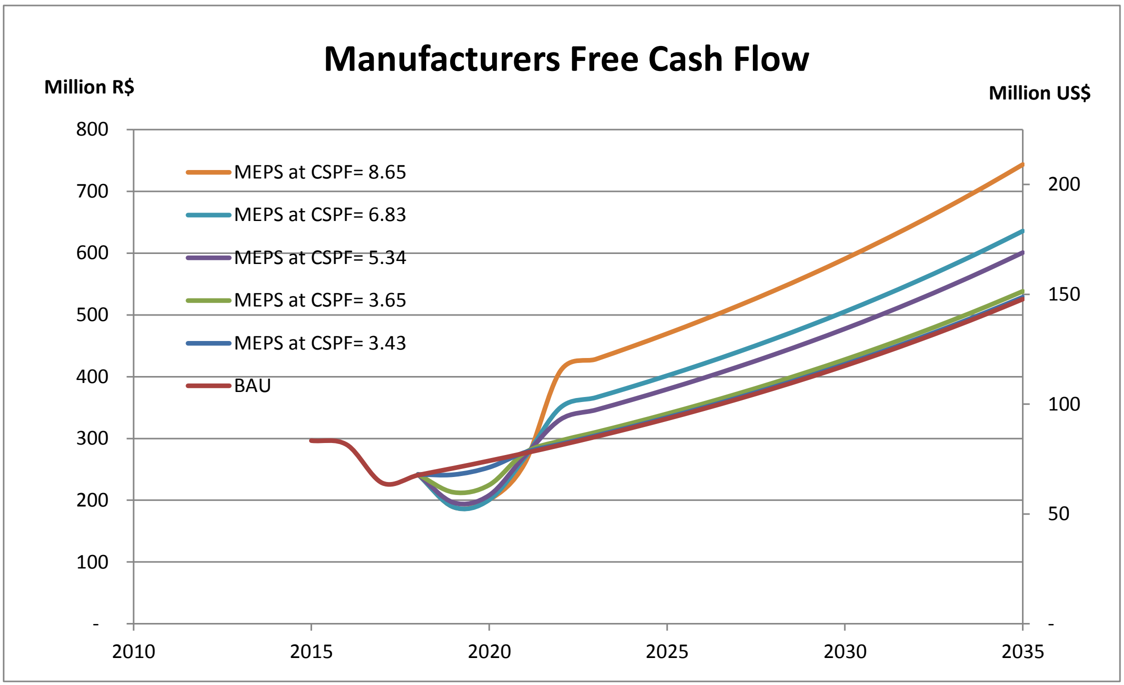

Figure 5. Brazilian AC manufacturer FCF under BAU and higher MEPS scenarios (with specified MEPS effective in 2021).

Table 7. Life-Cycle Cost and Payback Period Results for 1-RT, Mini-Split ACs.

Efficiency Level (EL)	Market-Weighted CSPF	Average Purchase Price	UEC	Average Electricity Bill	Average Life-Cycle Cost	Life-Cycle Cost Savings	Payback Period
	W/W	R$	kWh/year	R$	R$	R$	years
BAU	3.60	$1,258	469	$309	$3,411		
MEPS at CSPF = 3.43	3.64	$1,261	463	$306	$3,388	$23	0.7
MEPS at CSPF = 3.65	3.77	$1,289	447	$295	$3,342	$69	2.1
MEPS at CSPF = 5.34	5.36	$1,474	313	$206	$2,910	$501	2.1
MEPS at CSPF = 6.83	6.84	$1,578	243	$160	$2,692	$719	2.1
MEPS at CSPF = 8.65	8.65	$1,897	191	$126	$2,773	$637	3.5

Note 1: Life-cycle cost and payback-period calculations use an electricity rate of R$0.66/kWh, which is a weighted average between residential and commercial customers (ANEEL, 2018a; ANEEL, 2018b; Mitsidi Projetos, 2018). The life cycle cost calculation uses a 10.5 % discount rate and assumes a lifetime of 10 years based on stakeholder feedback.

- Cumulative (2021–2035) consumer benefits of **R$27 billion** (based on future sales, AC prices, and operating cost savings, with a 6.5 % discount rate)
- **16 TWh** in electricity savings annually by 2035, 132 TWh cumulative savings (2021–2035)
- **4.5 GW** of avoided demand in the power sector by 2035 (representing approximately R$30 billion)
- **60 million metric tons of avoided CO_2 emissions** (cumulative 2021–2035), considering a marginal carbon factor of 0.356 kg/kWh (MCTIC, 2018)

Conclusions and Recommendations

Our results show that manufacturers, consumers, and the nation will benefit the most in scenarios targeting high AC ELs. For example, the highest-MEPS scenario (MEPS = 8.65 CSPF) results in the largest increase in industry-wide net present value, almost R$1 billion, whereas the lowest-MEPS scenarios may reduce the INPV. At the same time, the highest-MEPS scenario results in a cost/benefit ratio of 1:400 between each amount of money invested in industry (R$132 million) and national benefits in terms of avoided generation capacity and electricity savings (R$57 billion). Because using low-GWP refrigerants does not significantly increase AC component costs or retail AC prices, our manufacturing analysis is applicable to

ACs that use low-GWP refrigerants. In addition, our regulatory analysis can inform the design of other policies that complement MEPS by promoting high-efficiency ACs. Therefore, as next steps, we recommend the following:

- Accelerate deployment of the variable-speed ACs needed to achieve high efficiency. Although variable-speed ACs are already entering the Brazilian market rapidly, the current EER metric does not accurately reflect the energy savings from their part-load operation, which could slow uptake. Changes to efficiency metrics/calculations would promote variable-speed ACs:
  - Adopt a seasonal CSPF metric for rating energy efficiency of both fixed-speed and variable-speed ACs based on ISO standard 16358.
  - Adopt a Brazil-specific temperature bin based on weather conditions found in most large Brazilian cities.
- Design complementary programs; for example, the new level A and B from the INMETRO label could target the ELs that offer the most benefit to manufacturers, to encourage them to invest in new technologies.
- Explore manufacturer financial incentives and other mechanisms such as bulk procurement programs or "cash-back" rebates, to drive down costs and encourage adoption of efficient technology by consumers. Financial mechanisms could be designed to encourage these investments and unlock the benefits to consumers, the Brazilian energy sector, and the local AC manufacturing sector.
- Coordinate AC efficiency-improvement programs with existing and future refrigerant-transition projects under the Montreal Protocol to reduce program-implementation costs to manufacturers (equipment redesign and retooling costs) and consumers (costs passed through from manufacturers).
- Adopt a roadmap for future revision of Brazil's MEPS based on the ISO 16358 CSPF metric.

References

ANEEL, 2018a, Nota Técnica nº 0158/2018-SPE-SEM/ANEEL, Agência Nacional de Energia Elétrica, Brasil.

ANEEL, 2018b, Relatórios Sobre as Tarifas Médias de Fornecimento, Agência Nacional de Energia Elétrica, Brasil.

Econoler, Navigant, CEIS, and ACEEE, 2011, Cooling Benchmarking Study Report.

EPE, 2018, Uso de Ar Condicionado no Setor Residencial Brasileiro: Perspectivas e contribuições para o avanço em eficiência energética, Nota Técnica EPE 030/2018, Empresa de Pesquisa Energética, Brasil.

Euromonitor, 2018, Air Treatment Products in Brazil, Passport, Euromonitor International.

Güths, S., 2018, Comparação de consumo de energia entre AC Split do tipo On/Off e Inverter, CB3E Federal University of Santa Catarina, Florianópolis, Brasil.

IEA (International Energy Agency), 2018, The Future of Cooling: Opportunities for Energy-Efficient Air Conditioning, International Energy Agency, OECD/IEA.

McNeil, M.A., Letschert, V., and Van Buskirk, D., 2007, User Instructions for the Policy Analysis Modeling System (PAMS), Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

MCTIC, 2018, Ministério da Ciência, Tecnologia, Inovações e Comunicações, Mitsidi Projetos, 2018, Kigali Project, Regulatory Impact Analysis: Data Collection Phase, Final Report.

Park, W., Shah, N., and Gerke, B. 2017. Assessment of Commercially Available Energy-Efficient Room Air Conditioners Including Models with Low Global Warming Potential (GWP) Refrigerants, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Riviere, P., Adnot, J., Grignin-Masse, L., Legendre, S., Marchio, D., Nermond, G., Rahim, S., Andre, P., Detroux, L., Lebrun, J., L'honest, J., Teodorose, V., Alexandre, J.L., Benke, G., Bogner, T., Conroy, A., Hitchin, R., Pout, C., Thorpe, W., and Karatasou, S., 2009, Preparatory Study on the Environmental Performance of Residential Room Conditioning Appliances, EuP (Eco-Design of Energy Using Products), Lot 10, Task 7, Final Report, prepared under contract to DGTREN.

Shah, N., Karali, N., Park, W., Khanna, N., and Ding, C., 2019 (forthcoming), Costs and Benefits of Improving the Efficiency of Room Air Conditioners in China, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Shah N., Khanna, N., Karali N., Park, W.Y., Qu, Y., Zhou, N., 2017, Opportunities for Simultaneous Efficiency Improvement and Refrigerant Transition in Air Conditioning, LBNL-2001021, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Shah, N., Wei, M., Letschert, V., and Phadke, A., 2015, Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Taylor, M., Spurlock, C.A., Yang, H.C., 2015, Confronting Regulatory Cost and Quality Expectations: An Exploration of Technical Change in Minimum Efficiency Performance Standards, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

USDOE (U.S. Department of Energy), 2016, Final Rule Technical Support Document: Energy Efficiency Program for Consumer Products: Residential Central Air Conditioners and Heat Pumps.

Acknowledgements

This work is supported by the Kigali Cooling Efficiency Program. The authors would like to thank our sponsors along with all the collaborators on the Kigali project in Brazil, including Roberto Kishinami, Suely Carvalho, and Ruy Barros from the project Advisory Committee; Marcos Borges from INMETRO; Marcel Siqueira, Marcelo Soares, and Victor Fonseca from PROCEL; Jeferson Soares and Thiago Rodriges from EPE; local manufacturer association ELETROS; and Arthur Cursino and his team from Mitsidi Projetos. Finally, we thank Jarett Zuboy for editorial assistance.