Measurement and verification of low income energy efficiency programs in Brazil: Methodological challenges

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Keywords

residential programs, lighting, refrigerators, low income, M&V

Abstract

Electric utilities in Brazil are investing about 80 million dollars annually in low-income energy efficiency programs, about half of their total compulsory investments in end-use efficiency programs under current regulation. Since 2007 the regulator has enforced the need to provide evaluation plans for the programs delivered. This paper presents the measurement and verification (M&V) methodology that has been developed to accommodate the characteristics of lighting and refrigerator programs that have been introduced in the Brazilian urban and peri-urban slums. A combination of household surveys, end-use measurements and metering at the transformers and grid levels were performed before and after the program implementation. The methodology has to accommodate the dynamics, housing, electrical wiring and connections of the population as well as their ability to pay for the electricity and program participation. Results obtained in slums in Rio de Janeiro are presented. Impacts of the programs were evaluated in energy terms to households and utilities. Feedback from the evaluations performed also permitted the improvement in the design of new programs for low-income households.

Introduction

Efforts to secure funds and activities in energy efficiency started in a more systematic way in 1998 when the Brazilian regulator ANEEL established mandatory investments to privatized utilities. Since 2005 a minimum of 50% of those investments must be allocated to low-income energy efficiency programs.

Electric utilities in Brazil are investing about 80 million dollars annually in low-income energy efficiency programs, about half of their total compulsory investments in end-use efficiency programs under current regulation (Table 1). The objective of this paper is to present a measurement and verification (M&V) methodology proposal to evaluate the results of a Low-Income Energy Efficiency Program in Brazil.

The paper presents the characteristics of low-income households and the M&V methodology used, divided in ex ante and ex post phases. Attempts to measure the benefits achieved by those programs and the opportunities of improvements to the next projects are also assessed.

The methodology includes: power grid assessment and measurement of the transformers that provide electricity to the low-income households; field visits aiming to identify the electrical and behavioural characteristics using a structured checklist; onsite measurements of the electricity consumption of both the low energy efficient appliances to be replaced in randomly selected households and the new energy efficient devices to be substituted; and a survey to identify household patterns of consumption by using an structured questionnaire conducted in a statistically defined sample of consumers.

Characteristics of the energy efficiency programs and the low-income communities

The provision of electricity services to low-income households requires a broader approach and is not restricted to the technical aspects of connection, operation, maintenance and billing of electricity. It needs to consider obvious issues such as local urban design, housing characteristics, the dynamics of socio-

Table 1. Utility investments in energy-efficient programs 2005/2006 and 2006/2007

	2005/2006	2006/2007
Investment (US$)	130 million	80 million
Low-income programs	63%	66%
Industry	15%	6%
Other programs	22%	28%

Source: ANEEL (2007)

Note: [1] US$ 1 = R$ 2.28 on March 19, 2009.

economic issues of this population highly affected by macro and micro-economic fluctuations, which relates to the ability to pay the bills and energy efficient appliances, regularization of the connections, land and housing tenure, etc.

The geographical location of Brazilian slums “favelas” very often offers significant challenges to the design and implementation of energy efficiency programs, and therefore to its evaluation. The lack of street design and numbering, housing construction patterns, almost daily fluctuations of the number of permanent residents and illegal connections, all this creates difficulties for establishing baselines for evaluation.

Within the challenges and specificities which characterize low-income energy efficient projects, the authors highlight the inaccurate or lack of information about the dwellings and consumers, the difficulty of collecting field data and access to the slums, the metering reliability in distribution transformers, high levels of commercial losses and transformers replacement.

The projects undertaken by utilities have been basically of two types: 1) donation of efficient refrigerators and lamps, and 2) educational programs. The former may also include improvements in the local power grid, indoor electrical wiring and meter installation or connection regularization in selected households. During 2005-2007 more than 5 million compact fluorescent lamps and 60 thousand efficient refrigerators were distributed via low income programs.

Educational and cultural actions are carried out often as part of the above mentioned interventions and frequently involve the so-called community agents, select dwellers of the community hired to perform visits to households. During these visits they provide information about safe and rational use of electricity.

Methodology and results

The proposed M&V methodology is based on the comparative analysis of the situations before and after the effective implementation of the energy efficiency measures in the studied communities.

The M&V methodology aims to evaluate the effectiveness of actions such as improvements in the power grid, meter installation or regularization and the substitution of energy efficient appliances for low energy efficient for the main end uses, such as compact fluorescent lamps for incandescent bulbs, refrigerators, electric showers, besides door-to-door information campaign oriented to the safe and rational use of electricity. Hence, the following aspects were necessary to carry out:

1. Analysis of the electrical characteristics of the low-income community: observatory field survey is recommended by using a structured checklist to get information regarding the power grid and outdoor characteristics of the dwellings in the community under study.
2. Installation of meters at selected transformers which provide electricity to the households to measure the load demand and consumption before and after the implementation of the energy efficiency activities in order to identify peak demand reductions and energy savings as a result of the appliance replacement program, regularization of the power grid, the electrical wiring and the standard electric meter: metering and analysis of the data before and after the implementation of the energy efficiency measures. Demand estimates of the electrical appliances should also be carried out.
3. Household declared ownership and consumption patterns survey: statistical sample definition, survey design to be conducted in the households sampled, training and orientation of the field team, descriptive statistics of the results and its presentation, and critical analysis of the problems identified.
4. Electricity consumption metering of the electrical appliances to be replaced, such as lamps, refrigerators and electric showers, in selected households. In the case of lamps, the measurement of the lamp with the highest time use and wattage is recommended, which in general occurs in the kitchen. The paper will present the measurements taken from the lamps of the kitchen in selected households through lighting loggers before and after the substitution.
5. In the ex post phase, after the implementation of the energy efficiency measures, the employment of a consumer satisfaction survey in the participant households is required, herein exemplified by those dwellings whose electrical wiring were reformed and the electric shower, lamps and refrigerators were substituted, depending on the nature of the program.

The methodology is complemented by the training of the field team regarding the employment of the questionnaires and checklists as well as the installation and data collection of the specific metering devices for lamps, refrigerators and electric showers in order to assure the reliability of the information.

There follows the details of the different stages of the proposed M&V methodology.

ANALYSIS OF THE ELECTRICAL CHARACTERISTICS OF THE LOW-INCOME COMMUNITY: EX ANTE AND EX POST

To characterize the community’s electrical system where the energy efficiency programs are implemented, the execution of the following stages is recommended either to the implementer or to a third party.

Checklist

The checklist is a structured instrument whose objective is to organize the collected information by using the observational field survey technique. The checklist is comprised of the following information: location and data of the electricity transformer station, data of the power grid and the household connection to the grid, characteristics of the constructions and the patterns of household use and occupation. There follows the objectives in brief of each information collected.

1. Location of the electricity transformer station

This identification enables the location on the plant of the electrical region and the verification of the results during the project implementation of the regularization of the grids and households grid connections. The coordinates and/or the street name and station number make possible that identification.

2. Data of the power grids

The grid data enables the identification of existent standards which ease or inhibit the reduction of electrical losses in the primary and secondary circuits and the commercial loss in the secondary circuit. The employment of an adequate standard for the region and the existence of a regularized electrical system reduce the technical and commercial losses that impact the results of an energy efficiency program.

3. Data of the electricity transformer station

To help the selection of the transformers whose electrical measurements will be carried out, the following information is important: transformer characteristics, the last 12 months of the transformer loading and its load curve, history of transformers burned out. As the consumer units sample selection must occur simultaneously with the transformers selection, to carry out the ex ante survey and the appliances energy consumption metering, the consumption of the last 12 months of the consumer units connected to the transformer station should be known.

The data of those consumer units are important to verify if they are residential units, their patterns of electricity consumption and if they represent a typical community's consumer for the program. Only households are considered by the monitoring and validation project. The other consumer units (commerce and public sector) can interfere in the analysis of the results.

The information of the installation of new connections or their retrofit in the electricity grids covered by the transformer station is considered as a grid regularization and results in energy savings.

4. Standard electric meters

The type of the standard electric meters used in the region (common standard electric meter, mounting on lighting pole measuring several consumer units, standard electric meter with concentric cable, polycarbonate meter boxes or other material to avoid electricity theft) permits to evaluate if the existence of standard meters that avoid frauds have worked out as well as to verify the opportunity to keep installing such meters during the grid regularization. Frauds results in commercial and technical electricity losses and the installation or regularization of electric meters reduce these losses, which in turn bring benefits towards energy efficiency. Then the information about the standard electric meters that will be installed in the program and the amount of households without meters will have impacts in the results of the energy savings. Depending on the type of standard electric meter, frauds can be reduced.

A better result of the energy efficiency program is linked to the current conditions of the existent electric meters. The verification of the electric meter conditions in households must occur in order to retrofit those meters that are in a precarious state.

5. Buildings

A significant amount of buildings where commercial activities take place or that are for rent or sale can negatively impact the results of the project. The selection of the transformer should prioritize the transformer station that presents the higher number of households with residential patterns of consumption. It is common in low-income households to find small commercial activities, such as bars. Another illustration is that women also washes and iron clothes for clients at home and food, groceries, drinks and ice cream are prepared to be sold on the street or are made to order.

The number of windows is important to check the amount of daylight that the household gets, avoiding the use of lamps during the day.

6. Evaluation of the consumer units during the visit

The patterns of consumption are evaluated during the visit. This information, such as open/closed doors and windows, presence of daylight inside the house or the use of lamps during the day could explain and eventually confirm higher electricity consumption for lighting during the day measured by the individual appliance meters or the meters installed at the transformers.

Measuring distribution transformers

The main objective is to compare the load demand and electricity consumption in the ex ante and ex post periods to identify, if possible, the energy savings and the reduction of peak demand by the appliances substitution and regularization of the electrical grid, internal electrical wiring and electrical meters.

To illustrate the use of these measurements from the transformers, there follows a comparative analysis of the measurements carried out from the secondary circuits of four selected transformers that provide electricity to low-income households in Rio de Janeiro as part of a utility's energy efficiency program. These measurements occurred before and after the substitution of CFLs for incandescent bulbs. First the methodology description for the comparative analysis is presented. The period of analysis was from June 1st to September 30th, 2008. The four transformers cover 385 households of the community out of 1996.

Methodology of the comparative analysis

For the comparative analysis of the measurements, two time perspectives were chosen to analyze the data, which are described as follows:

Daily perspective – represented by the daily average of the demand, calculated as the average of all demand data recorded over the day. The objective is to provide the daily variations of the average demand over the ex ante and ex post period of analysis. The maximum demand was calculated from the highest demand in the 288 daily data series recorded at every 5 minutes.

Hourly perspective – represented by the hourly average of the demand. The objective is to compare the average total demand load curves (from the transformers) and the average lighting demand load curves (from lighting loggers) in the ex ante and ex post period of analysis.

In this analysis context, the energy saved, the reduction of the maximum demand and the lighting demand use pattern are estimated for the ex ante and ex post period. There follows the results of the measurements performed in the four transformers' secondary circuits. The ex ante period took 2 months of measurements (June and July) as the ex post (August and September). The lamps substitution the energy efficiency program used as example occurred in the beginning of August 2008.

Table 2 presents the energy savings in Wh considering the four transformers, totaling approximately 70.1 MWh or a consumption reduction of 22.7%.

Figure 1 presents the average load curves for the transformers from the hourly perspective for the ex ante and ex post periods.

The average daily demand of the four transformers up to August 2 (ex ante) was 53,532 kW, decreasing to 40,319 kW after the lamps substitution. The average savings then resulted in 24.7%.

Regarding the reduction of the peak demand, it ranged from 15% to 20%. However, for one of the transformers the peak period was displaced from the usual period (18h to 21h) to late in the night (22h to 3h).

Even though the average demand reduction from the substitution of lamps was approximately 79%, the impact on the transformers was lower. It is due to the electricity consumption participation of other main end uses, such as refrigerator and electric shower. Another important impact on the electricity demand is the appliances energy use patterns. For the present analysis, questionnaires were used to identify these patterns, as described in the following section.

ESTIMATE OF THE APPLIANCES ELECTRICITY CONSUMPTION

The load demand estimate by end use, such as lighting, refrigeration and heating water, is based on the data gathered from the existent appliances, the more energy efficient ones and their time use. This in situ measurements were possible due to negotiations between the distribution utility and the dwellers, in which the utility made a commitment that the dweller would receive the energy efficient appliances in exchange of keeping the meters in their houses and under the measurements conditions.

In order to identify the appliance ownership and patterns of consumption of the community under the energy efficiency program, field surveys are recommended before and after the appliances substitution and other energy efficiency measures. These surveys are important to evaluate the existence of relevant changes in the patterns of consumption, which also influences the results of the program.

Ex ante and ex post field survey

The appliance ownership and patterns of electricity consumption survey in a representative sample of the universe of households enables the program to infer the energy saving estimates (consumption and demand) from statistical methods with the corresponding precision and confidence intervals. Then, the use of statistical methods is crucial for the reliability of the results.

Sample definition

The sampling methodology adopted is based on the methodology described by the International Performance Measurement and Verification Protocol – IPMVP) (EVO, 2007). Some statistical parameters used are described as follows.

The sample is randomly selected, meaning that each consumer unit of the community has the same probability to be sorted out.

The sample is sorted out from a homogeneous population, considering exclusively the residential consumer units (the public and commercial sectors are not considered).

The sample precision is 10%. The precision refers to the error bound around the true estimate (i.e. ± x % range around the estimate).

The superior confidence interval is 90%. Confidence refers to the probability that the estimate will fall in the range of precision (i.e. the probability that the estimate will indeed fall in the ± x % range defined by the precision statement).

Measurements of electricity consumption for individual appliances in households – the case of kitchen lights (ex ante and ex post)

The plan of monitoring and verification follows the following assumption already adapted to residential lighting:

1. The lamps are plugged in the same voltage level.
2. There are no influences of other electricity end uses on the lamps consumption.
3. The lamps operational periods are exactly the same as those recorded by the lighting loggers.
4. The highest use of the lamps occurs in the kitchen.

Illustrative sample and data handling

The time use of lamps in a sample of 18 households was measured to illustrate the consumption pattern of the community. The measurements occurred during 14 days: one week before the lamps substitution and one week after the replacement of incandescent bulbs with varying wattages by CFLs of 15 W.

The data recorded was retrieved through an USB cable into a computer and analyzed through the Software SMARTware version 2008. For each data file referred to each lighting logger, the data was divided within the periods of analysis (26 July – 02 August and 03 August – 09 August) and the respective lamp wattages were attributed to for the ex ante and ex post period. For the ex ante period, the most common wattages of the incandescent lamps ranged between 60 W and 100 W.

Inferred results

The load demand and energy consumption considering the averages for the whole week and working days are presented in Table 3. Figure 2 presents the load curves from the weekly perspective.

In the ex ante evaluation, the average load demand for each hour considering the week average is 0.53 kW, totaling a daily average electricity consumption of 12.65 kWh. On the other

Table 2. Energy savings in Wh – four transformers

ENERGY SAVINGS (Wh) TOTAL - 4 TRANSFORMERS					
	Month	Wh	Total (Wh)	Difference (Wh)	Reduction (%)
Ex ante	June	158.148.166	308.866.008	70.130.809	22,71%
	July	150.717.842			
Ex post	August	121.428.850	238.735.199		
	September	117.306.349			

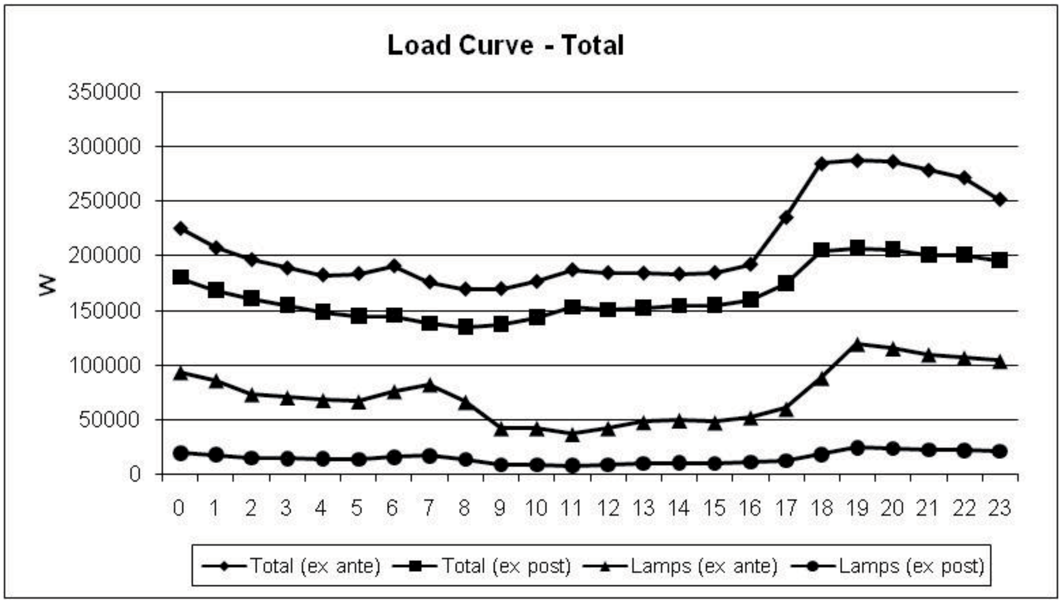

Figure 1. Hourly perspective for the 4 transformers: ex ante e ex post average load curve – total and lighting

hand, after the lamps substitution (ex post evaluation), the average load demand decreased to 0.13 kW, totaling a daily average electricity consumption of 3.13 kWh, a reduction of 75%.

Considering the peak demand, which occurred for both cases at 19h00, the peak reduced from 0.86 kW to 0.20 kW.

Figure 2 presents the lighting load curves from a weekly average perspective before and after the lamps substitution from the lighting loggers.

Conclusions

Low-income energy efficiency programs carried out by the distribution utilities in Brazil include improvements in power grid, indoor electrical wiring and meter installation or its regularization of illegal connections and donation of energy efficient appliances for the main end uses, such as refrigerators, electric showers, and compact fluorescent lamps. Educational and informative campaigns are also implemented as part of the low-income programs.

The methodology developed and tested under typical field conditions has the following components:

1. Analysis of the electrical and physical characteristics of the low-income community: annotated field survey using a structured checklist to get information regarding the conditions of local distribution grid characteristics, description of the local community, including its layout, housing characteristics.
2. Installation of meters at selected transformers which provide electricity to the households: metering and analysis of the data (kWh and kW) before and after the implementation of the energy efficiency measures. Demand estimates of the electrical appliances should also be carried out.
3. Survey of household appliance ownership and consumption patterns: statistical sample definition, household survey, descriptive statistics of the results and presentation to the utility and local agents. Critical analysis of the problems identified.
4. End use metering: measurement of household electricity consumption by targeted end use. For example: a smaller sample of households is selected lighting loggers are used to measure lighting usage patterns (energy and times of use) before and after the substitution.
5. Consumer satisfaction survey: the program (including the performance of the new appliances or services) is evaluated by households.

The methodology has helped to ascertain the benefits of efficiency programs to households and beneficial impacts on the local grid. However, it has been necessary to instruct the Utilities to improve their program design in order to accommodate data collection – especially ex-ante information – a practice which is not common amongst Brazilian utilities. End use metering in low income classes has proven to be challenging due

Table 3. Results of the analysis of the sample measured: ex ante and ex post.

		Weekly average		Working days	
		Hourly demand	Daily electricity consumption	Hourly demand	Daily electricity consumption
Ex ante	Average	0,53 kW	12,65 kWh	0,53 kW	12,91 kWh
	Peak demand	19h00 - 0,86 kW	-	19h00 - 0,86 kW	-
Ex post	Average	0,13 kW	3,13 kWh	0,13 kW	3,17 kWh
	Peak demand	19h00 - 0,2 kW	-	19h00 - 0,19 kW	-
Reduction	Average	0,4 kW	9,52 kW	0,4 kW	9,74 kW
	%	75%	75%	75%	75%
	Peak demand	0,66 kW	-	0,67 kW	-
	%	77%	-	78%	-

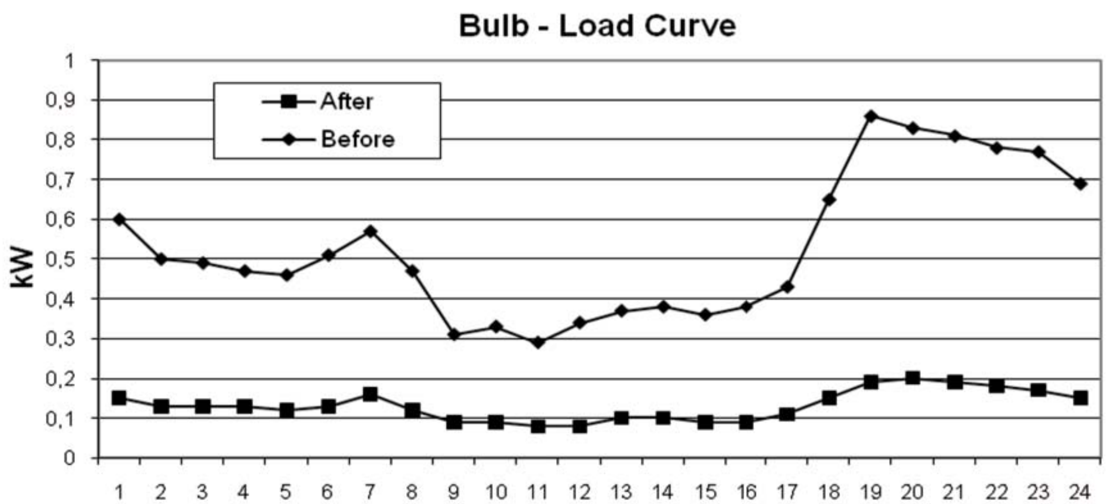

Figure 2. Lighting load curves: weekly average perspective

to specific poor housing conditions and access conditions to the M&V team.

Nevertheless, once data is collected with a reasonable accuracy and method it has been useful to show areas to improve program design and information efforts to local households. An additional step to be included in the presented M&V methodology will be a cost-benefit analysis.

As illustration, the main results of one low-income energy efficiency program implemented in Rio de Janeiro, showed a reduction of the electricity consumption by 22.7% (Figure 1). This result resulted from measurements made at the transformer level.

The daily average demand of the four transformers from a two-month ex-ante metering in 2008 was 53,352 MW. After the lamps substitution, this demand decreased to 40,319 MW in a two-month ex-post measurement, representing an average saving of 24.7%.

Regarding the peak demand reduction of the power system, the reduction verified ranged from 15% to 20%. However, for one of the transformers the peak period was displaced from the usual period (18h to 21h) to late in the night (22h to 3h).

Even though the average demand reduction from the substitution of lamps at the end-use point was approximately 79%, the impact on the transformers was lower. This is due to the electricity consumption participation of other main end uses, such as refrigerator and electric shower.

The methodology has to be robust enough in order to take care of the following issues: a) the physical access to the local community, which imposes challenges of time and costs surveys and measurements; b) poor quality of the existing data; c) disseminated practice of illegal connections.

In spite of all the difficulties, efforts were taken to establish a routine for data collection and analysis in order to assess the impacts of these programs on the local demand levels. A continuous improvement and systematic collection of information will help to better evaluate the costs and benefits of these programs.

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