Methodology for Measurement the Energy Efficiency Involving Solar Heating Systems Using Stochastic Modelling

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***Abstract*— The purpose of the present study is to evaluate gains through measurement and verification methodology adapted from the International Performance Measurement and Verification Protocol, from case studies involving Energy Efficiency Projects in the Goias State, Brazil. This paper also presents the stochastic modelling for the generation of future scenarios of electricity saving resulted by these Energy Efficiency Projects. The model is developed by using the Geometric Brownian Motion Stochastic Process with Mean Reversion associated with the Monte Carlo simulation technique. Results show that the electricity saved from the replacement of electric showers by solar water heating systems in homes of low-income families has great potential to bring financial benefits to such families, and that the reduction in peak demand obtained from this Energy Efficiency Action is advantageous to the Brazilian electrical system. Results contemplate also the future scenarios of electricity saving and a sensitivity analysis in order to verify how values of some parameters influence on the results, once there is no historical data available for obtaining these values.**

***Index Terms*—energy efficiency, geometric brownian motion, Monte Carlo simulation, performance measurement and verification, solar water heating.**

I. Introduction

THE use of solar energy in residential water heating has growing acceptance as an alternative or supplementary way to the heating provided by electric showers. Recently, Brazilian government programs have promoted the use of solar water heaters in homes of low-income families, such as Energy Efficiency Projects (EEP) of electricity distribution companies. These EEP are part of Energy Efficiency Program of Brazilian Electricity Regulatory Agency - ANEEL [1].

The application of the International Performance Measurement and Verification Protocol (IPMVP) is mandatory as a reference for Measurement and Verification (M&V) among other steps involved in evaluation of electricity saving and peak demand reduction of an EEP.

The IPMVP establishes rigorous criteria that lead many EEP to economic unviability, mainly due to long periods of measurement. To solve this problem, the Brazilian Association of Electricity Distributors (ABRADEE) developed M&V procedures from IPMVP to apply in EEP by final use, with contributions of consultancies and partnerships. Thus, a new M&V methodology by end use has been defined and approved by ANEEL, and passed on to electricity distribution companies in September 2014.

The annual consumption of electricity avoided, which represents annual electricity saving by the EEP depends on some factors that have random behavior over time such as: the number of residents of the housing project that received the Energy Efficiency Action (EEA), the bath habit of these people, changes in family income, and acquisition or replacement of electrical appliances in these houses.

This study aims to apply the M&V methodology adapted from IPMVP in order to get results and conclusions in terms of electricity saved and peak demand reduced from the replacement of electric showers by solar water heating systems, as EEA. The innovative aspects of this research shall be highlighted, once the application of the simplified methodology is recent and helpful for future improvements of it. This paper presents also the stochastic modeling for generation of future scenarios of electricity saving from these EEP. The random variable Annual Electricity Saving is modeled by using the stochastic process called the Geometric Brownian Motion with Mean Reversion (GBM-MR).

II. Project Definitions

The overall objective of the project consists in obtain results that can express the effects of the use of solar water heating in housing units of low-income families, to residents, to the Brazilian electrical system and finally to society. All of it by means of application of M&V adapted from IPMVP in EEP of CELG Distribution S/A (CELG-D), the electricity distribution company of Goias State. The specific objectives are: a) evaluate the average monthly savings of electricity to the consumers; b) evaluate the impact on demand of electricity at

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peak hours to the Brazilian electrical system; c) perform diagnosis and contributions to improvement of the M&V procedure from IPMVP adapted; d) generate future scenarios of electricity saving by stochastic modelling associated with the Monte Carlo simulation technique.

Three EEP of CELG-D related with solar water heaters in homes of low-income families in Goias State have been selected as case studies: municipality of Itumbiara, Real Conquista Residential and Orlando de Morais Residential – both located in Goiania that is capital of Goias State. For the two first EEP it was used data measured by CELG-D in September 2008 and June 2010, respectively, prior to the installation of solar heating systems. About the last one case, it was selected because it was in phase of installation of solar heating systems in the second half of 2014. Thus it was possible to carry out M&V in the last residences not yet covered by the EEA. Fig. 1 shows one of the solar water heating systems installed in homes of low-income families.

Initially some settings for the EEA are performed, as established in IPMVP. The following parameters are defined as in [2] and [3]: the measurement border, key performance parameter, independent variable, interactive effect, static factor, baseline period and reporting period.

The measurement boundary corresponds to the limits within which it is desired to check the energy savings and the reduction of peak demand. Depending on the EEA, the measurement boundary may be the whole installation or only equipment(s) or system(s) responsible for EEA. For these cases, the measurement boundary is defined as the set of power supply circuits of showers and resistors, in other words, isolating the electric shower.

The key parameters are those that are directly related to the consumption of electricity. The key parameters to be measured are the electric power during use of the shower and bath time.

Independent variables are the variables that, when there is correlation with the energy consumption of the installation or system, explain the variation of this consumption, being used for the necessary adjustments, through a linear regression analysis. The outdoor temperature is defined as independent variable. It is obtained from measurements of the nearest station of Brazilian National Institute of Meteorology - INMET.

Fig. 1. Solar water heating system in home of low-income family

According to the IPMVP, some energy effects affecting EEA may occur outside the measurement boundary. These are called interactive effects. According to the M&V Guide, it is necessary to define them, if any, and decide whether they will be estimated or ignored. In this context, it is considered that there are no interactive effects, once loss in power supply circuits of the house and of the shower are considered negligible.

Static factors are those that define the energy consumption pattern of the installation or system of this, such as installation size and number of people. Static factors are not considered in this case because of standard size residences and short measurement period, as described below.

It is also necessary to define, according to the IPMVP, the baseline and economic determination periods. The first corresponds to the measurement period prior to the installation of the equipment responsible for ESA, and should represent a full duty cycle of the components of the measurement boundary. The same applies to the period of determination of the economy, however, considering it after the implementation of EEA.

The baseline period is: seven days in EEP Orlando de Morais; eleven days in Real Conquista Residential; and sixteen days in Itumbiara. It is important to emphasize that these shorts measurement periods are justified by the methodology to be used for M&V adapted from IPMVP to the reality of EEP in order to obtain projects economically viable.

Measurements are not performed in the reporting period because the EEA results in installation of solar heaters systems and consequently in the removal of electric showers.

The IPMVP offers four options for determining energy savings. Option A corresponds to the measurement of at least one of the key parameters that define energy use by EEA-related systems isolated, and estimation of the other key parameters. Measurement periods can range from a short-term period to continuous measurement.

Option B corresponds to the measurement of all the key parameters that define energy use by ESA-related systems isolated, ranging from a short-term to a continuous period. It can be used, for example, in pilot projects involving new technology or methodology.

In Option C, the energy consumption assessment involves the whole facility, with continuous measurement in the period of determination of the economy. It is generally the option of lower cost, however, one must be more rigorous in relation to the static factors, since the measurement border is wider.

Option D involves assessing the energy consumption of the entire facility using simulation calibrated from actual data from distributor power bills. Used in new installations, where the model simulates data that does not exist for parameters of the baseline period.

From the above definitions, it is chosen Option A to determination of electricity savings and peak demand reduction from IPMVP, considering also that one of the key parameters has to be estimated.

III. METHODOLOGY

The first step related to the methodology used is the definition of sampling. It involves setting the initial number of samples in two ways, one determined according to the relation between the initial population and sample, given by NBR 5426 - Sampling Plans and Inspection Procedures by Attributes - considering severe inspection level (level 1), and second calculated by (1) and (2) [3].

$$n_0 = \frac{z^2 \times cv^2}{e^2} \tag{1}$$

$$n = \frac{n_0 \times N}{n_0 + N} \tag{2}$$

In (1), n_0 represents the size of initial sample, z is a standard value of normal distribution as "t-Table" available in IPMVP (it shall be adopted value of 1.96, equivalent to 95% confidence), cv corresponds to the coefficient of variation (it shall be adopted from previous projects or 0.5 if no existent) and e is the level of precision desired (it shall be adopted 10%). In (2) n is the size sample for small populations and N is the population size.

The results obtained through the two above methods provide a basis for the decision on the initial sample, considering equipment, people, costs and time restrictions. After obtaining the values measured in baseline period, shall be calculated the precision obtained with the initial sample size, for each key parameter. This is calculated by (1), using the coefficient of variation calculated from the data obtained. If the precision of 10% is not reached (if value is greater), it is necessary increase the number of samples, thereby performing iterative process until the desired precision is obtained [5].

After obtaining the keys parameters data in the baseline period and temperatures corresponding to the dates of measurements, it is assessed if there is a correlation between the parameters and independent variable, using linear regression analysis. The first evaluation criterion calculated is the determination coefficient (R^2), calculated by (3), where $\hat{y}_i$ is the key parameter value adjusted by the model to a given point using the corresponding value of the independent variable.

$$R^2 = \frac{\sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{3}$$

The second evaluation criterion is the Coefficient of Variation of Root-Mean Squared Error - *CV(RMSE)*, which measures the forecast accuracy. The calculus is done by (4), dividing the standard error of the estimate by the mean of the electricity consumed. In (4) p is the number of independent variables.

$$CV(RMSE) = \frac{\sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n-p-1}}}{\bar{y}} \tag{4}$$

The last evaluation criterion is the *t-statistic*, a statistical test to determine whether an estimate has statistical significance due to the possibility of variation of regression coefficients. The *t-statistic* is calculated by (5), dividing the regression coefficient (slope) by the standard error of each coefficient of the regression model.

$$t - statistic = \frac{b}{\sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2 / (n-2)}{\sum_{i=1}^{n}(x_i - \bar{x})^2}}} \tag{5}$$

Where b represents the regression coefficient (for the 1-unit increase of the independent variable there is increase of "b" units of key parameter), x_i corresponds to the value of independent variable and $\bar{x}$ is the mean of the values of independent variable.

According to [6], maintaining the criteria of the case passed on to electricity companies there is correlation between electricity consumption and outdoor temperature if at least two of the following three criteria are met: R^2 greater than 0.75; *CV(RMSE)* less than 5%; *t-statistic* greater than 2.

If correlation is verified and validated, regression is used as a basis for setting baseline and reporting periods, to leveling electricity consumption in the measurement boundary without influence of outdoor temperature. Thus, the calculation of electricity savings shall be done by (6) [2].

$$ES = C_{bl} - C_{rp} \tag{6}$$

Where ES corresponds to the electricity saving, C_{bl} is the electricity consumption in baseline period adjusted to fixed conditions and C_{rp} represents the electricity consumption in reporting period adjusted to fixed conditions. If there is no correlation the same equation is used without adjustments.

Calculation of reduction of electricity demand at peak hours does not require adjustments, occurring through (7) [2].

$$DR = D_{bl} - D_{rp} \tag{7}$$

Where DR corresponds to the demand reduction in peak hours, D_{bl} represents the mean of peak demand in baseline period and D_{rp} is the mean of peak demand in reporting period.

Several stochastic processes have been used in the Brazilian Electricity Market to model the uncertainties present in this, such as the spot price, affluence, electrical demand and consumption of electricity. These random variables can be modeled as time series by using the Monte Carlo simulation technique, associated with the stochastic process called Random Walk [4].

Once the annual electricity saving obtained by EEP is dependent of variables with random behavior, it is necessary to generate future scenarios of this random variable by using an adequate stochastic process.

The Geometric Brownian Motion (GBM) is a particular case of Ito's process, which in turn corresponds to the generalization of Brownian motion with drift [8]. According to [9], when a random variable follows a GBM, their values tend to diverge from the original starting point, since the variance grows linearly with time. In this context, the process of BGM with Mean Reversion, also called Ornstein-Uhlenbeck process, forces the values obtained to the random variable over time to revert in direction of the equilibrium position, i.e., the starting value (mean value, for example). According to [7], there is a force of reversion acting on the random variable pulling it to a long-term equilibrium level.

The random variable Annual Electricity Saving by EEP (*EE*) can be obtained by (5) that represents the model by the GBM with Mean Reversion.

$$EE_{t+1} = EE_t . e^{\left\{\left[\eta.(\ln \overline{EE} - \ln EE_t) - \frac{1}{2}\sigma^2\right].\Delta t + \sigma.\varphi.\sqrt{\Delta t}\right\}} \qquad (8)$$

Where η is the mean reversion speed, $\overline{EE}$ represents the mean value of the random variable, σ is the constant that represents the percentage volatility random variable, t represents the time and φ corresponds to a random variable with standard normal distribution – *N(0,1)*.

The stochastic behavior of the random variable can be represented by curves containing the values obtained for annual electricity saving on the time horizon defined, as a family of time series, using the Monte Carlo simulation. The stochastic process can be also represented by the evolution of the Probability Density Function (PDF) of the random variable over time [7].

IV. Results

The step of the methodology regarding to the sampling definition was included only in the case study involving EEP Orlando de Morais Residential, once there were definitions before M&V, which there were not possible in relation to the other cases, whereas that measurement data were obtained in past periods.

The key parameters electric power and bath time were obtained by measuring energy consumed by electric showers. The meters used were calibrated at the measurement laboratory of CELG-D, using reference pattern meter tracked by the Brazilian Calibration Network. These meters were installed directly between the shower and electric installation of the residence, on the other hand, the Fig. 2 shows the process of extracting the measurement data from the mass memory of the meter.

The initial sample size corresponds to the product of the number of residences with the number of days in the baseline period. Thus, based on estimates from the equivalence given by NBR 5426 and (1) and (2), and also considering the restrictions on the available number of meters and the short time until the installation of solar heating systems on the latest residences in Orlando de Morais Residential, the initial sample in this EEP consisted of 77 day.residence, which corresponds to 11 homes with measurements in 7 days of the baseline period.

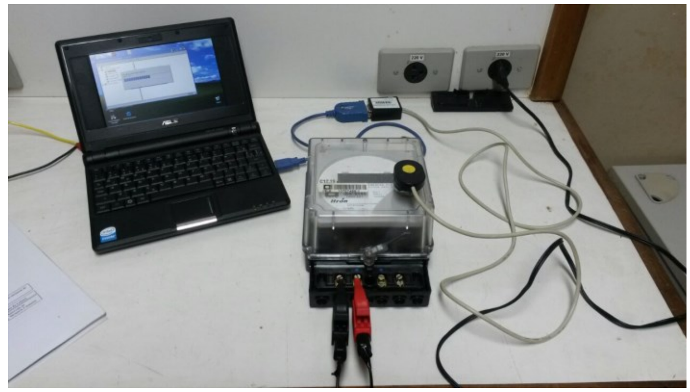

Fig. 2. Extraction of measurement data

In this way, once that the used meters measure energy consumed by the shower over time, it is possible to transform the obtained values in electric power and bath time, that is, the defined key parameters. This procedure is recommended in the methodology in order to have the sampling level of precision obtained, for the variability of power values is smaller than electricity consumed values. It should be pointed out that without this transformation, the range of desired precision level leads to excessive increase in the number of samples, which can make an EEP economically unviable.

Table I shows the results of obtaining the precision level of sampling in the three case studies. In order for a sampling to be statistically valid, the accuracy level must be less than or equal to 10% for at least one of the key parameters, such parameters being considered measurement. The bath-time key parameter is considered as an estimate (not measurement), since the desired level of accuracy is not obtained, besides the fact that the meter used does not perform continuous measurement of bath time, from the records of energy consumed by the shower during the intervals of 5 minutes.

TABLE I
Data Comparison and Results of Energy Economy of PEE

Number of samples	Orlando de Morais	Real Conquista	Itumbiara
Number of residences with M & V.	11	8	16
Number of measurement days.	7	11	4
Number of samples (residence.day).	77	88	64
Precision level parameter key: electrical power.	18%	8%	12%
Precision level parameter key: bath time.	27%	13%	17%

The sampling precision levels obtained for key parameters power and bath time are 18% and 27%, respectively, thus not reaching the target of 10%. Thus, there would be necessary to increase the number of samples which was not possible due to the completion of installation of the solar heating systems in the remaining houses. The continuity of methodology phases even not reaching the precision level is justified by the experimental nature of the project.

Regarding to data relating to M&V in EEP Real Conquista Residential and municipality of Itumbiara, 8% level of precision was obtained for the key parameter electric power in the first, thereby achieving the desired criteria. However, this did not occur in the case of EEP municipality of Itumbiara, while that the obtained level of precision was 12%. As the data correspond to measurements taken in the past, in residences where the installation of solar heating systems was completed, the number of samples could not be increased.

Among the key parameters, electric power has been defined as the parameter most likely to be influenced by the independent variable. In the three case studies it was not found correlation between the electric power on shower use and outdoor temperature in the baseline period, once the criteria have not been met. As an example, the results of calculations relating to the EEP Orlando de Morais Residential were: R^2 equal to 0.2% (less than 75.0%; *CV(RMSE)* equal to 78.4% (greater than 5.0%); *t-statistic* equal to 0.35 (less than 2.00).

The average daily electricity economy per housing unit was calculated by (3), disregarding the adjustments for not exist correlation between key parameter and independent variable. Table I shows the average daily power measured, the average daily bath time, average outdoor temperature in baseline period, averages of daily and monthly consumption with electric showers – which corresponds to savings as result of EEA, the main variable for comparison - and the annual savings considering all the residences contemplated by EEP, for the three case studies. By the current conventional electricity tariff for low-income homes of CELG-D – R$ 0,26/kWh – for consumption between 31 and 100 kWh (once the average consumption of low-income homes is 77 kWh) and considering the exchange between Brazilian currency and US dollar in July 2015, it is calculated the monetary value of those annual savings, which are presented in Table II.

It is possible to observe that the average daily consumption of electricity avoided per housing unities significantly higher in EEP Real Conquista and in Itumbiara. Such as the average electric power as the average daily bath time are lower in EEP Orlando de Morais.

The daily bath time can be a result of the amount of baths in the residences, as well as local routine in relation to bath time. To check these two influences, it would be necessary to consider data related to static factors and habits of the residents of the homes included in the samples, which was not possible for the EEP Real Conquista and Itumbiara. Thus, the importance of the survey and storage of behavioral information about the families' routine of the sample of an EEP is shown. So it is possible to do comparisons between results, taking into account the conditions and realities of the population of each location evaluated.

The difference between the average daily electric power obtained in the EEP Orlando de Morais and those obtained in the others case studies can also be explained by the electric shower position used during the measurement period (power level). While analyzing the average outdoor temperature in days of measurement of each EEP, there is large difference between EEP Orlando de Morais and others. In this place, the average outdoor temperature was 30.5°C, while considering the days of measurement in EEP Real Conquista and Itumbiara the values were of 22.9°C and 24.0°C, respectively, which may have influenced by the position associated to a higher power used in electric shower and therefore the highest average daily electric power obtained from each EEP.

TABLE II
RESULTS OF ELECTRICITY SAVING IN EEP APPLICATIONS

Results	Orlando de Morais	Real Conquista	Itumbiara
Average daily electric power per house (kW)	1.56	2.79	2.79
Average total daily bath time per house (minutes)	9.87	33.21	34.57
Average daily consumption of electricity avoided per house (Wh)	256.38	1545.34	1606.01
Average outdoor temperature in baseline period (ºC)	30.5	22.9	24.0
Average monthly consumption of electricity avoided per house (kWh)	**7.69**	**46.36**	**48.18**
Number of homes in the EEA	544	478	1080
Annual electricity consumption avoided with EEP (MWh)	50.21	265.92	624.42
Monetary values of annual savings (US$)	4054.10	21471.96	50418.69

It also contributes to the fact that such mean values are obtained considering even samples in which the daily values of these key parameters correspond to zero, that is, where There was no record of electricity consumption by the shower on the day of measurement at the residence. This occurred in 19 of the 77 samples from this case study, either because there was no bath on the day at the residence or more likely because, due to the high temperature, the bath was taken with unheated water, thus not being recorded.

These samples with zero-parameter values reduce the mean values obtained, but by disregarding them, the energy savings obtained with the PEE can be overestimated. When disregarded, the average power at the PEE Orlando de Morais becomes 2.04 kW, which is closer to the power of a common shower in the "summer" position, and the average bath time becomes 12.46 minutes. That is, when the average values of the key parameters are analyzed, they may seem low, but it is guaranteed that energy savings and reduction in peak demand are not overestimated, thus respecting one of the IPMVP principles.

To obtain the average electric power relating to the use of showers in peak hours the average power measured has been multiplied by the average total bath time of this time range, and this value has been divided by three, since this is the number of hours of peak interval. Then the average value of electric power taken from peak demand with EEA in one residence in each EEP has been achieved, and considering the population of the studies, the reductions in peak demand reached from the analyzed EEP have been calculated. The results are shown in Table III for the three case studies.

In the same way that the average daily economy of electricity, the average reduction in peak demands for one residence is significantly higher with EEP Real Conquista and Itumbiara. Possible causes of this difference are the same as mentioned in comparing results related to electricity savings (outdoor temperature and power selected for shower operation), since both the average electric power and the average bath time at peak hours are smaller in EEP Orlando de Morais.

TABLE III
RESULTS OF PEAK DEMAND REDUCTION IN EEP APPLICATIONS

Results	Orlando de Morais	Real Conquista	Itumbiara
Number of homes in the EEA	544	478	1080
Average daily electric power per house (kW)	1.96	2.46	3.08
Average daily bath time at peak hours per residence (minutes)	7.96	19.82	19.09
Average reduction in the peak demand per residence average (kW)	0.09	0.27	0.33
Reduction in the peak demand per residence with EEP (kW)	47.28	129.29	352.92

Table IV shows the comparative of the uncertainty calculated for the key parameters used to obtain the avoided electric energy consumption, in each case study. The observed difference reflects the dispersion of the measurement values that impact the sampling uncertainty, especially in relation to the PEE Orlando de Morais, since the modeling uncertainty was not considered and the measurement uncertainty is the same in all cases. The comparison of the uncertainty calculated for the key parameters used to verify the reduction in peak demand in the three case studies is presented in Table V.

The annual consumption of electricity avoided depends on some factors that have random behavior over time. As already mentioned, the random variable Annual Electricity Saving is modeled by using the stochastic process called the Geometric Brownian Motion with Mean Reversion (GBM-MR).

TABLE IV
COMPARISON OF UNCERTAINTY CALCULATED FOR ENERGY SAVINGS IN CASE STUDIES

Relative uncertainty of key parameters.				
Orlando de Morais	Power (kW)	1,56	±	18%
	Usage time (min / day)	9,87	±	27%
Real Conquista	Power (kW)	2,79	±	8%
	Usage time (min / day)	33,21	±	13%
Itumbiara	Power (kW)	2,79	±	12%
	Usage time (min / day)	34,57	±	17%

TABLE V
COMPARATIVE OF THE UNCERTAINTY CALCULATED FOR REDUCTION IN THE DEMAND OF TIP IN THE CASE STUDIES

Relative uncertainty of key parameters.				
Orlando de Morais	Power (kW)	1,96	±	10%
	Usage time (min / day)	7,96	±	15%
Real Conquista	Power (kW)	2,46	±	8%
	Usage time (min / day)	19,82	±	12%
Itumbiara	Power (kW)	3,08	±	8%
	Usage time (min / day)	19,09	±	11%

For generation of future scenarios of electricity saving from an EEP, it is defined as the starting value to the random variable Electricity Saving (in the initial year) the annual electricity consumption avoided by the EEP Real Conquista Residential (265.92 MWh). Table VI presents the input data for simulation.

TABLE VI
INPUT DATA FOR SIMULATION

Average value (MWh)	265.92
Volatility of the random walk (MWh)	103.71
Mean reversion speed	0.50
Time horizon of simulation (years)	10
Interval between simulation periods (years)	1
Number of scenarios	2000

The volatility (σ) of the random walk is defined as the estimated standard deviation of Annual Electricity Saving, obtained by multiplying the coefficient of variation calculated with the measured values of electric power in the EEP Real Conquista Residential (0.39) for the electricity saving in the initial year (mean). For the mean reversion speed (η) it is assigned the value 0.50. Both parameters of the random walk should have assigned values based on historical data. However, considering the absence of these data, it was not possible to perform appropriate statistical analysis to obtain these values, which led to the aforementioned assignments, considering the pioneering nature of this study.

Fig. 3 presents the simulation results for one scenario of the random variable Electricity Saving, which shows how the random walk can occur along the horizon.

Fig. 4 shows the PDF for each year of the study horizon, as another way of representation of future scenarios for annual electricity saving obtained by the EEP Real Conquista Residential. The red line shown in this figure represents the mean of the values obtained from time series, in each year, which remains around 265 MWh.

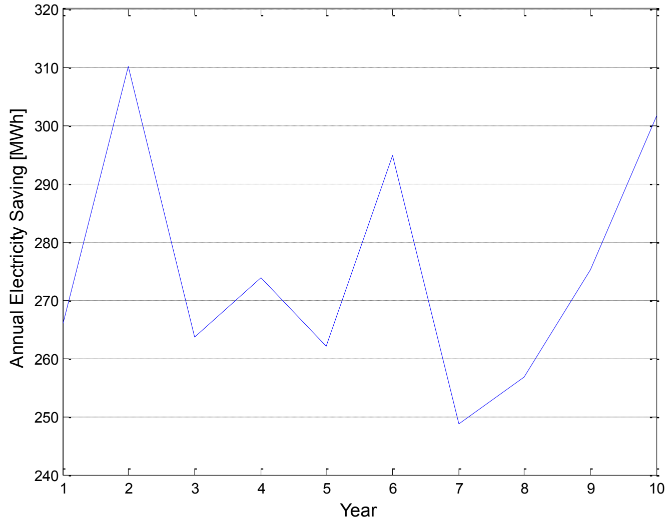

Fig. 3. Behavior of the annual electricity saving over time – one scenario

In the simulation results presented in Fig. 4 the values of the mean reversion speed (η) and the volatility (σ) of the annual electricity saving were assigned once there are no historical data of them until this moment.

To verify the influence of these parameters on the results, sensitivity analysis was performed. For this objective, it was adopted a variation range of 0.00 to 265.92 MWh with step of 13.30 MWh for the volatility (σ), and range of 0.10 to 10.00 with step of 0.10 for the mean reversion speed (η) , both for the year 3 of the initial horizon of the simulation.

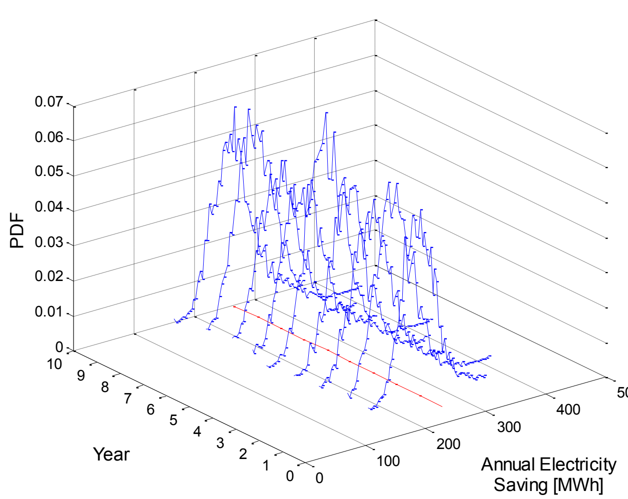

Fig. 4. Probability density function of the annual electricity saving

Fig. 5 shows the behavior of the maximum and minimum values of the annual energy for the 2000 scenarios obtained for the year 3, in function of the variation of the standard deviation and the mean reversion speed. This figure represents the stochastic behavior of the electricity saving for a large range of situations. As expected, there is an increasing of the peak-to-peak amplitude of annual electricity saving with the increasing of both the standard deviation and the mean reversion speed.

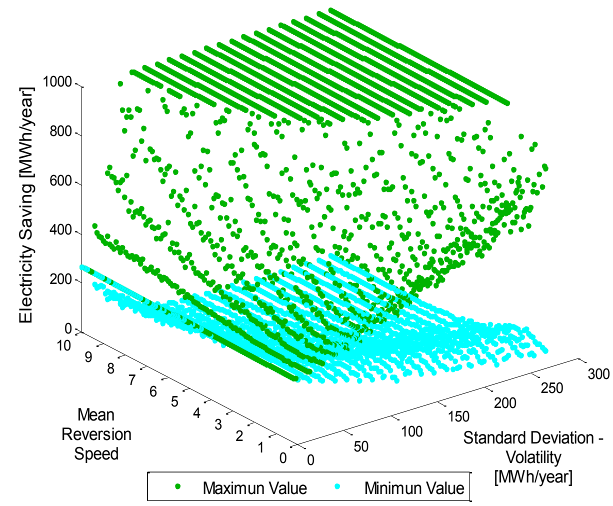

Fig. 5. Amplitude of electricity saving by variation of σ and η

The behavior of the expected value and the standard deviation of the annual electricity saving for the 2000 scenarios in the year 3, in function of the variation of the volatility and the mean reversion speed is shown in Fig. 6.

As the variation of the parameters mentioned in this sensitivity analysis results in some extremely high values of annual electricity saving, Fig. 5 and Fig. 6 have the z axis graphically limited to 1000 MWh/year, in order to highlight the behavior throughout the variations.

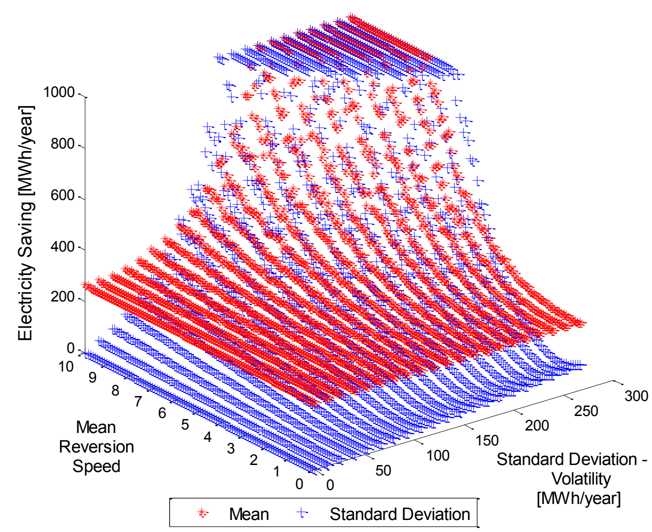

Fig. 6. Mean and standard deviation of electricity saving by variation of σ and η

It can be seen by these figures that increasing the standard deviation leads to greater spread of results, however, it is with the increase of the mean reversion speed that is observed a sharp increase of the mean and standard deviation of the 2000 series.

Such behaviors are also visualized through Fig. 7 and Fig. 8. In the first, the reversal velocity was maintained at the constant at 0.5 and the standard deviation representing the volatility was varied. In Fig. 8, the standard deviation

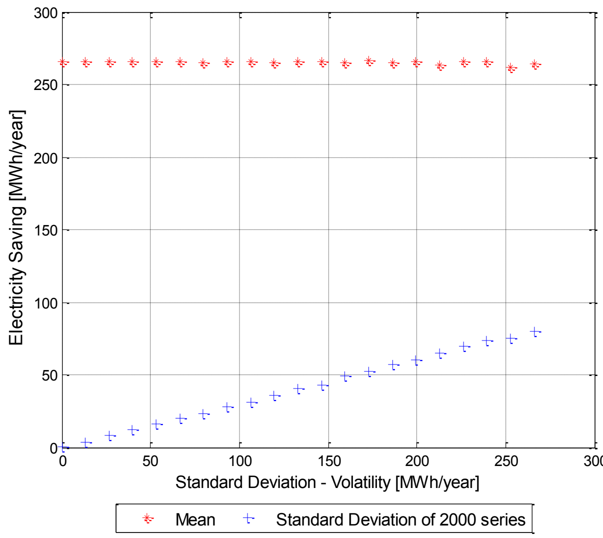

Fig. 7. Mean and standard deviation of electricity saving by variation of σ

Fig. 8. Variation of mean and standard deviation of the energy saving values varying η

(volatility) was fixed at 103.71 MWh and the rate of reversion was varied to the mean. It is also possible to verify in this that the standard deviation of the 2,000 series reaches the lowest value when the speed is 1, that is, when the slope of the trend line formed by historical data is 45º degree or 135º degree.

V. CONCLUSIONS

First of all it is possible to evaluate that these EEP resulted in benefits for families. It was found that these savings are approximately 10%, 60% and 62% of the average monthly electricity consumption in low-income residences in the Goias State, from EEP Orlando de Morais Residential, Real Conquista Residential and Municipality of Itumbiara, respectively. This saving has great potential to mitigate the increase of the monetary values of electric bills that have recently been taking place in Brazil.

Another evaluated aspect is that the reduction in peak demand obtained with the EEP. Considering estimate done with all residences with the benefit of the EEA, the reduction represents 0.054% of the maximum peak demand in the Goias State in 2014. It was found that the cost of this reduction in demand is less than the cost of electricity generation in US$/kW, considering estimation performed with data results of electricity auctions published in August 2015 by Electrical Energy Commercialization Chamber (CCEE).

Therefore it can be concluded that, added to the reduction achieved with EAA of other end uses in EEP, such as changing light bulbs and appliances for more efficient ones, there are contributions to the postponement or the relocation of investments by electricity companies.

The application of the M&V procedure adapted from the IPMVP in the case studies of this work allowed to obtain contributions for future applications in PEE of the CELG-D and other distributors of electric energy of Brazil.

First, from the results obtained for the level of precision of the sampling and for the combined uncertainty in the case studies of this work, the importance of the planning of the measurement considering the process of obtaining sampling is highlighted.

The adoption of the largest number of samples obtained through the two mentioned estimates, i.e. through NBR 5426 and the expressions provided by the IPMVP, increases the chances of reaching the level of precision required without the need for additional measurement. If there are constraints on the number of meters to comply with the initial defined sampling, it is necessary to consider complementary measurement periods in the M&V process planning.

The follow-up of the M&V stages in the Orlando de Morais PEE also made it possible to conclude on the importance of the alignment of the periods of the stages of a PEE, more specifically in relation to the measurement periods in the baseline and installation of the solar water heating system In the residences, in order to avoid the loss of samples caused by the installation of the heating system during the period of measurement of the key parameters for the electric shower, which also impairs the level of sampling precision required for the reliability of the Results.

Short measurement periods are essential for the viability of M&V and consequently of the PEE, being important adaptations for the current M&V procedure. However, considering the results obtained by checking the correlation between the ambient temperature and the electric power of the shower, it is verified that the variation of the independent variable will hardly explain the variation of the key parameter. However, the comparison between PEE results whose measurement occurred and different times of the year, the ambient temperature may be more influential on such results, as could be verified through the case studies.

The results presented for PEE Residencial Orlando de Morais also reinforce the importance of future work involving the development of propagation methodology for the full year of energy saving and reduction of peak demand verified in a certain period of the year, thus considering Seasonality. The measurements performed in October in this case study can be considered atypical, since the mean values of the key parameters were significantly lower than the values obtained in the other case studies.

Finally, it is also recommended for future M&V the use of meters whose energy recording is done in intervals of less than 5 minutes, in order to avoid overestimation or underestimation of the key parameters, which contributes to a higher reliability of the economy results. Electric power and reduction in peak demand, while taking into account the balance between cost and benefit highlighted by IPMVP.

The application of the methodology of stochastic modeling to forecast future electricity saving by EEP leads to the conclusion that the reliability of its use is conditioned to obtaining historical data for volatility and mean reversion speed, given the abrupt variation of results. As new results of electricity saving by M&V in EEP will be obtained, it will be constituted a sufficient set of historical data for the assignment of these constants used in stochastic modeling.

Considering these contributions and new information to be used in the stochastic model, as the useful life of equipment, this methodology can be used to obtain prediction of electricity saving by use of solar water heating systems.

Finally, it is concluded that the society gets benefits from EEA, considering the highlighted economies and the reduction of environmental impacts associated with the generation, transmission and distribution of electricity, which contributes to a better use of natural resources of the planet.

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