MONITORING AND VERIFICATION PROCEDURES USED IN THE TEXAS LoanSTAR AND REBUILD AMERICA PROGRAMS

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ABSTRACT

The monitoring and verification procedures that have been developed for the Texas LoanSTAR program and the ESL's Rebuild America Program have become a foundation for a number of other state and federal M&V programs, including the United States Department of Energy's (USDOE's) 1996 NEMVP, 1997 IPMVP, 2001 IPMVP, ASHRAE's GP 14P, and the 1999 Texas Performance Contracting Guidelines. This paper reviews the basic procedures that are used for monitoring and verifying energy savings in commercial buildings that receive energy conservation retrofits, including procedures that are used for measuring energy savings in buildings where hourly pre-retrofit and post-retrofit whole-building data have been collected; buildings where monthly pre-retrofit and hourly post-retrofit data are collected; and buildings where monthly pre-retrofit and monthly post-retrofit data are used to verify savings.

INTRODUCTION

Savings for LoanSTAR and Rebuild America retrofits are determined using before-after savings methods, which develop a statistical "baseline model" of the energy use of each building from the consumption data measured before the retrofit is performed. This model is then used to predict what the building energy consumption would have been if the retrofit had not been performed. This prediction is made using the post-retrofit weather and occupancy conditions. The savings are then determined by subtracting the measured post-retrofit energy use from the baseline predictions of the building's energy use (i.e. without the retrofit). For the majority of the buildings the measurement of energy use is accomplished with time-series measurements of electricity, thermal energy use, and the coincident ambient conditions, usually on an hourly basis.

In the simplest cases, retrofit savings can be measured by directly comparing the unadjusted pre-retrofit monthly energy use to the post-retrofit monthly energy use. Unfortunately, this simple comparison can contain as much as 10-20% error in buildings that have varying schedules and/or experienced different weather conditions during the pre/post periods. This can be a problem for those sites where the savings are expected to be 10-20% of the utility bill.

SAVINGS CALCULATION METHODOLOGY

In the Energy Systems Laboratory (ESL), for the larger retrofits, it was decided that hourly data would be measured during the pre-retrofit period to construct baseline models. These data are then used to predict what the building would have consumed in the post-retrofit period had the retrofit not been implemented. This is the basic concept behind the program's before-after savings analysis. This methodology has been recommended and adopted for use in measuring energy savings in performance contracts in Texas (TECC 1999) and as Option C in the IPMVP (USDOE 2001) and has been proposed as the before-after analysis method in ASHRAE Guideline 14P (ASHRAE 2000; Haberl et al. 2001).

The basic modeling approaches used in the LoanSTAR program can be grouped into two generic types: regression models, and calibrated engineering models. The data used in the regression models consists of billing and/or monitored data and utilizes one, two, three, and four parameter change-point models, or multiple linear regression models as shown in Figure 1. Simple linear and change-point linear models (i.e., one, two, three, four and five parameter change-point models) are chosen for several reasons. Mainly, because there is a physical basis for selecting such models because they statistically represent thermostatic on-off behavior in many classes of buildings as well as the internal-external cooling-heating patterns that are observed in many buildings. In general, the approach used to apply the change-point models usually involves applying all the models to a dataset and then selecting the best model based on the goodness-of-fit and, in some cases, known physical characteristics about the building such as control schedules and/or occupancy periods.

The calibrated engineering models range from sophisticated DOE-2 calibrated models to calibrated simplified HVAC system models. In general, calibrated, simplified, air-side models have been found to be the easiest to apply and yield results that are suitable retrofit savings analysis. Application of DOE-2 to savings analysis has been limited to only a few buildings due to the added cost of applying such complex software. Additional information about the analysis techniques can be found in Claridge et al. (1992); Fels (1986); Fels et al. (1995); Haberl et al. (1995); Haberl et al. (1998); Haberl and Bou Saada (1998); Katipamula and Claridge (1992); Kissock et al. (1992); Kissock (1993); Kissock et al. (1994); Reddy et al. (1992); Ruch and Claridge (1991); and Ruch and Claridge (1993). Software for calculating linear and change-point linear models includes Emodel (Kissock et al. 1994), and ASHRAE's Inverse Model Toolkit (IMT) (ASHRAE 2001).

In each case where regression models are used it is important to identify the pre-retrofit period, construction and post-retrofit period. Then, depending on the type of model, hourly data are usually converted to average daily data prior to performing the regressions since it has been found that daily models give a superior fit to average daily temperature over hourly models from the same building. Statistical indices are then calculated and the best model chosen on the basis of its goodness of fit, usually using a combination of CV-RMSE and/or R^2 indicators (CV-RMSE is the coefficient of variation of the root mean square error. R^2 is the coefficient of determination; definitions of these variables can be found in the 1996 NEMVP and 1997 IPMVP). Often, to assure completeness, all models are applied to all buildings and the best model is chosen. The statistical models are then used to project the baseline use in the post-retrofit period. Savings are then calculated by the difference between the pre-retrofit baseline energy use and the measured post-retrofit energy use.

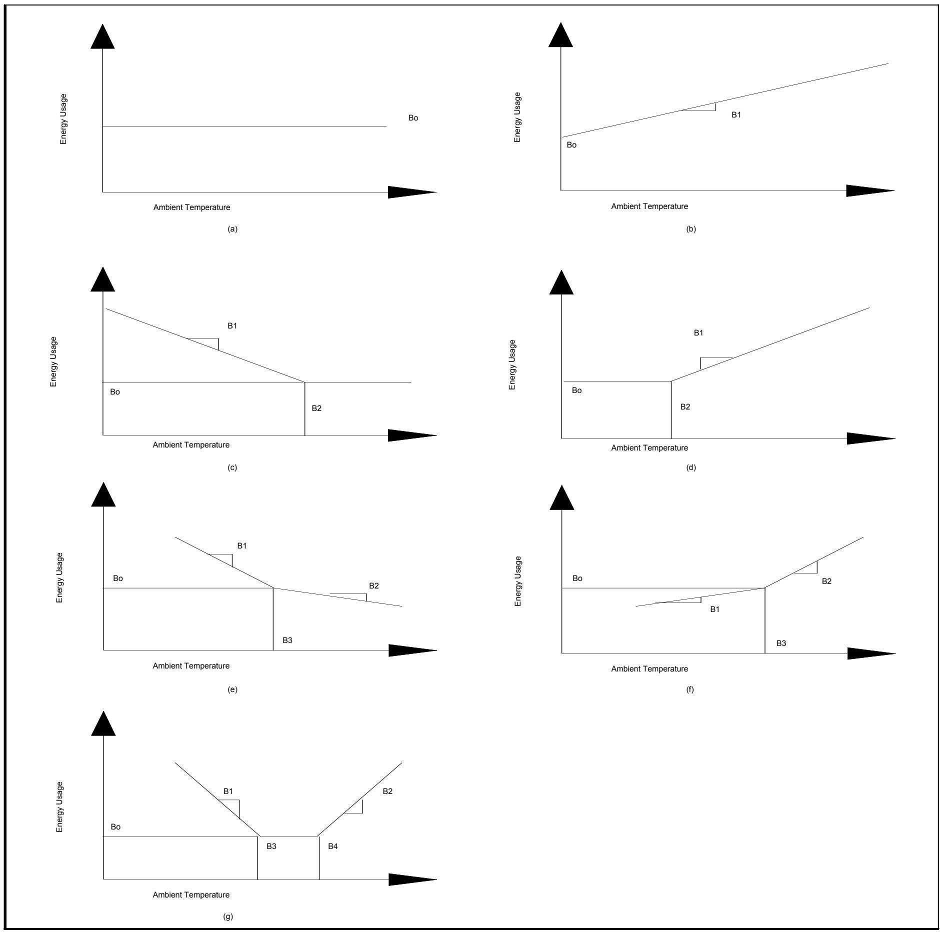

Figure 1: Primary before-after models used in the LoanSTAR and Rebuild American programs. This figure shows the primary models used in the Texas LoanSTAR program and in the Rebuild America programs, including: 1a) 1 parameter linear model; 1b) 2 parameter linear model; 3 parameter change-point linear model for 1c) heating; and 1d) cooling; 4 parameter change-point linear model for 1e) heating; and 1f) cooling; and 1g) a 5 parameter change-point linear model.

THE LoanSTAR AND REBUILD AMERICA PROGRAMS

The Texas LoanSTAR Program is a $98.6 million revolving loan program which provides low interest loans to fund energy conservation retrofits in the State of Texas, local government, and school buildings. The Energy Systems Laboratory (ESL) at Texas A&M University has provided Metering and Verification (M&V) for the program since its inception in 1989. State agencies are mandated to meter and monitor their energy use to establish baseline energy use models and accordingly verify that the energy and dollar savings predicted from the retrofits are occurring. Additional information about the LoanSTAR program can be found in Verdict et al. (1990), Claridge et al. (1991), Turner et al. (1998), Turner et al. (2000).

The Rebuild America Program is another program that shares the same objective as the LoanSTAR program; however, it is funded by the US Department of Energy (DOE). Rebuild America partners are encouraged to participate in selecting Energy Conservation Measures (ECMs) suitable for their facility, capital improvements priorities and the financial plan that uniquely fits their need. Additional information about the Rebuild America program can be found in Saman et al. (1998), Haberl et al. (2000), and Yazdani et al. (2000).

The first step of any M&V effort should be the M&V plan. An M&V plan would at least include the following:

a. A description of the ECMs and their predicted effect.
b. What will be measured.
c. What time interval(s).
d. What instruments will be used.
e. How such instruments will be calibrated.
f. Baseyear conditions and operating schedules.
g. Specification of the data analysis procedures and assumptions.
h. Specification of the data storage and retrieval procedures.
i. Specification of data quality assurance procedures.
j. A sample periodic energy savings report.
k. What the total budget will be for metering, monitoring and reporting throughout the post-retrofit period.

Relationship Between the LoanSTAR and Rebuild America Programs and the IPMVP and ASHRAE GP14P.

As mentioned previously, the primary savings analysis calculation techniques in the LoanSTAR and Rebuild American programs rely upon before-after regression models and, in some instances, calibrated simulation. The well-documented analysis techniques have served as a foundation for Options B, C and D in the IPMVP, and in all three Options in ASHRAE Guideline 14P (i.e., component isolation, before-after analysis and calibrated simulation. In certain instances, Option A has been used in the LoanSTAR program, namely for street lighting retrofit projects, and for calculation of continued program savings beyond the period covered by the monitored savings. However, application of the analysis techniques varies from project to project depending upon the available M&V resources, project timing, complexity of the retrofit and, in some instances, unforeseen changes to the facility.

THE BASELINE ENERGY USE AND DEMAND MODELS

Equation 1 provides a general form of the baseline energy use and demand models applicable for the one, two, three, or four-parameter case.

Baseline energy use (or demand) =
$Y_{CP} + LS * (T - X_{CP})^{-} + RS * (T - X_{CP})^{+}$ (1)

Where:

Y_{CP} = constant or mean
LS = low temperature region slope (left slope)
RS = high temperature region slope (right slope)
X_{CP} = temperature change point
T = billing period average temperature

In equation 1, the superscript signifies that the term $(T-X_{CP})^{-}$ is equal to zero unless $(T-X_{CP})^{-}$ is negative. Similarly, the superscript + signifies that the term $(T-X_{CP})^{+}$ is equal to zero unless $(T-X_{CP})^{+}$ is positive. The baseline energy use is measured in kWh/day to correct for any unusual billing periods. The value predicted by the baseline energy use model is then multiplied by the number of days in the billing period. Baseline model for demand, however, is not corrected for the number of days in the billing period since demand is a monthly value measured in kW.

CASE STUDIES

Table 1 shows three buildings which received retrofits either through the LoanSTAR program or the Rebuild America program. Building # 1 is the University of Texas Health Science Center / Houston, University Center Tower. This building is used for office space, classrooms and laboratories. The building received a lighting retrofit in 1999. The construction period covered the period from September through October 1999. To measure the impact of the retrofit, a data logger was installed in the building a year before the retrofit took place. Hourly whole-building electricity data were retrieved from the data logger weekly and stored in the LoanSTAR database at the ESL.

Table 1. Studied Buildings

#	Building Name	City, State	Floor Area (sq. ft.)	Pre-Retrofit (Baseline) Period
1	University Center Tower	Houston, TX	315,000	Sep 1998 – Aug 1999
2	Brazos County Courthouse	Bryan, TX	100,000	Jan 1994 – Dec 1997
3	George Allen Jr. Courts Building	Dallas, TX	473,800	Jun 1998 – May 1999

Different models were applied to the baseline energy use for this building. The model that yielded the least CV-RMSE is shown in Table 2 and Figure 2. The hourly data were summed for each month and then divided by the number of days to get a kWh/day average. The kWh/day data were plotted versus the monthly average temperature using the EModel software (Kissock et al. 1994). A four-parameter change point model represented the best regression fit. Similarly, the demand model was obtained by plotting the maximum hourly kW value for the month versus the average temperature. The data were best represented by a three-parameter change point model as shown in Figure 3.

Table 2. Baseline Energy Use and Demand Models

#	Building Name	Model	Y_{CP}	LS	RS	X_{CP}	R^2	CV-RMSE
1	University Center Tower	WBE	30210.30	204.42	520.95	76.30	0.95	2.60%
		WBD	1715.70	0.00	26.33	81.08	0.92	2.60%
2	Brazos County Courthouse	WBE	6506.30	0.00	82.33	65.07	0.68	6.20%
		WBD	426.30	0.00	3.08	68.20	0.60	3.60%
3	George Allen Courts Building	WBE	28965.45	0.00	279.10	50.46	0.92	3.60%
		WBD	2003.52	0.00	7.05	76.66	0.31	5.80%

Building #2 in Table 1 is Brazos County Courthouse. The building received a lighting retrofit, cooling tower replacement and Energy Management Control System (EMCS) upgrade as a part of the Rebuild America program. The lighting retrofit construction began in March of 1998 and ended in August of 1998. The cooling tower replacement was completed by April of 1999. The EMCS project was not completed until September of 2000. To measure the savings a data logger was installed in the building in late 1997. Unfortunately, there were not enough data collected for the baseline period since the construction started in March of 1998. Therefore, monthly utility data for electricity use and demand were used to develop the baseline models. Table 2 shows the three parameter change point models for both electricity use and demand. The models are also shown in graphical form in Figures 4 and 5. As post-retrofit data continued to be available, the savings have been calculated using the measured hourly data.

Building #3 in Table 1 is the Dallas County George Allen Courts Building. The 9-story courthouse is a multi-purpose facility allocated to offices, courtrooms and jail. The scope of work included lighting retrofit, EMCS upgrade and chiller replacement. The lighting retrofit began on April 1999 and was completed in October 1999. The chiller replacement retrofit was implemented through a change order to the initial list of retrofits that was proposed as a part of a performance contract. The chiller replacement was completed by the end of June 2000. The EMCS project had to be delayed until the completion of the chiller plant retrofits. The EMCS upgrade was then completed by the end of September 2000. To measure savings the building utilized the existing data logger that was a part of an old LoanSTAR retrofit. In this project, the ESL was retained as a third party M&V contractor by Dallas County to verify that the guaranteed savings from a project with an ESCO.

Both the Building owner and the performance contractor agreed to using utility billing data for both baseline and post-retrofit measurement with the availability of the hourly data to track any operational changes and take the proper action to rectify any problem. Table 2 shows the baseline models for both electricity use (Figure 6) and demand (Figure 7). The guaranteed savings period was set to start on July 2000. The ESL was asked to provide savings calculations for the three-month period preceding July 2000 to see whether partial savings were showing. Since the reported savings were for the billing months of April, May and June 2000, the full impact of the chiller retrofit and the EMCS was not yet showing.

On the other hand, the full impact of the lighting retrofit was supposed to be clear since it had been completed several months before the reported savings period. Initial measured savings were significantly less than the predicted savings, and the ESL was asked to reconcile the differences. The hourly data were then used to develop daytype profiles for weekends and weekdays separately for March 1999, November 1999 and May 2000. The mean daytype was chosen to compare across the three months. March 1999 and November 1999 were chosen to represent the daytype right before and right after the lighting retrofit construction period. Figure 8 and 9 show the lighting retrofit initially saving over 300kW during weekdays. However, there was a subsequent addition of approximately 150 kW of 24-7 load in the building; therefore, an adjustment was recommended to the baseline predicted energy use to account for that increase in the building load, which was satisfactory to the ESCO and to Dallas County.

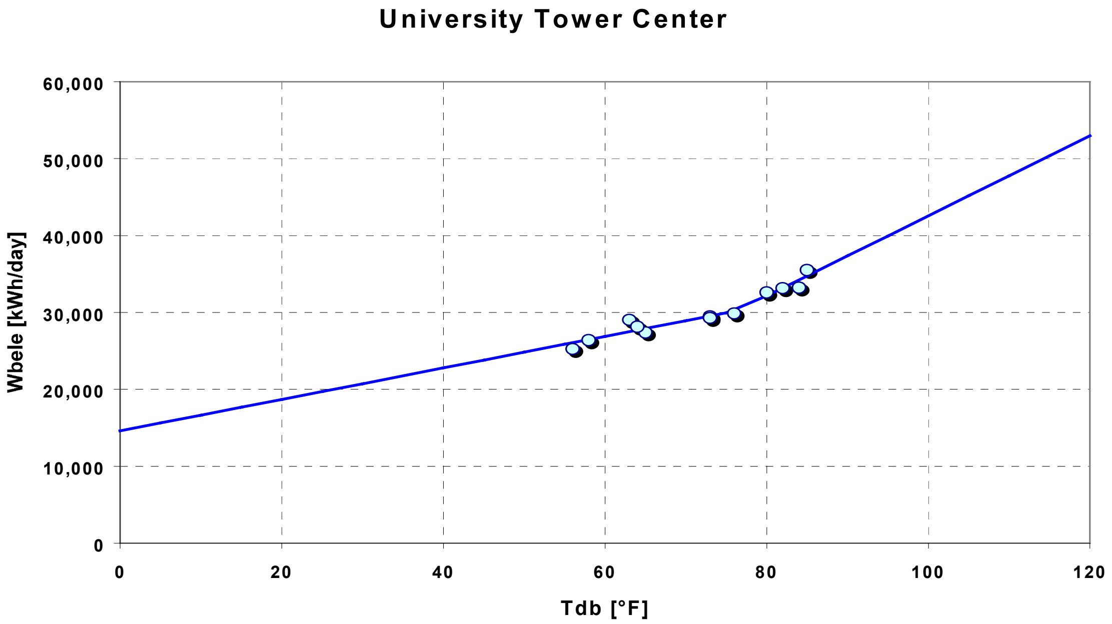

Figure 2: Monthly 4-parameter change-point linear baseline model for calculating daily average electricity usage (kWh/day) at the UT Health Science Center. This model shows the 4-P model that was used to regress electricity usage against the average drybulb temperature for each billing period.

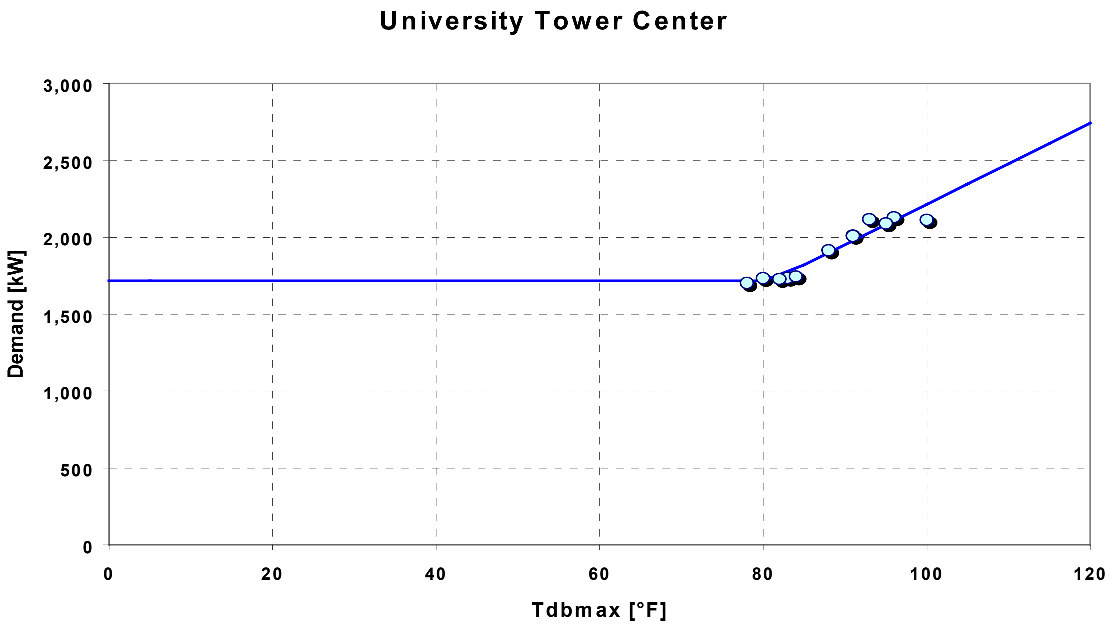

Figure 3: Monthly 3- parameter change-point linear baseline model for calculating the electric demand (kW/mo) at the UT Health Science Center. This model shows the 3-P model that was used to regress the electric demand data against the maximum daily drybulb temperature for each billing period.

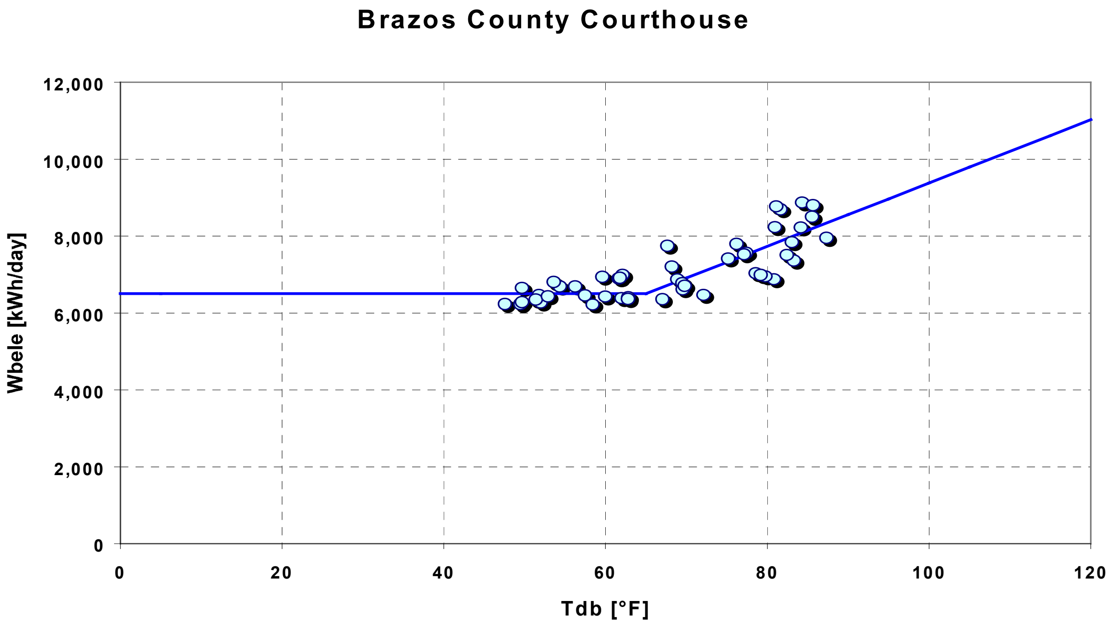

Figure 4: Monthly 3-parameter change-point linear baseline model used for calculating the average daily electricity usage (kWh/day) at the Brazos County Courthouse. This model shows the 3-P model that was used to regress electricity usage against the average drybulb temperature for each billing period.

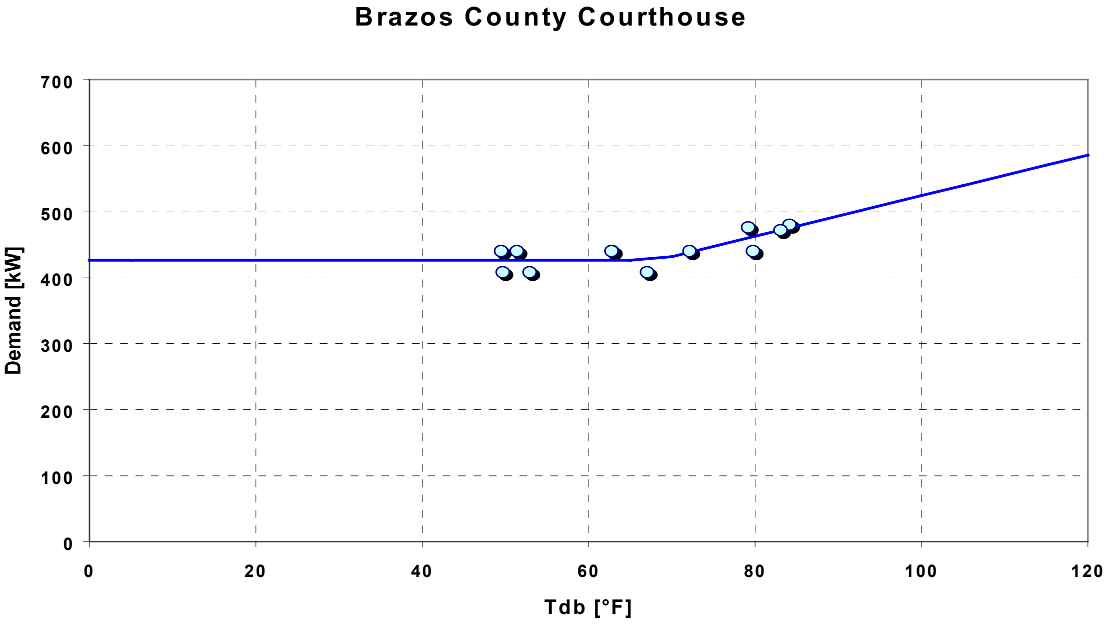

Figure 5: Monthly 3- parameter change-point linear baseline model for calculating the electric demand (kW/mo) at the Brazos County Courthouse. This model shows the 3-P model that was used to regress the electric demand data against the average daily drybulb temperature for each billing period.

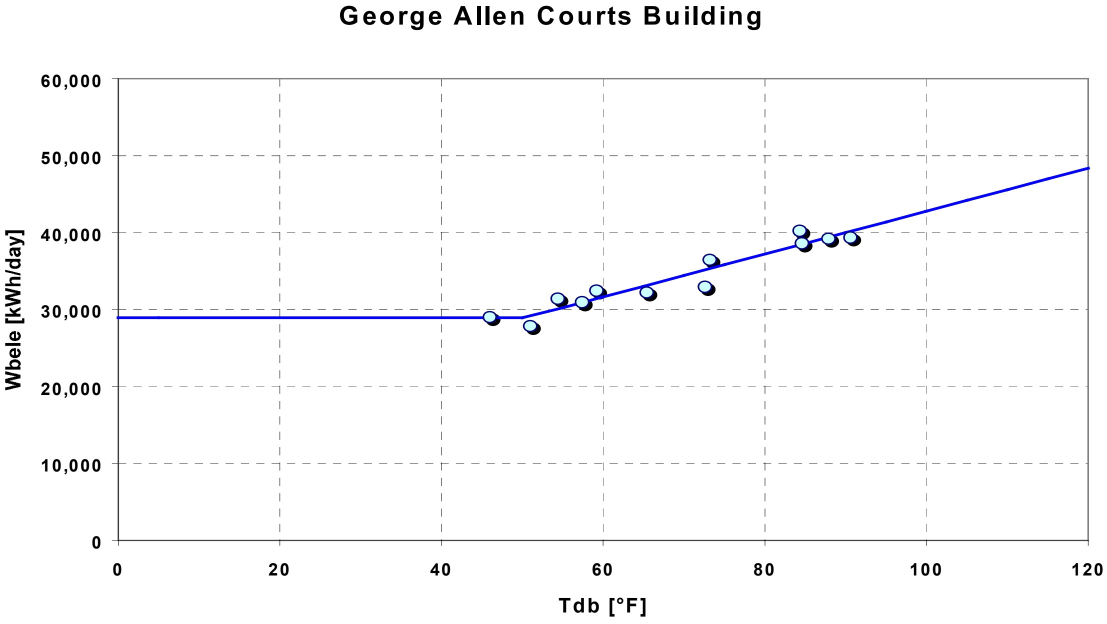

Figure 6: Monthly 3-parameter change-point linear baseline model used for calculating the average daily electricity usage (kWh/day) at the Dallas County Courthouse. This model shows the 3-P model that was used to regress electricity usage against the average drybulb temperature for each billing period.

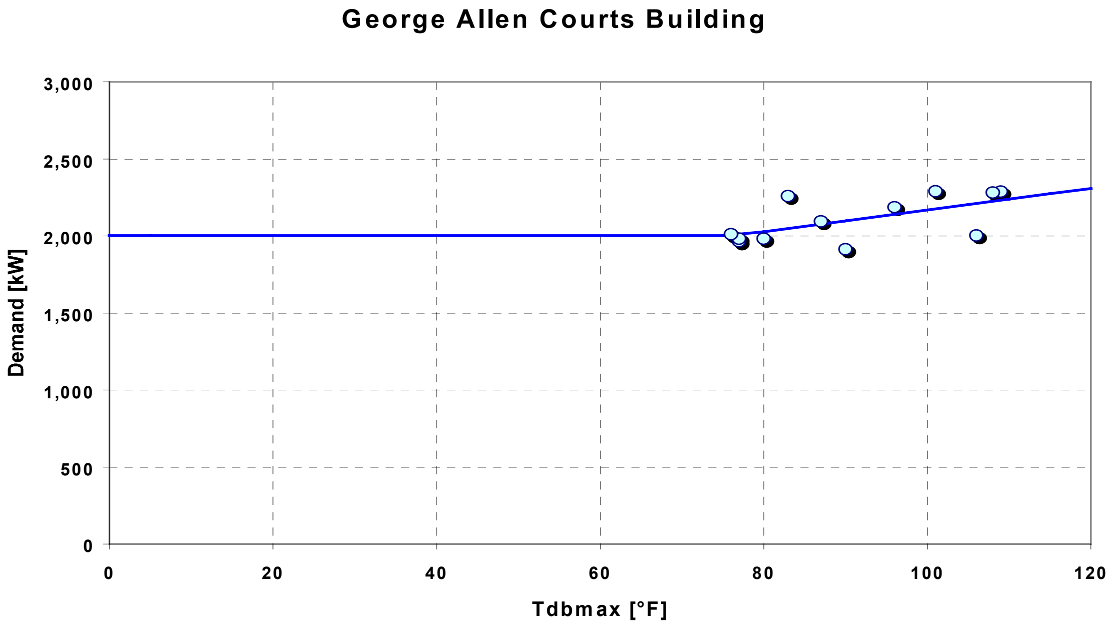

Figure 7: Monthly 3- parameter change-point linear baseline model for calculating the electric demand (kW/mo) at the Dallas County Courthouse. This model shows the 3-P model that was used to regress the electric demand data against the maximum daily drybulb temperature for each billing period.

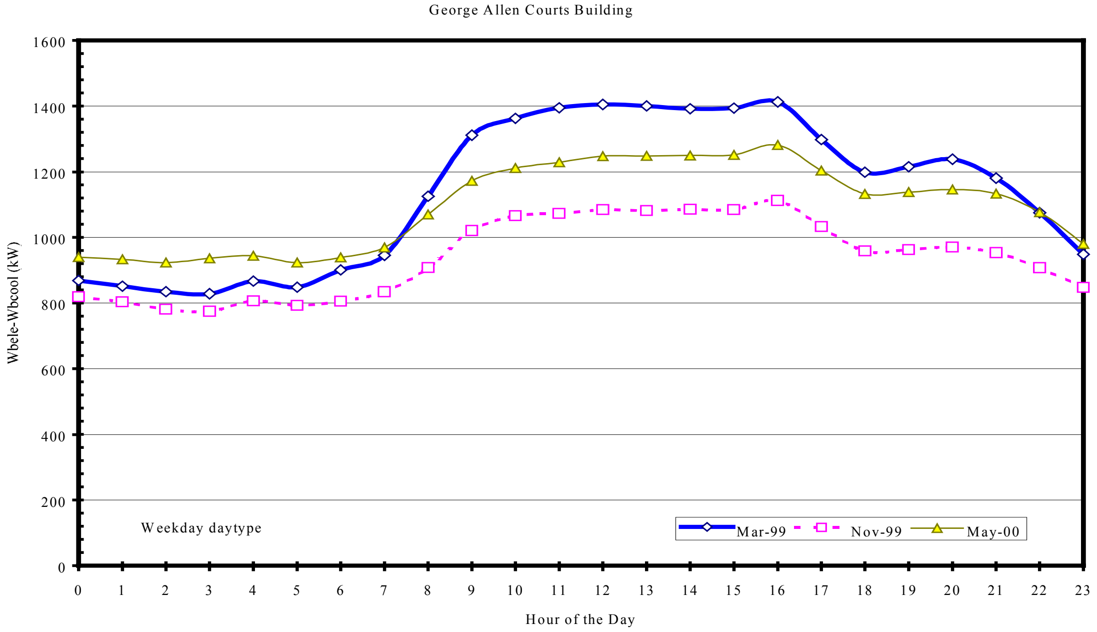

Figure 8: Weekday, 24-hour daytype profiles for the Dallas County Courthouse. This figure shows the three daytype profiles needed to resolve the savings from a lighting retrofit.

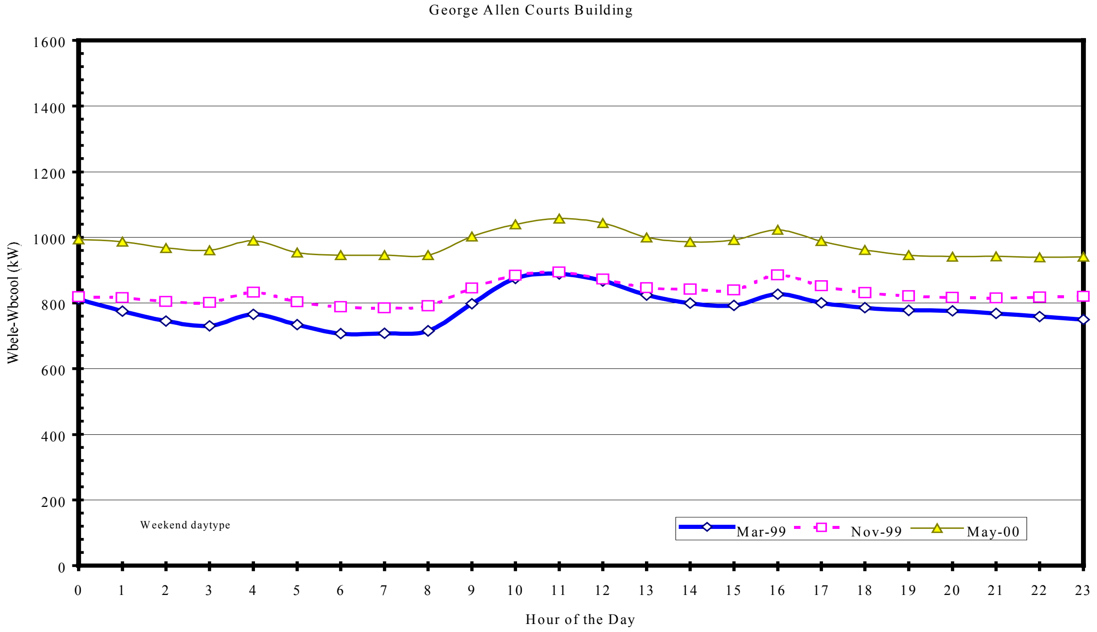

Figure 9: Weekend, 24-hour daytype profiles for the Dallas County Courthouse. This figure shows the three daytype profiles needed to resolve the savings from a lighting retrofit.

MEASURED SAVINGS RESULTS

Building #1 has saved $67,116 in 15 months of measurement. Savings were calculated for the period of November 1999 through January 2001. In Building #1 the measured savings are 102% of the predicted retrofit savings for the same period. Building #2 has saved $22,345 in 16 months of measurement. Savings were calculated for the period of January 1999 through April of 2000. Comparison with the predicted savings from the lighting and cooling tower replacement retrofits show the measured savings to be 99% of the savings predicted by the engineering firm. As we continue to update the savings past September of 2000 the savings from the EMCS upgrade will be verified as well. Building #3 has saved $28,730 during April, May and June 2000. This number was compared to the predicted savings of all ECMs to see how far the number was from the guaranteed savings. The measured savings are 60% of the predicted savings. However, the measured savings were significantly higher than the lighting savings, which was the only measure that was fully implemented by June 2000. As we continue to report savings past June 2000 we should start to see the full impact of the chiller replacement and the EMCS upgrade, especially during the hot summer months.

CONCLUSIONS

The monitoring and verification procedures that have been developed for the Texas LoanSTAR program and the ESL's Rebuild America Program have become a foundation for a number of other state and federal M&V programs. This paper has presented the basic procedures that are used for monitoring and verifying energy savings in commercial buildings that receive energy conservation retrofits, including procedures that are used for measuring energy savings in buildings where hourly pre-retrofit and post-retrofit whole-building data have been collected; buildings where monthly pre-retrofit and hourly post-retrofit data are collected; and buildings where monthly pre-retrofit and monthly post-retrofit data are used to verify savings. Three case study sites were also provided, and the results of the savings calculations discussed.

Lessons Learned

During the last eleven years, the Energy Systems Laboratory has developed, documented and used linear, change-point linear and multiple regression models for the majority of the energy savings calculations. These simple models were chosen over more accurate, complex models, such as neural networks, or fourier series models (Kreider and Haberl 1994; Haberl and Thamilseran 1996), because they are repeatable, accurate and easier to understand.

However, applying these models to commercial buildings requires careful inspection of the data and the resultant regressions. When this is performed in a consistent manner, highly reliable results can be obtained that can be relied upon to be accurate and consistent across a broad spectrum of buildings.

In general the following guidelines have been found useful in determining when to use monthly data, or install a data logger to collect short-term or continuous data.

1. Weather normalization analysis requires daily average drybulb temperature data. At the ESL, the NWS data is used because it is easy to duplicate and readily available. NWS daily min-max data does not equal the minimum and maximum from hourly data because different methods are used to collect the different data types. NWS data is not perfect and does contain missing records, which must be filled-in. Also, hourly NWS data is not true time series data, since it represents a 3 to 5 minute average of the conditions about 15 minutes before the hour.
2. Getting started with linear and change-point linear models such as Emodel and IMT requires less work than developing one's own models and the results can be linked to peer-reviewed publications.
3. Use of monthly utility billing data for analysis is useful for any case where the savings are expected to be greater than the CV(RMSE) error. Monthly analysis should be expressed as energy use per day to normalize for differences in billing period lengths and regressed against average billing period temperature.
4. Use of monthly utility billing data will indicate if the gross savings are being accumulated. However, if there is a problem, monthly data is not very helpful in determining what the problem is.
5. Use of hourly pre and post-retrofit data collection is preferred if the budget can justify the expense of the installation, maintenance, data collection and data processing. Costs of data loggers, data collection and processing are coming down. Web-based applications are now appearing as well.
6. Use of short-term hourly data collection is very useful for trouble shooting monthly utility bill analysis.
7. Procedures for baselining and savings calculations can be automated, which will lead to large-scale applications, such as data mining of utility customers.

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