M&V Process in the NYC Municipal Building Energy Conservation Program

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ABSTRACT

Under the leadership of Mayor Michael R. Bloomberg, New York City has initiated a leading-edge greenhouse gas reduction program with building energy efficiency at its core. To date, over $80 million has been committed to fund energy-savings projects for the City's portfolio of more than 4,000 buildings. Savings from retrofit projects are observable, but have not been rigorously measured. A measurement and verification protocol has been developed, in a pilot phase in FY 2013, to calculate and validate energy savings for City-owned and managed facilities, utilizing change-point linear regression analysis and publicly-accessible energy analysis software. Early findings demonstrate electricity use savings may be determined and validated for un-retrofitted and retrofitted facilities, but gas or steam use savings show mixed results. Recommendations are made for the next phase of work, with the goal of ensuring the protocol has the potential to be scaled and replicated in a municipal or institutional setting.

INTRODUCTION

In 2007, Mayor Michael R. Bloomberg launched PlaNYC, a plan to create a "greener, greater New York" through the implementation of initiatives in key areas of interest, including Energy and Climate Change. PlaNYC set forth the ambitious goal of reducing citywide greenhouse gas emissions (GHG) by 30 percent below 2005 levels by 2030 (30x30). During fiscal year 2006, the NYC government consumed about 6.5 percent of all energy used in the City, at a cost of nearly $900 million, and produced approximately 3.8 million tons of GHG emissions (Maron and Rosenberg 2010). In an effort to accelerate the 30x30 goal and jumpstart implementation of the PlaNYC initiative to "provide energy efficiency leadership in City government buildings and operations," Mayor Bloomberg signed Executive Order 109 in 2007, which required the City to reduce energy consumption and GHG emissions from buildings and operations by 30 percent by 2017 (30x17); and committed 10 percent of the City's FY2008 energy budget to fund "energy-saving investments" in City buildings and operations each year going forward.

Some of the building-related strategies suggested in the initial 30x17 action plan included: benchmarking energy consumption; establishing an energy audit program; training facilities managers; operations and maintenance programs, building retrofits and real-time metering and monitoring; and establishing measurement and verification (M&V) protocols to track program energy savings (New York City 2007).

In 2009, the Department of Citywide Administrative Services (DCAS) Energy Management (DEM) group was assigned to implement the long-term 30x17 plan. DEM establishes, audits and pays electricity, natural gas and steam accounts for more than 4,000 buildings across 80 City agencies – from schools, courthouses and firehouses to municipal office buildings, recreation centers and sanitation garages. With an average age of 60 years, these buildings present a huge opportunity for energy savings through the upgrade of HVAC, lighting and other building systems.

DEM's 30x17 strategy emphasizes a comprehensive data-driven approach, focused on two major building energy efficiency program areas, which together account for more than half of expected reductions: (1) building retrofits; and (2) improvements to building operations and maintenance.

<u>Open Collaborative Lab</u>

In September 2012, the Building Performance Lab (BP Lab) at the City University of New York

(CUNY) established the Open Collaborative Lab (OCL), through a partnership with DCAS, to study and document DEM energy efficiency projects; and to provide CUNY students with real-world experience to better prepare them for careers in building operations and management and energy services. Since then, CUNY engineering and architecture students have been placed in internship positions to document energy reduction projects at City facilities using an M&V protocol developed during the program's inaugural year.

Though the focus of OCL has been on M&V since its inception, several strategies for accomplishing this task were piloted throughout the first year. The first strategy involved evaluating facilities at three different stages of energy reduction: pre-retrofit, retrofit and post-retrofit. Eight facilities from a mix of City agencies were assigned to OCL under these criteria. This strategy involved multiple site visits and coordination with facilities personnel, so was deemed too time-consuming for high-volume analysis.

The second strategy involved evaluation of facilities through the analysis of interval data only – no site visits were involved. Seven facilities were added to the OCL list of projects for this effort, all from the Department of Parks and Recreation. The range of data available proved insufficient for effective analysis, so this path was deferred.

The third and final strategy was also straight data analysis, but with monthly energy use data and a focus on: 1) ascertaining whether energy savings could be determined for facilities that had not yet had retrofits; and 2) calculating and validating energy savings for facilities with completed retrofits. Eighteen facilities representing various agencies were added to the OCL list of projects at this point. The third strategy proved successful, as straight data analysis is minimally time-consuming and most facilities were able to be classified as being in a pre- or post-retrofit phase.

Work completed in FY 2013 represents initial findings for the pilot stage of OCL's work. This paper summarizes results for all 33 facilities assigned under the pilot.

Previous Work

Numerous methodologies and guidelines are available for determination of retrofit-related energy savings (Kissock et al 2003; ASHRAE 2004; ASHRAE 2005; Haberl et al 2005; Matson et al 2005; Haberl et al 2005; Bonneville Power Administration 2011; IPMVP 2012). Methodologies include simple linear regressions, multiple linear regressions, change-point models, bin methods, computer simulations and many more. Case studies have shown application of these methodologies at different physical scales, such as whole building analysis or retrofit isolation analysis; different time scales, such as hourly, daily or monthly periods; and different sectors, such as the residential, commercial and industrial sectors (Kissock et al 2004; Kissock et al 2007; California Commissioning Committee 2008; Mills 2009; Abels et al 2011; Effinger et al 2011; Sever et al 2011; Effinger et al 2012).

In addition, numerous software applications have become available to calculate retrofit-related energy savings. These applications include the Princeton Scorekeeping Method (PRISM), ETracker, Energy Explorer and Metrix.

Focus of Current Work

Various criteria informed selection of the methodology and energy analysis software used for this analysis. The primary factors were: (1) data availability – physical scale, time scale and number of independent variables; (2) building function; (3) analysis difficulty level; and (4) access to and cost of energy analysis software.

First, in terms of data availability, access was available for whole building monthly energy use data as well as daily outdoor air temperature (OAT). Therefore, the physical scale was whole building analysis, the time scale was monthly, and the number of independent variables was one (OAT). In light of data limitations, multiple linear regression analysis could not be considered.

Second, in terms of building function, this analysis considered buildings with different energy use patterns during the winter and summer months; as such, energy use versus temperature trends did not exhibit a pattern that could be explained by simple linear regressions. Therefore, this method was insufficient.

Third, in terms of difficulty level, more technical types of analysis, like computer simulations, were not considered because of the level of training and sophistication required for this type of methodology.

Fourth, public accessibility and cost minimization was desired in selection of an energy software application; a high-cost application would inhibit scalability and potential for replication in a municipal or institutional setting.

Based on these criteria, the change-point linear regression model method was selected for the current work. Generally, linear change-point models are applicable when energy use varies above and below a change-point temperature. For example, most buildings in this analysis show almost constant cooling energy use above a change-point temperature; and increased energy use for heating below that same change-point temperature. ETracker, free software developed to support the EPA's ENERGY STAR buildings program (Kissock 1999), was chosen for this analysis, as it met the criteria of public accessibility and cost minimization.

METHODOLOGY

The objective of this analysis was twofold: (1) to see if energy savings could be determined for facilities that had not yet had retrofits ("un-retrofitted facilities"); and (2) to calculate and validate energy savings for facilities with completed retrofits ("retrofitted facilities"). Using ETracker, this analysis was conducted on 10 un-retrofitted facilities and 23 retrofitted facilities across multiple City agencies, including: Fire, Police, Sanitation, Parks and Recreation; the Board of Education; and the Department of Cultural Affairs.

The analysis of un-retrofitted facilities was carried out in three steps:

1. Gather Required Data: This data consisted of: (a) the most recent 12 months of monthly energy use data available (May 2012 to April 2013) ("baseline period"); and (b) daily outdoor air temperatures.

2. Determine Baseline: ETracker was used to build change-point models for the baseline period. Note that ETracker automatically chooses a four- or five-parameter change-point model for each facility. ETracker generated four-parameter models for all but one of the un-retrofitted facilities, for which it deemed the five-parameter model the best fit.

3. Statistical Metrics Review: Statistical metrics were reviewed for the Baseline Period regression model, as outputted by ETracker: coefficient of determination (R^2) and coefficient of variation of the root-mean squared error (CV-RMSE). (See Appendix A for detail on statistical metrics employed.) After a review of relevant M&V standards and related literature, and in consultation with a practicing M&V professional, R^2 values equal to or above 0.75 and CV-RMSE values equal to or below 25% were deemed acceptable for this analysis. However, as explained in the results section, deviations from such R^2 and CV-RMSE values do not necessarily constitute invalid results.

The energy savings determination and validation analysis for retrofitted facilities was carried out in five steps:

1. Gather Required Data: This data consisted of: (a) 12 months of pre-retrofit monthly energy use data; (b) all available post-retrofit monthly energy use data; (c) daily outdoor air temperatures; (d) retrofit project scopes; (e) monthly retrofit start and end dates; and (f) projected energy savings from energy audits (where available).

2. Generate Change-Point Model, Adjusted Baseline, and Determination of Energy Savings via ETracker: The required data were run through ETracker to create a pre-retrofit period baseline regression model, post-retrofit period adjusted baseline and determination of energy savings.

3. Statistical Metrics Review: Statistical metrics were reviewed for the pre-retrofit period baseline regression model and post-retrofit energy savings, as outputted by ETracker; namely R^2, CV-RMSE and uncertainty. As stated earlier, R^2 values equal to or above 0.75 and CV-RMSE values equal to or below 25% were deemed acceptable. Uncertainty values were obtained at the 95% confidence level and results were categorized as being above or below 50 percent of reported savings.

4. Validation of Energy Savings: Energy savings were validated through the comparison of energy savings, percent whole building savings, and percent uncertainty. In terms of percent whole building savings, results were categorized as being above or below 10 percent. For percent uncertainty, results were categorized as being above or below the percent whole building savings.

5. Comparison of Calculated Energy Savings and Projected Energy Savings from Energy Audit: A comparison was conducted between energy savings as reported by energy audits prior to retrofit implementation and as reported by ETracker after retrofit implementation.

See Appendix C for data and other issues pertaining to select facilities.

DATA AND INFORMATION

Types and Sources of Data: Weather, Energy, Retrofit and Projected Energy Savings

ETracker requires an input file containing daily OAT, which it then converts to monthly average temperatures. This dataset was obtained for the LaGuardia Airport weather station, from the average daily temperature archive at the University of Dayton. Monthly energy use data, retrofit project scopes, retrofit start and end dates and energy audits were obtained directly from DEM. For this analysis, monthly energy use types included electricity, gas and steam use as billed for each facility. Energy values for electricity use are reported in kWh; energy values for gas and steam use are reported in therms.

Assumptions: Data

Two assumptions regarding data are maintained throughout this analysis. First, it is assumed that monthly billing periods coincide with calendar months (this assumption was not able to be verified). Second, it is assumed that retrofit start and end dates represent the true retrofit period. It is known, however, that these dates actually represent project sign-off dates; therefore, it is possible that a retrofit started after the stated retrofit start date or ended prior to the stated end date.

Modifications to retrofit periods were made under certain circumstances: (1) when less than 12 months of pre-retrofit data were available and the energy trend did not seem to show changes in consumption during this period (one facility); (2) when there was a meter change resulting in unusual energy trends (one facility); and (3) when a facility underwent more than one retrofit but only one project was completed to date, in which case the retrofit period for the first project was used (two facilities). Retrofit period modifications are noted in this paper.

Assumptions: Statistical Metrics

According to ASHRAE Guideline 14-2002, there are two types of whole building M&V approaches: performance path and prescriptive path. The performance path requires use of all pre-retrofit data and a minimum of 12 months of post-retrofit data for energy savings analysis. This path does not require a minimum threshold for percent whole building savings; it does not appear this analysis falls under the performance path. The prescriptive path requires a minimum of 12 months of pre-retrofit data and all post-retrofit data for energy savings analysis. This path states that whole building savings must be greater than 10 percent of the measured whole building energy use. In contrast, the International Performance Measurement and Verification Protocol (IPMVP 2012) does not distinguish between different types of whole building approaches. IPMVP 2012 states that savings must be greater than 10 percent of the baseline or adjusted baseline whole building energy use. For the purposes of this analysis, percent whole building savings was defined as the percent savings over the adjusted baseline whole building energy use.

Facilities

As previously mentioned, this analysis was performed on 10 un-retrofitted facilities and 23 retrofitted facilities. The table in Appendix B lists facility name, retrofit start and end dates, primary scope and scope description. Of the 23 retrofitted facilities, 10 had primarily lighting system retrofits; eight had primarily HVAC system retrofits; and five had more than one type of retrofit. Facilities with special issues, such as no gas or steam meters, are noted. (See Appendix C for a description of special issues.)

RESULTS – UN-RETROFITTED FACILITIES

ETracker Monthly Energy Use vs. Monthly OAT

The first objective of this analysis was to see if energy savings could be determined for facilities that had not yet had retrofits ("un-retrofitted facilities"). Twelve months of the most recent monthly energy use data and daily OAT were used to create four-parameter baseline change-point models via ETracker. Figure 1 is an example of the ETracker graph outputted for monthly electricity use for the Veteran's Residence facility.

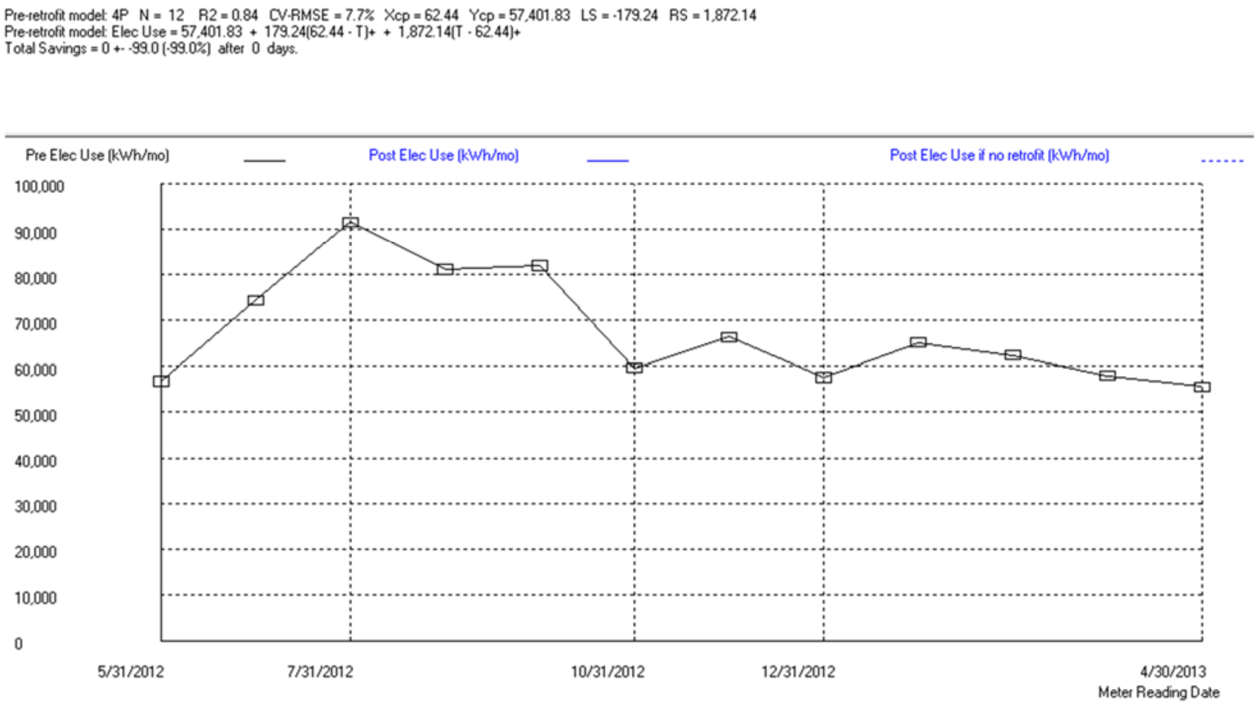

Figure 1. Monthly Electricity Use Example – Veteran's Residence

Baseline Four-Parameter Change-Point Model

The four-parameter change-point model consists of two linear line segments joined by a change point. This change point refers to the point at which there is a change in the slope of the monthly energy use (dependent variable) as a function of monthly average OAT (independent variable). In other words, the change point refers to the monthly average OAT at which there is a change in the sensitivity of monthly energy use. Since electricity and gas or steam use have different sensitivities to temperature, ETracker generates separate models for electricity and for gas or steam use. Typical cooling and heating four-parameter change-point models would take the form:

Cooling Energy Model =

Yint - LS*(Xint - T)+ + RS*(T - Xint)+

Heating Energy Model =

Yint + LS*(Xint - T)+ - RS*(T - Xint)+

Yint refers to the energy use at the change-point temperature; Xint refers to the change-point temperature; LS refers to the slope that describes the linear dependency of electricity or gas/steam use on temperature below the change point (left side); RS refers to the slope that describes the linear dependency of electricity or gas/steam use on temperature above the change point (right-side); T refers to the temperature for period of interest; and the parenthetic superscripted plus ( )+ indicates zero is substituted when the enclosed term is negative.

Using the Veteran's Residence as an example, the electricity use four-parameter change-point model is shown in Figure 2. The model is represented by the solid black line; additional data displayed on the graph includes baseline period monthly electricity use, represented by the black squares.

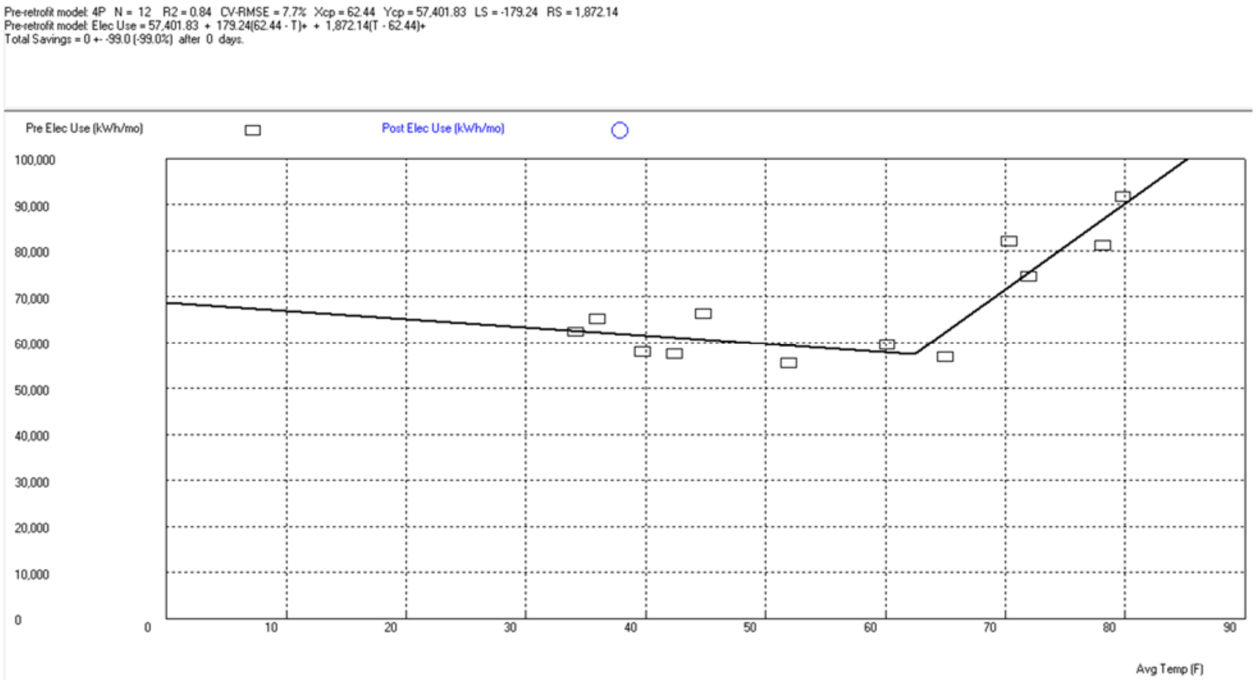

Figure 2. **Electricity Use Baseline Four-Parameter Change-Point Model Example – Veteran's Residence**

Electricity and Gas/Steam Model Statistical Metrics

Since un-retrofitted facilities have no post-retrofit data, energy savings and uncertainty values are not calculated for these facilities. Statistical metrics provided for un-retrofitted facilities are the R^2 and CV-RMSE values. These statistical metrics are provided for electricity baseline models and gas or steam baseline models in Table 1.

Table 1. **Statistical Metrics – Electricity Usage and Gas/Steam Usage**

	Electricity Usage		Gas/Steam Usage	
Facility	**R^2**	**CV-RMSE**	**R^2**	**CV-RMSE**
Precinct/Firehouse 1	0.74	17%	0.95	24%
Recreational Facility 1	0.81	6%	0.98	8%
Courthouse	0.87	4%	0.54*	123%*
Skating Rink/Pool 1	0.74	51%*	No meter	No meter
Zoo Exhibit Building	0.82	5%	No meter	No meter
Veteran's Residence	0.84	8%	0.99	7%
Skating Rink/Pool 2	0.75	5%	No meter	No meter
Sports Stadium	0.73	11%	No meter	No meter
Museum 1	0.71	22%	0.48*	103%*
Power Substation	0.82	13%	No meter	No meter

*See notes section in Appendix C for a summary of issues impacting this result.

Overall, electricity use statistical metrics are acceptable, with R^2 values close to, equal to or above 0.75 and CV-RMSE values equal to or below 25%. Four facilities (Precinct/Firehouse 1, Skating Rink/Pool 1, Sports Stadium and Museum 1) have R^2 values between 0.70 and 0.75, which are marginally acceptable. One facility (Skating Rink/Pool 1), with a CV-RMSE of 51%, is the one facility with an unacceptable CV-RMSE value. In part, CV-RMSE provides for a measure of the spread of actual energy use from energy use modeled by the linear four-parameter change-point models. Therefore, facilities with a large spread in energy use can be expected to have high CV-RMSE values.

For example, Figure 3a contains a graph for the monthly electricity use vs. OAT for Skating Rink/Pool 1. This graph shows wide variations in electricity use, from about 530,000 kWh in November 2012 to 11,500 kWh in April 2013, which is almost a 5,000 percent decrease. This variation is a function of the sizeable amount of electricity needed to maintain this type of facility in the winter.

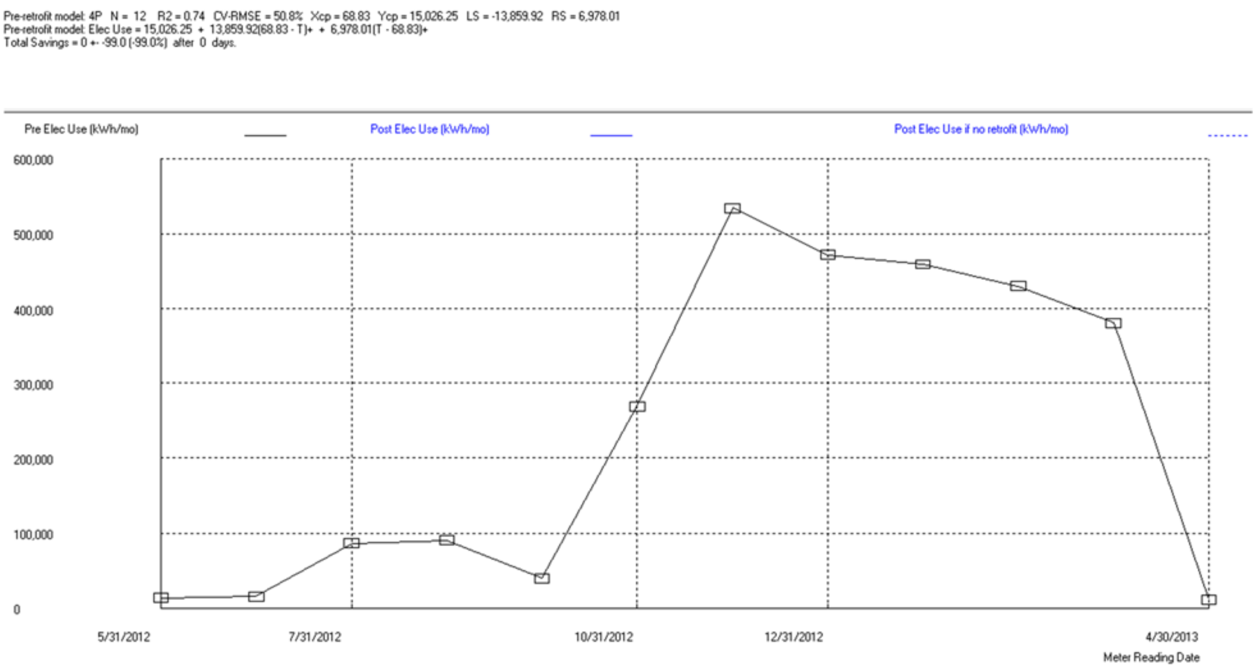

Figure 3a. Monthly Electricity Use with High CV-RMSE Example – Skating Rink/Pool 1

In contrast, results for gas use statistical metrics are mixed. First, five of the 10 un-retrofitted facilities have no gas or steam meters. It is possible that some of these facilities consume fuel oil, which is a dataset not made available for this analysis. Two of the remaining five facilities (Courthouse and Museum 1) have R^2 values below 0.75 and CV-RMSE values above 25%. These facilities also show a wide spread in gas or steam use, which may explain the large CV-RMSE values. R^2 values provide for a measure of how well the independent variable (i.e., OAT) explains variation in the dependent variable, (i.e., monthly gas or steam use); so a low R^2 value may indicate another independent variable is affecting energy use. For example, Figure 3b shows atypically high gas usage in March 2013 for Museum 1; however, this dramatic increase can be explained by the fact that the facility is currently undergoing an expansion.

RESULTS – FACILITIES WITH RETROFITS

ETracker Monthly Energy Use and Adjusted Baseline vs. OAT

The second objective of this analysis was to calculate and validate energy savings for facilities with completed retrofits ("retrofitted facilities"). Data required by ETracker to quantify energy savings included: (a) 12 months of pre-retrofit monthly energy use data; (b) all available post-retrofit monthly energy use data; (c) daily OAT; and (d) monthly retrofit start and end dates.

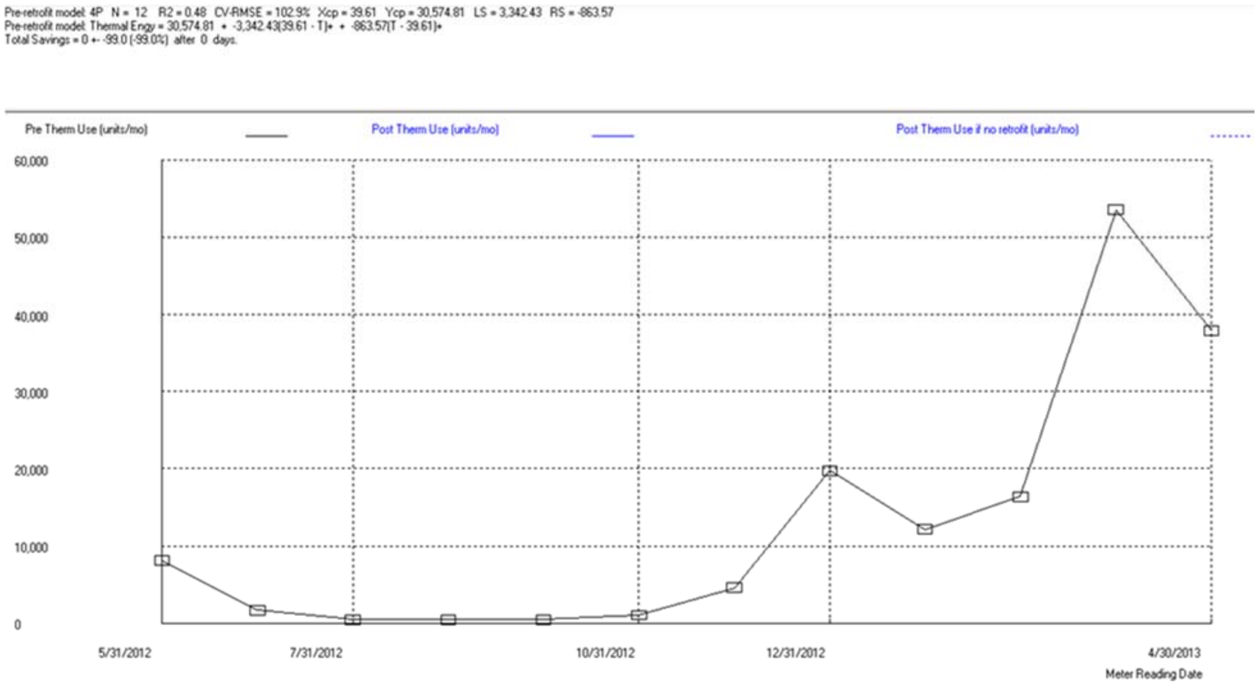

Figure 3b. Monthly Gas Use with High CV-RMSE and Low R^2 Example – Museum 1

ETracker calculates energy savings by subtracting post-retrofit adjusted baseline energy use from actual energy use. Post-retrofit adjusted baseline energy use is calculated by inputting post-retrofit monthly OAT into the pre-retrofit baseline four-parameter change-point model. For example, in Figure 4, the Municipal Office Building's steam use is represented by the solid black line on the left; post-retrofit steam use by the solid blue line on the right; and the post-retrofit adjusted baseline by the dotted blue line above it. This facility had an HVAC system upgrade related to steam use, so steam use savings are expected as shown in the graph.

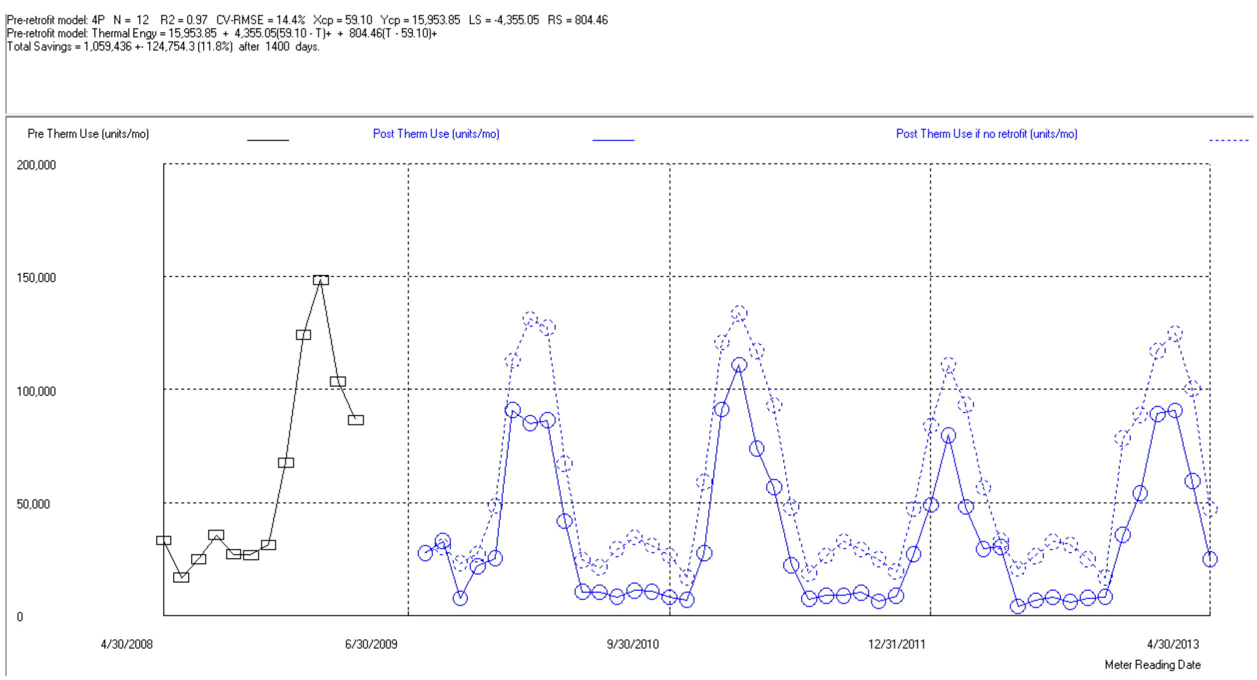

Figure 4. Monthly Steam Use and Adjusted Baseline vs. OAT Example – Municipal Office Building

Pre-Retrofit Four-Parameter Change-Point Model

ETracker generated four-parameter change-point models for all retrofitted facilities; on the outputted graphs, the blue circles represent post-retrofit energy data.

Figure 5 shows the electricity use pre-retrofit change-point model and post-retrofit energy use for the Parks Department Offices. Since the change-point model is graphed along with the post-retrofit electricity use, one can immediately see decreased electricity use across all temperatures in the post-retrofit period. This trend shows a decrease in the baseload and is consistent with the retrofit at this facility – a lighting upgrade. Similar usage trends are apparent in the gas or steam use models generated by ETracker, where a decrease in gas or steam use across all temperatures is demonstrated in facilities that have had an HVAC upgrade.

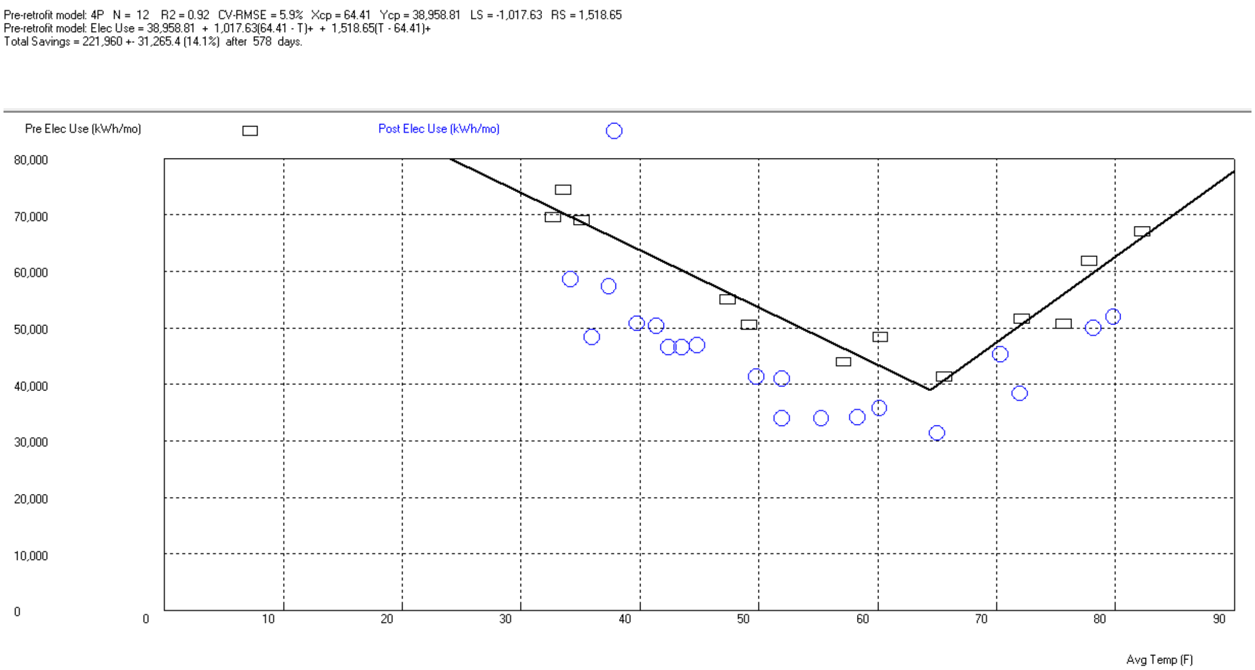

Figure 5. Monthly Electricity Use Pre-Retrofit Four Parameter Change-Point Model and Electricity Use Post-Retrofit Example – Parks Department Offices

Electricity Use Model Statistical Metrics Review

Statistical metrics provided by ETracker for retrofitted facilities are the R^2, CV-RMSE and uncertainty values. These statistical metrics for electricity use are provided in Table 2a.

Results for R^2 values equal to or above 0.75 are mixed. In contrast, CV-RMSE values equal to or below 25% are met for all facilities. Of the 23 retrofitted facilities, two do not have complete meter data available and one has no available retrofit dates. Of the remaining 20 facilities, only half have R^2 values equal to or above 0.75.

As discussed previously, R^2 values provide for a measure of how well the independent variable (i.e., OAT) explains variation in the dependent variable (i.e., electricity use). Low R^2 values suggest that temperature alone cannot explain variations in energy use.

The last statistical metric outputted by ETracker is percent uncertainty, which is reported at the 95% confidence level. At that level, 15 of the 20 facilities with available electricity use data meet the requirement that the maximum level of percent uncertainty should be less than 50% of the reported savings.

Table 2a. Electricity Use Statistical Metrics

Facility Name	R^2	CV-RMSE	% Uncertainty (95% Confidence)
Police Precinct 1	0.47	10%	74%
Police Precinct 2	0.56	10%	18%
Police Precinct 3	0.91	6%	52%
Police Precinct 4	N/A	N/A	N/A
Precinct/Firehouse 2	0.88	15%	97%
Museum 2	0.79	7%	86%
Sanitation Garage 1	0.64	9%	11%
Parks Department Offices	0.92	6%	14%
Sanitation Garage 2	0.92	6%	22%
School 1	0.84	6%	16%
Sanitation Garage 3	N/A	N/A	N/A
Sanitation Garage 4	0.95	6%	11%
Municipal Office Building	0.95	6%	11%
Museum 3	0.14*	18%	5%
Police Precinct 5	0.69	17%	104%
School 2	0.65	13%	35%
School 3	0.35	16%	33%
School 4	0.65	10%	21%
School 5	0.77	12%	13%
Police Vehicle Garage	N/A	N/A	N/A
Recreational Facility 2	0.54	6%	29%
Recreational Facility 3	0.94	5%	29%
Fire Vehicle Garage	0.45	9%	38%

*See notes section in Appendix C for a summary of issues impacting this result.

Gas or Steam Use Model Statistical Metrics Review

Statistical metrics for gas or steam use are provided in Table 2b. R^2 values above or equal to 0.75 were generally obtained, with two exceptions: Police Precinct 4 and Sanitation Garage 4. (The Fire Vehicle Garage had an R^2 value very close to 0.75, at 0.74.) Results for CV-RMSE equal to or below 25% were generally not obtained; only eight of the 19 facilities met this criterion. As stated previously, CV-RMSE values provide, in part, for a measure of the spread of actual energy use from energy use modeled by the change-point models. Therefore, facilities with a large spread in energy use may be expected to have high CV-RMSE values. Since gas or steam is primarily used for heating, low gas or steam use can be expected for summer months, while high gas or steam use can be expected for winter months. As a result of this wide variation between seasons, high CV-RMSE values may be expected for some facilities.

With respect to uncertainty values, at the 95% confidence level only seven of the 19 facilities with available gas use data meet the requirement that the maximum level of percent uncertainty should be less than 50% of the annual reported savings.

Table 2b. Gas or Steam Use Statistical Metrics

Facility Name	R^2	CV-RMSE	% Uncertainty (95% Confidence)
Police Precinct 1	0.83	50%	106%
Police Precinct 2	0.83	40%	183%
Police Precinct 3	0.84	42%	59%
Police Precinct 4	0.67*	62%	49%
Precinct/Firehouse 2	0.94	21%	158%
Museum 2	0.98	10%	53%
Sanitation Garage 1	0.93	33%	32%
Parks Department Offices	0.99	11%	117%
Sanitation Garage 2	0.94	30%	148%
School 1	0.90	19%	46%
Sanitation Garage 3	N/A	N/A	N/A
Sanitation Garage 4	0.51*	36%	1%
Municipal Office Building	0.97	14%	12%
Museum 3	0.93	32%	4%
Police Precinct 5	0.99	14%	88%
School 2	N/A	N/A	N/A
School 3	0.98	18%	105%
School 4	0.83	46%	193%
School 5	0.98	17%	114%
Police Vehicle Garage	N/A	N/A	N/A
Recreational Facility 2	0.83	26%	107%
Recreational Facility 3	N/A	N/A	N/A
Fire Vehicle Garage	0.74*	52%	16%

*See notes section in Appendix C for a summary of issues impacting this result.

Electricity Model Results

Table 3a shows the total number of post-retrofit months, as well as the total post-retrofit electricity use savings, percent whole building electricity use savings, and percent uncertainty. In this case, total refers to the entire post-retrofit period with available data through April 2013. For these facilities, the retrofit period varied from two to 60 months. All facilities with available electricity use data had retrofits that would impact electricity use. Of the 23 facilities, three do not have full electricity use data available; 16 facilities have positive savings over the entire post-retrofit period; and four facilities have negative savings over the entire post-retrofit period.

Table 3b contains the same type of information as Table 3a, except results are presented for the last 12 months for which data were available (May 2012 to April 2013).

Police Precinct 1, Precinct/Firehouse 2 and Museum 3 demonstrate negative savings over the recent 12-month period, as well as over the entire post-retrofit period. In contrast, though Recreational Facility 3 showed negative savings over the entire post-retrofit period, it showed positive savings in the recent 12-month period. The only facility to have positive savings in the entire post-retrofit period, but not the recent 12-month period, was Police Precinct 3; however, these negative savings are relatively small at one percent.

Table 3a. Total Post-Retrofit Electricity Model Savings

Facility Name	Total Post-Retrofit Months (thru 4/2013)	Total Savings (kWh/Total Post-Retrofit Period)	% Total Whole Building Savings	% Uncertainty (95% Confidence)
Police Precinct 1	52	-189,143*	-4%*	74%
Police Precinct 2	45	439,783	17%	18%
Police Precinct 3	39	106,654	4%	52%
Police Precinct 4	35	N/A	N/A	N/A
Precinct/Firehouse 2	22	-121,440**	-7%**	97%
Museum 2	3	«866,040»	«11%»	86%
Sanitation Garage 1	35	974,373	28%	11%
Parks Department Offices	19	221,960	21%	14%
Sanitation Garage 2	24	285,220	11%	22%
School 1	47	1,591,967	12%	16%
Sanitation Garage 3	N/A	N/A	N/A	N/A
Sanitation Garage 4	10	«1,641,454»	«38%»	11%
Municipal Office Building	46	12,348,667	17%	11%
Museum 3	25	-3,400,951*	-139%*	5%*
Police Precinct 5	19	92,121	8%	104%
School 2	50	211,138	12%	35%
School 3	16	119,232	26%	33%
School 4	38	292,035	17%	21%
School 5	45	2,581,045	27%	13%
Police Vehicle Garage	35	N/A	N/A	N/A
Recreational Facility 2	2	«40,729»	«32%»	29%
Recreational Facility 3	60	-92,261**	-5%**	29%
Fire Vehicle Garage	14	490,034	13%	38%

*See notes section in Appendix C for a summary of issues impacting this result.

**Adjusted baseline modeled use larger than actual.

« » Less than 12 months of post-retrofit data.

Table 3a lists the electricity use percent whole building savings over the entire post-retrofit period. Of the 23 facilities analyzed, three do not have the required electricity use data and four have negative savings. Of the 16 remaining facilities, 14 have percent whole building savings that are greater than 10 percent. In contrast, Table 3b lists the electricity use percent whole building savings over the recent 12-month post-retrofit period. For this period, 15 of the 16 facilities with available electricity use data and non-negative savings show greater than 10 percent whole building savings.

In the context of percent whole building savings, percent of uncertainty can also be evaluated. It was set out that percent uncertainty should be less than percent whole building savings. Of the 20 facilities with available electricity data, only six met this criterion at the 95% confidence level.

Table 3b. **Recent Post-Retrofit Electricity Model Savings**

Facility Name	Recent Post-Retrofit Months (5/2012 To 4/2013)	Recent Savings (kWh/Recent Post-Retrofit Pd.)	% Recent Whole Building Savings
Police Precinct 1	12	-125,358*	-11%*
Police Precinct 2	12	153,015	22%
Police Precinct 3	12	-9,601**	-1%**
Police Precinct 4	12	N/A	N/A
Precinct/Firehouse 2	12	-80,406**	-8%**
Museum 2	3	«866,040»	«11%»
Sanitation Garage 1	12	378,973	31%
Parks Department Offices	12	138,855	21%
Sanitation Garage 2	12	139,262	11%
School 1	12	634,241	19%
Sanitation Garage 3	N/A	N/A	N/A
Sanitation Garage 4	10	«1,641,454»	«38%»
Municipal Office Building	12	4,418,262	24%
Museum 3	12	-1,627,060*	-381%*
Police Precinct 5	12	19,797	3%
School 2	12	68,868	17%
School 3	12	95,759	28%
School 4	12	110,459	20%
School 5	12	1,083,307	42%
Police Vehicle Garage	35	N/A	N/A
Recreational Facility 2	2	«40,729»	«32%»
Recreational Facility 3	12	42,488	12%
Fire Vehicle Garage	12	382,117	12%

*See notes section in Appendix C for a summary of issues impacting this result.

**Adjusted baseline modeled use larger than actual.

« » Less than 12 months of post-retrofit data were available.

Gas or Steam Model Results

Table 4a shows the total number of post-retrofit months, total post-retrofit gas or steam use savings, percent whole building gas or steam use savings and percent uncertainty. In this case, total refers to the entire post-retrofit period with available data through April 2013. For these facilities, the retrofit period varied from two to 60 months.

Although only seven facilities with available data had retrofits that would impact gas or steam use, this analysis was conducted on all facilities. Of the 23 facilities, four do not have full electricity use data available; 10 have positive savings; and nine have negative savings. Table 4b contains the same type of information as Table 4a, except results are presented for the last 12 months for which data were available (May 2012 to April 2013). All facilities with negative savings in the entire post-retrofit period have negative savings in the recent 12-month post-retrofit period.

Table 4a. Total Post-Retrofit Gas or Steam Model Results

Facility Name	Total Post-Retrofit Months (thru 4/2013)	Total Savings (Therms/Total Post-Retrofit Pd.)	% Total Whole Building Savings	% Uncertainty (95% Confidence)
Police Precinct 1	52	-22,112**	-13%**	106%
Police Precinct 2	45	4,432	7%	183%
Police Precinct 3	39	-21,709**	-26%**	59%
Police Precinct 4	35	60,144	45%	49%
Precinct/Firehouse 2	22	4,820	6%	158%
Museum 2	3	«-60,881»	«-15%»	53%
Sanitation Garage 1	35	-208,615**	-41%**	32%
Parks Department Offices	19	7,506	4%	117%
Sanitation Garage 2	24	-35,283**	-11%**	148%
School 1	47	4,795	12%	46%
Sanitation Garage 3	N/A	N/A	N/A	N/A
Sanitation Garage 4	10	«-97,711*»	«-3,618%*»	1%
Municipal Office Building	46	1,059,436	40%	12%
Museum 3	25	-215,961*	-388%*	4%*
Police Precinct 5	19	2,276	7%	88%
School 2	50	N/A	N/A	N/A
School 3	16	4,630	8%	105%
School 4	38	-14,452**	-9%**	193%
School 5	45	30,387	5%	114%
Police Vehicle Garage	35	N/A	N/A	N/A
Recreational Facility 2	2	«5,154»	«25%»	107%
Recreational Facility 3	60	N/A	N/A	N/A
Fire Vehicle Garage	14	-128,195**	-226%**	16%

*See notes section in Appendix C for a summary of issues impacting this result.

**Adjusted baseline modeled use larger than actual.

« » Less than 12 months of post-retrofit data were available.

Table 4a lists the gas or steam use percent whole building savings over the entire post-retrofit period. Of the 23 facilities, four do not have the required electricity use data and nine have negative savings. Of the 10 remaining, only four have percent whole building savings greater than 10 percent. In contrast, Table 4b lists the gas or steam use percent whole building savings over the recent 12-month post-retrofit period. For this period, five of the 10 facilities with available electricity use data and non-negative savings show greater than 10 percent whole building savings.

Of the 19 facilities with available electricity data, only one demonstrated percent uncertainty less than percent whole building savings at the 95% confidence level.

Table 4b. Recent Post-Retrofit Gas or Steam Model Results

Facility Name	Recent Post-Retrofit Months (5/2012 to 4/2013)	Recent Savings (Therms/Recent Post-Retrofit Pd.)	% Recent Whole Building Savings
Police Precinct 1	12	-7,680**	-20%**
Police Precinct 2	12	847	5%
Police Precinct 3	12	-4,415**	-17%**
Police Precinct 4	12	20,754	43%
Precinct/Firehouse 2	12	4,282	10%
Museum 2	3	«-60,881»	«-15%»
Sanitation Garage 1	12	-118,023**	-64%**
Parks Department Offices	12	9,174	9%
Sanitation Garage 2	12	-15,855**	-9%**
School 1	12	1,799	18%
Sanitation Garage 3	N/A	N/A	N/A
Sanitation Garage 4	10	«-97,711*»	«-3,618%*»
Municipal Office Building	12	314,030	44%
Museum 3	12	-115,134*	-381%*
Police Precinct 5	12	1,591	8%
School 2	12	N/A	N/A
School 3	12	3,873	10%
School 4	12	-1,844**	-3%**
School 5	12	46,949	26%
Police Vehicle Garage	35	N/A	N/A
Recreational Facility 2	2	«5,154»	«25%»
Recreational Facility 3	12	N/A	N/A
Fire Vehicle Garage	12	-126,545**	-262%**

*See notes section in Appendix C for a summary of issues impacting this result.

**Adjusted baseline modeled use larger than actual.

« » Less than 12 months of post-retrofit data were available.

<u>Energy Savings Comparison</u>

This analysis attempted to compare projected annual energy savings from facility energy audits to the most recent 12-month energy savings generated using ETracker. Ten energy audits were provided; however, the comparative analysis was only possible for one of those facilities (School 3), as the other facilities were either missing retrofit dates, had short post-retrofit periods, or had audits that were produced after the retrofit start date.

All retrofits recommended in the energy audit for School 3 were implemented. Table 5 includes: annual projected energy savings from the energy audit; recent 12-month (May 2012 to April 2013) energy savings as reported by ETracker; and percent difference for both kWh and therms usage. Total kWh savings were projected at 108,787 kWh in the energy audit, but were calculated by ETracker to be 95,759 kWh. This results in a difference of -12%. In contrast, total therms savings are projected at only 674 therms, while ETracker reports those savings at 3,873 therms; which means there is +474% difference between the two reported values. One possible explanation could be that there was an additional retrofit implemented at the facility that was not funded through DCAS. If this was the case, energy audit projected savings and retrofit information on such a project would not have been included in this analysis.

Table 5. Energy Savings Comparison – Energy Audit vs. ETracker – School 3

Energy Audit	Annual kWh Savings	Annual Therms Savings
Upgrade Lighting	105,697	-149
Install ENERGY STAR A/C Units	2,100	0
Argon Window Upgrade	990	824
Total Savings:	**108,787**	**675**
ETracker Calculated Savings:	**95,759**	**3,873**
% Difference:	**-12%**	**+474%**

DISCUSSION

Recap of Results (Un-retrofitted vs. Retrofitted)

Results for the un-retrofitted facilities analysis were presented for the period of May 2012 to April 2013. Electricity use four-parameter change-point models demonstrate R^2 values that are close to or above 0.75, and almost all facilities have CV-RMSE values equal to or below 25%. However, findings are limited for the gas or steam use baseline models. For example, seven of the 10 un-retrofitted facilities have either: (1) no gas or steam meters; (2) consume fuel oil for heating (e.g., the Courthouse); or (3) are undergoing an expansion. The remaining three facilities do show acceptable R^2 and CV-RMSE values.

Electricity use savings results demonstrated that most retrofitted facilities had positive savings, with the exception of: (1) Museum 3, which underwent an expansion prior to retrofit implementation; (2) Police Precinct 1, where the change-point model indicated that the facility changed from a non-cooling HVAC system to a cooling HVAC system; and (3) Precinct/Firehouse 2 and Recreational Facility 3, which show adjusted baseline modeled use that is less than actual use. Likewise, most facilities were found to have larger than 10 percent whole building savings; and most facilities show percent uncertainty values below 50 percent for the electricity use models.

However, electricity use four-parameter change-point models for the pre-retrofit period show mixed R^2 values, above and below 0.75. One possible explanation for the mixed R^2 values is that a variable in addition to temperature is impacting energy consumption. As an example, of the five schools included in this analysis, the elementary and intermediate schools have R^2 values below 0.75; while the high schools have R^2 values equal to or above 0.75. This trend may occur because some high schools have summer classes, while the other types of schools likely do not. Figures 6a and 6b show graphs of electricity use vs. temperature for School 1 and School 3. The graph for School 1 shows electricity use that decreases and increases with temperature, even during summer months; in contrast, the graph for School 3 does not. As a result, additional parameters may need to be introduced into the analysis, such as number of students per month for all or certain types of schools.

A second explanation is that the retrofitted analysis required use of older, archived energy datasets, which may not be as accurate. As a comparison, recent energy data (May 2012 to April 2013) was used for baseline four-parameter change-point models for the un-retrofitted facilities analysis. R^2 values obtained for that analysis showed values greater than or close to 0.75. In contrast to the mixed R^2 result for retrofitted facilities, CV-RMSE values were deemed acceptable as they were all below 25%. Finally, values for electricity use percent uncertainty at the 95% confidence level were generally found to be larger than percent whole building savings.

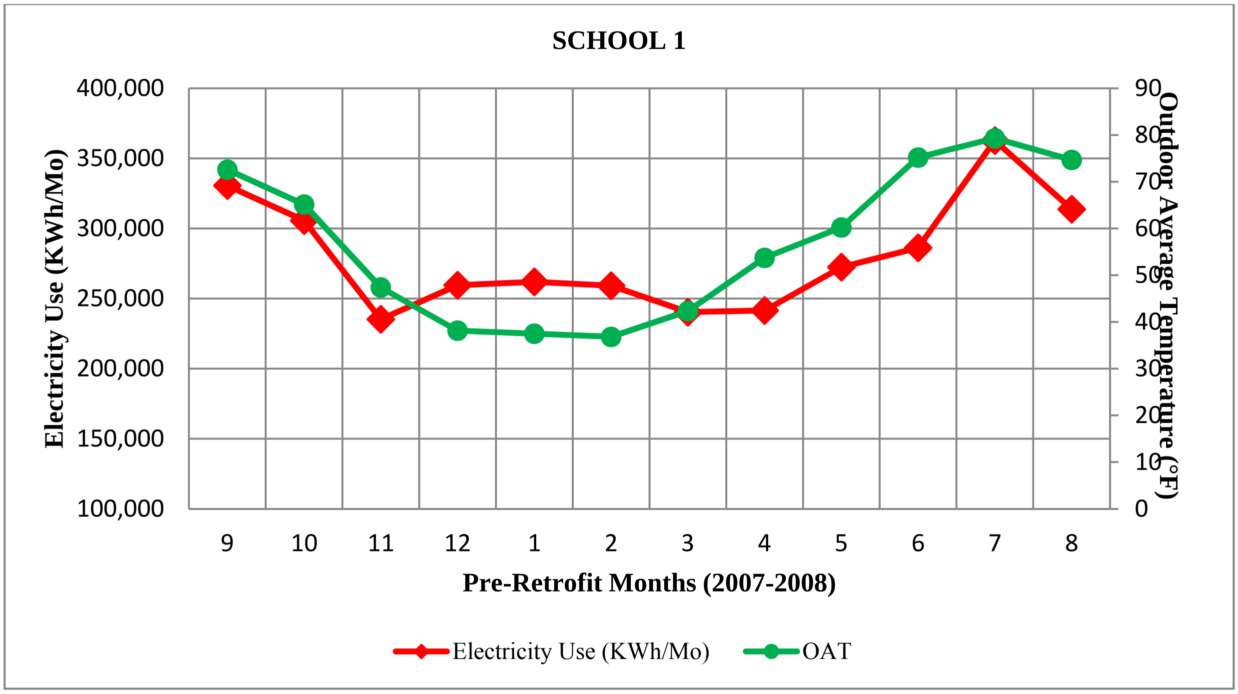

Figure 6a. **Pre-Retrofit Electricity Use vs. Outdoor Air Temperature $R^2 > 0.75$**

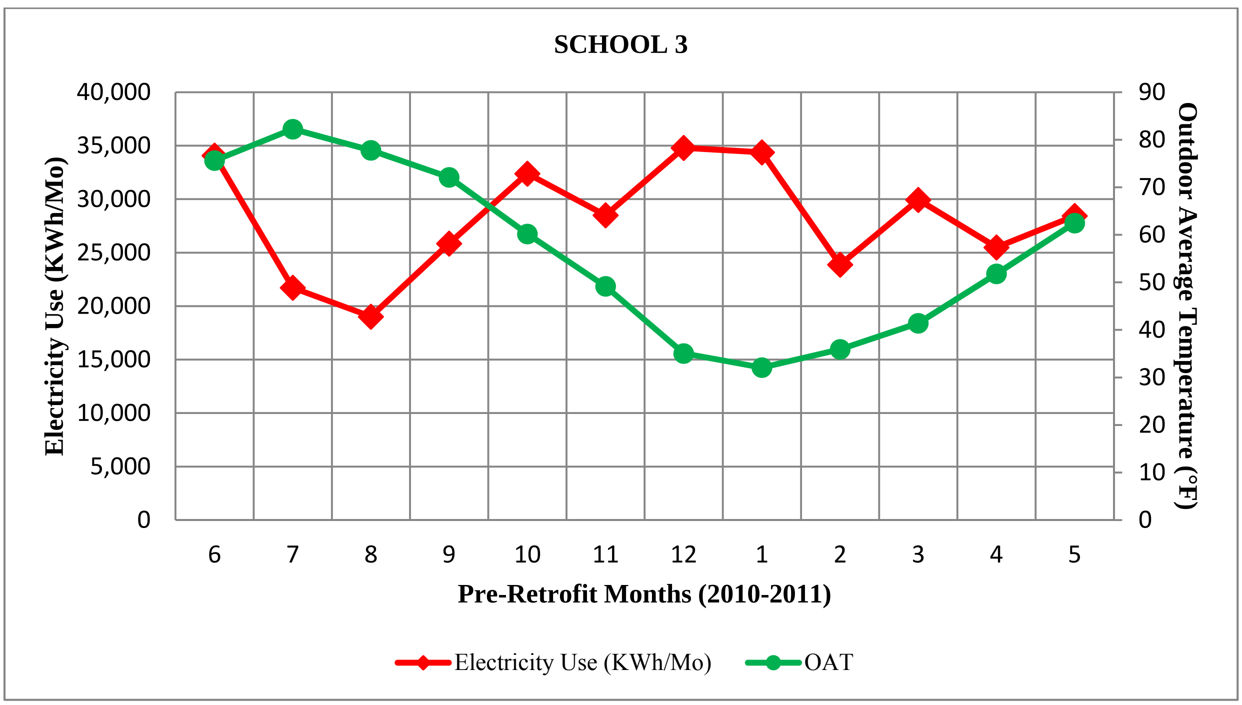

Figure 6b. **Pre-Retrofit Electricity Use vs. Outdoor Air Temperature $R^2 < 0.75$**

Gas or steam use savings findings are mixed but interesting. As expected, negative gas or steam use savings were found for a facility where there was an expansion (Museum 3). However, negative savings were also found for several facilities where retrofits would not impact gas or steam use. This may be explained by (a) a short post-retrofit period (Museum 2); or adjusted baseline model use that was less than actual use (Police Precinct 1, Police Precinct 3, Sanitation Garage 1, Sanitation Garage 2, Sanitation Garage 4, School 4 and the Fire Vehicle Garage). These facilities should not have shown negative gas or steam use savings. As such, these negative savings may be due to operational practices or other limitations. As a result of these issues, most buildings show equal to or below 10 percent whole building savings.

In contrast, gas or steam use models for retrofitted facilities demonstrated acceptable R^2 values, with just two exceptions: (1) Police Precinct 4, which may be explained by bi-monthly meter readings in the pre-retrofit period; and (2) Sanitation Garage 4, which appears to be missing gas use data in the pre-retrofit period. CV-RMSE values showed mixed results. High CV-RMSE values may be explained by a large spread in gas or steam use in climates such as that of New York, where there is high gas or steam use in the winter for heating but none in the summer. In terms of uncertainty, it was found that most facilities show percent uncertainty values above 50 percent for the gas or steam use models. In a similar vein, values for percent uncertainty at the 95% confidence level were generally found to be larger than percent whole building savings.

Finally, there were a number of general data issues encountered during the course of this analysis, which potentially impacted results:

1. Monthly energy use data obtained from DCAS contains both actual and estimated values. Records indicating actual vs. estimated values are maintained in the database for the current and prior fiscal year only; earlier records are archived, but not easily accessible.
2. Energy use data prior to fiscal year 2009 is archived and therefore difficult to access. This created issues for the analysis of facilities with older retrofit projects.
3. Fuel oil is procured directly by the City agencies. As such, fuel oil data were not made available, so this analysis is limited in its ability to completely determine and validate energy savings for facilities utilizing this energy type.
4. Some database errors and inconsistencies were found, including: zero gas use meter readings; and inconsistencies between two different energy use reports for the same facility.
5. Electricity use meter readings seem to be rounded to the nearest hundredth or tenth; this is believed to be occurring at the meter level, not the billing level.
6. Some gas use meters have bi-monthly meter readings prior to FY 2011.
7. Retrofit data for projects that may have been funded directly by an agency or the New York Power Authority (NYPA) were not made available for this analysis.
8. Retrofit start and end dates represent project manager sign-off dates; so it is possible that a retrofit started later than anticipated or ended earlier than the sign-off date. This theory was tested during the analysis, by pushing the start forward into the retrofit period for three facilities with moderate, but less than 0.75 R^2 values; R^2 values did improve as a result.

CONCLUSION

Many lessons were learned throughout the course of this analysis, which piloted three distinct M&V strategies across a sample of 33 facilities. The most important outcome was the development of a standard methodology that can be used to calculate and validate energy savings for the portfolio of New York City-owned and managed facilities; and has the potential to be scaled and replicated in a municipal or institutional setting.

Going forward, attention will be given to: determination of required levels of percent uncertainty; use of other statistical metrics, such as standard error; a method for establishing the best retrofit start and end dates; issues related to mixed gas or steam use energy savings; acquisition of fuel oil usage data; additional independent variables which may provide further insight, such as occupancy or operating hours.

Other M&V methodologies will be examined, including: additional interval data analysis; special work with City facilities that have building automation systems (BAS); and a refined method to establish baselines in un-retrofitted facilities to help identify and prioritize potential retrofit opportunities.

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APPENDIX A. SAVINGS STATISTICAL METRICS

Coefficient of Determination (R^2)

The coefficient of determination (R^2) is a measure of the ability of the model to describe the data. R^2 values of 1.0 imply the model accurately describes the data while R^2 values of 0.0 imply the model does not describe the data. R^2 is defined as:

$$R2 = 1 - \frac{\sum_n (y - \hat{y})^2}{\sum_n (y - \bar{y})^2}$$

where y represents the actual observed energy value, ŷ represents the model predicated energy value, ȳ represents the mean of the actual observed energy values, and n represents the number of actual observed energy values.

Root Mean Squared Error (RMSE)

The root mean square error (RMSE) is a measure of the spread of the model from the data. High RMSE values imply a larger spread of the model from the data. RMSE is defined as:

$$RMSE = \left[\frac{\sum_n (y - \hat{y})^2}{n - p} \right]^{1/2}$$

where y represents the actual observed energy value; ŷ represents the model predicated energy value; n represents the number of actual observed energy values; and p is the number of regression coefficients in the model.

Coefficient of Variation of the Root Mean Squared Error (CV-RMSE)

The coefficient of variation of the root mean squared error (CV-RMSE) is a mean normalized, non-dimensional measure of the spread of the model from the data. High CV-RMSE values imply a larger spread of the model from the data. CV-RMSE is defined as:

$$\text{CV-RMSE} = (\text{RMSE} / \bar{y}) \text{ x } 100$$

where ȳ represents the mean of the actual observed energy values.

Savings Uncertainty

Savings uncertainty depends on how well the pre-retrofit model predicted energy use (ε_{pre}) as well as how accurate post-retrofit energy measurements are (ε_{meas}). ε_{pre} is defined as:

$$\varepsilon_{pre} = 1.96 \text{ RMSE } (m (1 + 2/n))^{1/2}$$

where RMSE is the root mean squared error of the pre-retrofit model, m is the number of post-retrofit observations and n is the number of pre-retrofit observations. In contrast, ε_{meas} is defined as:

$$\varepsilon_{meas} = (\text{percent error}) \sum_{j=1}^{m} E_{Meas,\,j}$$

As a result, the savings uncertainty is equal to:

$$\varepsilon_{save} = (\varepsilon_{pre}{}^2 + \varepsilon_{meas}{}^2)^{1/2}$$

APPENDIX B. FULL LIST OF FACILITIES STUDIED

Facility Name	Retrofit Start Date	Retrofit End Date	Primary Project Type	Scope Description
Precinct/ Firehouse 1*	N/A	N/A	N/A	N/A
Recreational Facility	N/A	N/A	N/A	N/A
Courthouse*	N/A	N/A	N/A	N/A
Skating Rink/ Pool 1	N/A	N/A	N/A	N/A
Zoo Exhibit Building	N/A	N/A	N/A	N/A
Veteran's Residence	N/A	N/A	N/A	N/A
Skating Rink/ Pool 2	N/A	N/A	N/A	N/A
Soccer Stadium	N/A	N/A	N/A	N/A
Museum 1*	N/A	N/A	N/A	N/A
Power Substation	N/A	N/A	N/A	N/A
Police Precinct 1*	Jul. 2008	Dec. 2008	HVAC	Chillers
Police Precinct 2	Dec. 2008	Jul. 2009	Lighting	Upgrade interior lighting
Police Precinct 3	May 2009	Jan. 2010	Lighting	Upgrade interior lighting
Police Precinct 4*	Jul. 1, 2008	May 1, 2010	HVAC	Boilers
Precinct/ Firehouse 2*	Mar. 2009	Jun. 2011	Lighting, Boilers, HVAC	Upgrade lighting system; boilers & HVAC
Museum 2*	Jul. 2008	Jan. 2013	HVAC	Phase I: Chilled water conversion (public halls); rotunda lighting and daylight controls; occupancy sensors; lighting upgrade; VFD on garage exhaust; Phase II: Chilled water conversion (science and administration); campus commissioning; Phase III: Ventilation optimization; steam system upgrades
Sanitation Garage 1	Jul, 2009	May 2010	Lighting	Upgrade lighting systems
Parks Dept. Offices	Jan. 2011	Sep. 2011	Lighting	Upgrade interior lighting
Sanitation Garage 2*	Nov. 2010	Apr. 2011	HVAC	Upgrade interior lighting system; install rapid roll-up doors

Facility Name	Retrofit Start Date	Retrofit End Date	Primary Project Type	Scope Description
School 1	Sep. 2008	May 2009	Lighting	Upgrade interior lighting systems; install occupancy sensors
Sanitation Garage 3*	N/A	N/A	HVAC	Install rapid roll-up doors; thermostat controls for garage heaters; lighting controls in main garage area
Sanitation Garage 4*	Jun. 2009	Jun. 2012	HVAC, Lighting	Install rapid roll-up doors; replace 14 package rooftop HVAC units and controls; upgrade interior lighting, install occupancy sensors
Municipal Office Building	Apr. 2009	Jun. 1, 2009	HVAC, Lighting	Install thermal blankets on steam and dual temperature system; install energy efficient interior and exterior lighting fixtures
Museum 3*	Nov. 2009	Mar. 2011	HVAC	Install premium efficiency motors, DDC controls, VFDs, high efficiency modular chillers, VAV boxes; clean/inspect ductwork
Police Precinct 5	Sep. 2010	Sep. 2011	HVAC	Chillers
School 2*	Apr. 2008	Feb. 2009	Lighting	Upgrade interior lighting
School 3*	Jun. 2011	Dec. 2011	Lighting	Upgrade lighting systems; window AC units; upgrade windows
School 4*	Jun. 2009	Feb. 2010	Lighting	Upgrade interior lighting
School 5	Jan. 2009	Jul. 2009	Lighting	Upgrade interior lighting; install occupancy sensors
Police Vehicle Garage*	Jun. 2008	May 2010	HVAC	Boilers
Recreational Facility 2	Jan. 2012	Feb. 24, 2012	Comprehensive	Upgrade lighting systems; daylighting; install occupancy sensors, efficient motors, entrance vestibule, pool cover; steam traps.
Recreational Facility 3	Oct. 2007	Apr. 2008	Lighting	Upgrade interior lighting
Fire Vehicle Garage*	Oct. 1, 2009	Feb. 2012	Lighting, Other	Upgrade interior lighting; install solar photovoltaic system

Notes:
*See notes section in Appendix C for a summary of issues pertaining to this facility.

APPENDIX C. SITE-SPECIFIC DATA AND OTHER ISSUES

Precinct/Firehouse 1, Precinct/Firehouse 2

- Two agencies co-located; combined energy use reported, but locations of retrofits not identified.

Courthouse

- Fuel oil data not made available for this analysis.
- Gas data appears to be for kitchen meter.

Skating Rink/Pool 1, Zoo Exhibit Building, Skating Rink/Pool 2, Sports Stadium, Power Substation

- No gas meter.

Museum 1

- Currently undergoing expansion; may explain sporadic gas use.

Police Precinct 1

- Possible HVAC system change from non-cooling in pre-retrofit period to cooling in post-retrofit period.

Police Precinct 4

- Short pre-retrofit period (eight months)
- Retrofit start date changed from Mar. 2008 to Jul. 2008; retrofit end date changed from Sep. 2011 to May 2010.
- Archived electricity use data unavailable.
- Bi-monthly gas readings in pre-retrofit period.

Museum 2

- Short post-retrofit period (three months).

Sanitation Garage 2

- Bi-monthly gas readings in pre-retrofit period.

Sanitation Garage 3

- Retrofits not DCAS-funded; retrofit dates not provided, so analysis was not possible.

Sanitation Garage 4

- Short post-retrofit period (10 months).
- Facility has two gas meters, one of which shows zero values in pre-retrofit period and large values in post-retrofit period.

Municipal Office Building

- Listed end date is for first retrofit project (HVAC system upgrade). Second retrofit project (lighting system upgrade) is ongoing, was 90% complete by end of FY 2013. Results may show savings from the second retrofit, and future additional savings should be expected after the second retrofit project is completed.

Museum 3

- Expansion occurred during retrofit period.

School 2

- Non-high school, shows decreased electricity use during the summer.
- Archived gas use data unavailable.

School 3, School 4

- Non-high school, shows decreased electricity use during the summer.

Police Vehicle Garage

- Retrofit start date was June 2008, requiring archived energy data, which was not available.

Recreational Facility 3

- Archived gas use data unavailable.

Recreational Facility 2

- Listed end date is for the first retrofit project. However, there is a second ongoing retrofit project at this site (solar thermal and summer condensing boiler), which was 70% complete by the end of FY 2013. Results may show savings from the second retrofit and future additional savings should be expected after the second retrofit project is completed.
- Short post-retrofit period (two months).

Fire Vehicle Garage

- Retrofit end date changed to date of electric usage meter change, to account for sharp change in usage during those seven months following actual May 6, 2010 start date.
- Fuel oil data not made available for this analysis.