METHODOLOGY FOR ANALYZING ENERGY AND DEMAND SAVINGS FROM ENERGY SERVICES PERFORMANCE CONTRACT USING SHORT-TERM DATA

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ABSTRACT

This paper presents selected results from the application of the M&V to the first year's savings for the Fort Hood Energy Services Performance Contract, and includes the methodology developed to calculate the electricity and demand use savings based on different data sources including hourly data from permanently installed logger, hourly data from portable loggers, and weekly manual readings. New methods, which were developed to measure hourly demand savings from short-term data, were also discussed.

INTRODUCTION

The Fort Hood Army Base has selected an Energy Services Performance Contract (ESPC) contractor to help achieve its energy reduction goals as mandated by Executive Order. This ESPC is expected to be a $3.8 million, 20 year contract, which includes five primary types of Energy Conservation Measures (ECMs) in 58 buildings, including: boiler insulation, control system upgrades, vending machine controls, cooling tower variable frequency drives (VFDs), and lighting retrofits. The plan of action for the ESPC includes cost effective M&V, using Options B and C of the International Performance Monitoring and Verification Protocols (IPMVP) (IPMVP 2001) for the first two years after the retrofits are installed, and Option A combined with annual performance verification for the remainder of the contract.

To accomplish the cost-effective M&V, a data collection effort was initiated in the early stages of the ESPC contractual process, which included permanently installed data loggers, portable data loggers and manual weekly readings on those buildings that had been identified as candidates for retrofits. These data were then used as the basis for the baseline models and savings calculation (Haberl et al. 2002, 2003b). The weather-dependent and weather-independent regression models used were linear and change-point linear models calculated with ASHRAE's Inverse Model Toolkit (IMT) (Haberl et al. 2003; Kissock et al. 2003), to satisfy the requirements of the IPMVP and ASHRAE's Guideline 14-2002 (ASHRAE 2002), which were specified as part of this contract. The weather-independent analysis, which utilizes 24-hour profiles developed using ASHRAE's 1093-RP diversity factor procedures (Abushakra et al. 2001) were used to evaluate demand savings. Due to missing data in the pre-retrofit period for some buildings, ASHRAE's IMT change-point linear models were applied to extend the demand prediction from the 1093-RP demand savings analysis to months where no demand data was available.

RETROFITS

The retrofits identified by the ESPC contractor covered 58 buildings on the Ft. Hood army base. These buildings encompassed 1.8 million square feet of conditioned space[1], including office buildings, dormitories, kitchens, recreation centers, and a large number of motor pools. There were four primary types of retrofits that have been implemented by April 2005, including:

1) Improved building controls with a Utility Management Control System (UMCS),
2) Vending machine controls,
3) Cooling tower retrofits, and
4) Lighting retrofits.

DATA COLLECTION

As a first step in the data collection effort, existing hourly metering equipment at Ft. Hood was recalibrated[2] and new equipment was installed in the more consumptive buildings, including the III Corp HQ building, and the 87000 block thermal plant. In order to save metering costs Watt transducers with manual readouts were installed in selected 87000 block buildings and other buildings that were

[1] In most buildings this represented heated and cooled space. In some buildings, for example the motor pool buildings, this space was only heated.
[2] This included loggers in the main electrical substation, north base electrical substation and the Darnal hospital.

determined to be part of the ESPC project. Manual readings of these meters and other existing meters were taken weekly to develop a record of energy use (kWh/week), which was used to calculate energy savings for electricity use savings. Hourly demand readings (kW) were taken with portable ACR loggers that recorded the instantaneous signal from the Watt-hour meters for short periods. These demand readings were needed to measure and calculate electric demand savings in those buildings where demand savings were anticipated. In buildings with small anticipated savings where no meters were installed, the electricity use was to be recorded early in the retrofit project by the ESPC contractor for several weeks prior to the retrofit, including a “blink” test[3] or hourly recordings to measure 24-hour demand profiles before the retrofits were installed.

Appendix A summarizes the results of the data collection effort at Ft. Hood from 2000 through 2005. According to the construction start and end dates listed in the second and third columns, the pre-retrofit period and post-retrofit period for each building were identified. Then the electricity consumption, electrical demand, and gas use data collected through manual weekly readings, permanently installed loggers, and portable data loggers were inspected to see if there is sufficient data to perform the saving analysis.

As shown in Appendix A and Figure 1, for the sites with permanently installed data logger (the 87000 block thermal plant -87018 and III Corps -1001), hourly data retrieved from the loggers were used in the baseline modeling and savings analysis. Otherwise, manual reading data were used for electricity and gas baseline analysis and ACR data were used for demand models.

However, in some sites, there were no manual readings since April 03. Retrofits were completed after 2004 for most of sites. For the buildings with manual weekly readings only, the savings analysis could not be completed due to the missing post-retrofit data. For the buildings with Watt transducers and portable data loggers, the manual reading data was compared against the ACR data for the pre-retrofit period to determine if the ACR data is reliable and could be used for baseline modeling and savings analysis. Once this was accomplished, the baseline models for some buildings were modified using more recent ACR data.

In Appendix A, the fourth, eighth, and twelfth columns list the type of IMT model chosen to represent the baseline gas, electricity, and electrical demand use for each building, respectively, which were developed in the 2002 and 2003 baseline report sent to Fort Hood (Haberl, et al. 2002; Haberl, et al. 2003b).

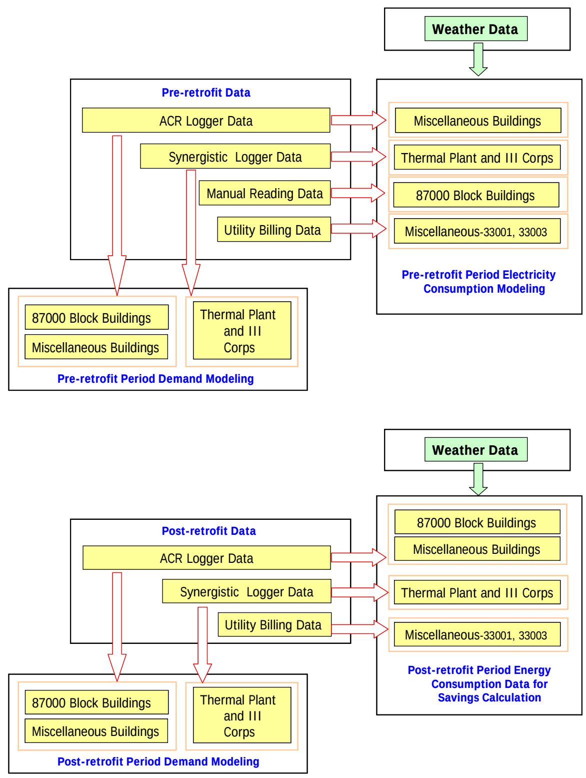


Figure 1: *Summary of Pre- and Post- Retrofit Data for Baseline Modeling and Savings Analysis*

SAVINGS ANALYSIS METHODOLOGY

Linear and change-point linear models of whole-building electricity use (kWh)

The basic modeling approaches used in this project for electricity consumption are regression models as shown in Figure 2. The weather-dependent and weather-independent linear and change-point linear models were calculated with ASHRAE’s IMT.

The whole-building electricity savings were determined using before-after savings methods, which use a statistical “baseline model” of the energy use of each building from the consumption data

[3] In a blink test, the building’s electricity use is recorded with a data logger at a 1-minute or 5-minute level for a period of several hours. During this time the building’s loads are cycled on/off, and the change in consumption noted to record the connected load associated with the device or sub-system.

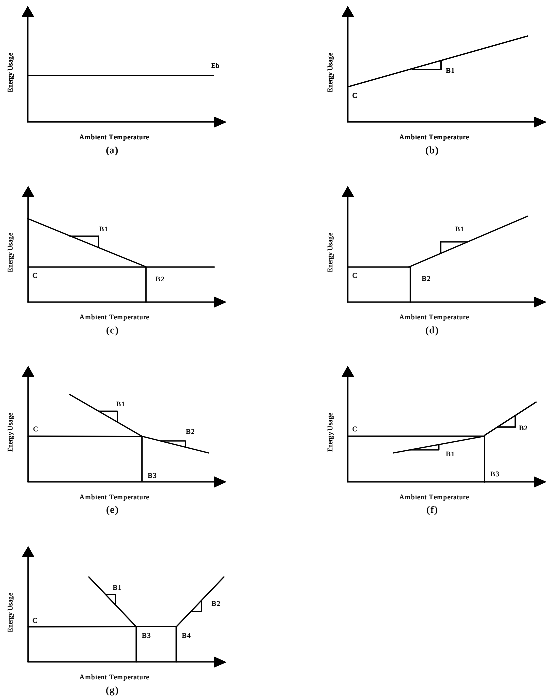


Figure 2: *Models used for the Whole-building Analysis. Included in this figure is: (a) mean or 1 parameter model, (b) 2 parameter model, (c) 3 parameter heating model (similar to a variable based degree-day model (VBDD) for heating), (d) 3 parameter cooling model (VBDD for cooling), (e) 4 parameter heating model, (f) 4 parameter cooling model, and (g) 5 parameter model.*

measured before the retrofit was performed. This model was then used to predict what the building energy consumption would have been if the retrofit had not been performed. This prediction was 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 pre-retrofit energy use (i.e., without the retrofit).

As previously discussed, hourly data retrieved from the installed Synergistic loggers or portable ACR loggers, or manual reading weekly data were used during the pre-retrofit period to construct baseline models. These models were then used to predict what the building would have consumed in the post-retrofit period had the retrofit not been implemented.

Diversity factor models for whole-building electric demand (kW)

The hourly data from Synergistic loggers and portable ACR loggers were used to develop the diversity factors models using ASHRAE's Diversity Factor Toolkit, developed as part of Research Project 1093- RP. The 24-hour profiles from the diversity factor analysis were used to assess the demand savings in the weather-independent buildings, as shown in Figure 3. Diversity factor models were developed for those buildings where significant electric demand savings were expected.

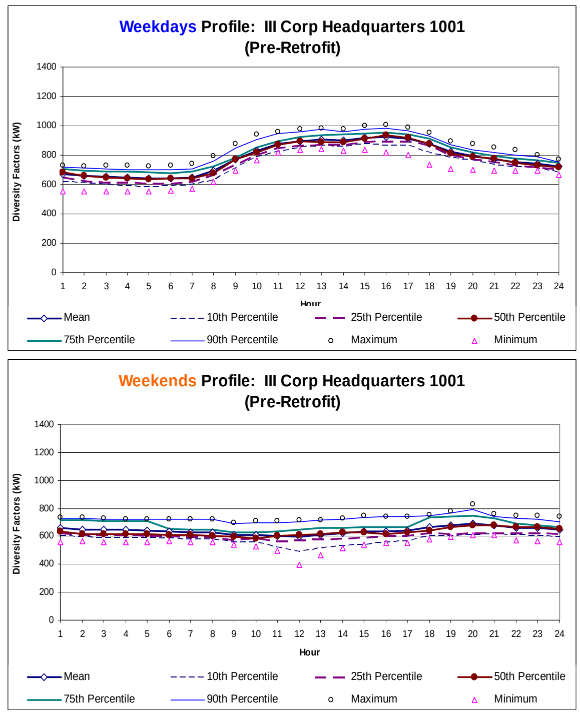


Figure 3: *1093-RP Diversity Factor Analysis for III Corp Building (1001)*

To calculate the demand savings, as the first step, the 24-hour profiles for each month of pre-retrofit period and post-retrofit period for a building were developed. Then the maximum kW use (90th percentiles) from a month of post-retrofit period was compared against the maximum kW use from the same month of pre-retrofit period to calculate the demand savings for that month.

However, due to missing data in the pre-retrofit period for some buildings, in order to compare the months of post-retrofit period against the same months of pre-retrofit period, ASHRAE's IMT change-point linear models were applied to extend the demand prediction from the 1093-RP demand savings analysis to months where no demand data was available.

To accomplish this, the maximum monthly demand (90th percentile profile) is plotted against the maximum average daily temperature of the month for the pre-retrofit period. Then a linear or change-point linear model was chosen for the demand use model. Finally, the demand savings for the missing months were calculated by comparing the maximum demand from the post-retrofit month against the estimated demand from the demand model for the corresponding pre-retrofit month.

CASE STUDIES

The selected four buildings shown in Table 1 are used as examples to demonstrate the different approaches to evaluate savings for the electricity and demand use in the Ft. Hood project. The data collected at these four buildings were from various sources. Therefore, different data processing and modeling methods were chosen in the analysis.

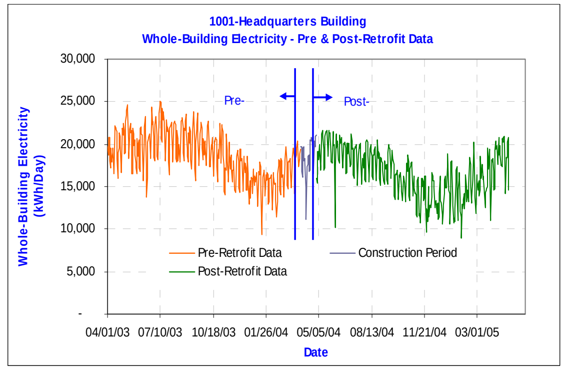
Building Number	1001	91002	52024	87014
Building Name	III CORP	HEADQUAR-TERS	COMANCHE CHILD	CO HQ BUILDING
Floor Area (sq. ft.)	312,800	38,462	34,779	14,162
Baseline Period	Apr 03 to Mar 04	Sep 03 to Feb 04	Aug 03 to May 04	Dec 00 to Mar 03
Pre-retrofit Data Type	Hourly Data from Synergistic Logger	Hourly Data from Portable Logger (ACR)	Hourly Data from Portable Logger (ACR)	Weekly Manual Readings
Post-retrofit Data Type	Hourly Data from Synergistic Logger	Hourly Data from Portable ACR Logger	Hourly Data from Portable ACR Logger	Hourly Data from Portable ACR Logger
Retrofits	Lighting	Lighting, HVAC Controls	Lighting, HVAC Controls	Lighting, HVAC Controls

Table 1: *Example Buildings*

<u>Savings analysis for whole-building electricity use</u>

Figure 4 shows an example of one of the change-point linear models used to measure the daily electricity use of the III Corp Building (site 1001). The data for this model used measured hourly data from the permanently installed logger in this building, which were then converted to daily totals and regressed against average daily temperature. Models of this type were calculated for the 87000 block thermal plant, and the III Corp building, where hourly data from Synergistic loggers were available for both pre- and post-retrofit periods.

The upper plot in Figure 5 shows the time series plot of the measured daily electricity use for the 91002 building for the period September 2003 through April 2005. These data were obtained from the hourly data collected through the portable watt-hour meter. The hourly data were converted to daily usage and then modeled with ASHRAE's IMT change-point linear models for weekdays and weekends separately, as shown in the middle and lower plots in Figure 5. Models of this type were calculated for the measured miscellaneous sites. Figure 6 shows another example of three parameter model for the electricity use of 52024 building developed using this type of hourly data, but with no consideration on the weekdays and weekends.



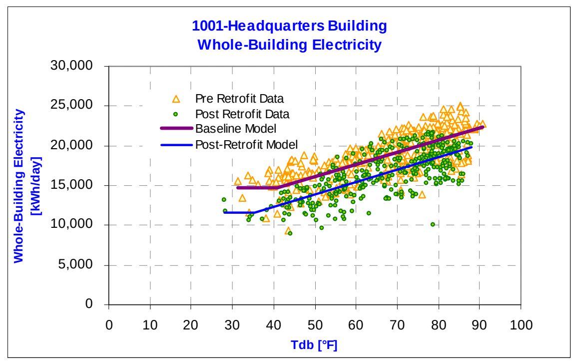


Figure 4: *Building 1001 Electricity Use Weather-dependent Daily Model from Hourly Logger Data*

Figure 7 shows the data that were collected through manual readings of the existing electricity meters at building 87014. These meters were read each week over a series of months, and then were regressed against the average weekly temperature as shown in Figure 7. Quite surprisingly, these models were found to be acceptable in a large number of the buildings, which helped to reduce the costs of installing loggers and developing the baseline models from hourly data. For most of the measured 87000 block buildings, baseline models were developed using the manual reading data. However, since the manual reading effort stopped in April 2003, the post-retrofit data were collected through portable loggers.

In order to determine if the hourly data from the portable ACR logger is reliable for these sites, the hourly data from portable ACR loggers were compared against the manual readings for an overlap period in the pre-retrofit period before the post-retrofit hourly data were used for calculating savings (Figure 8). If the manual readings did not agree with the ACR loggers then a reconciliation process was initiated to determine the problem.

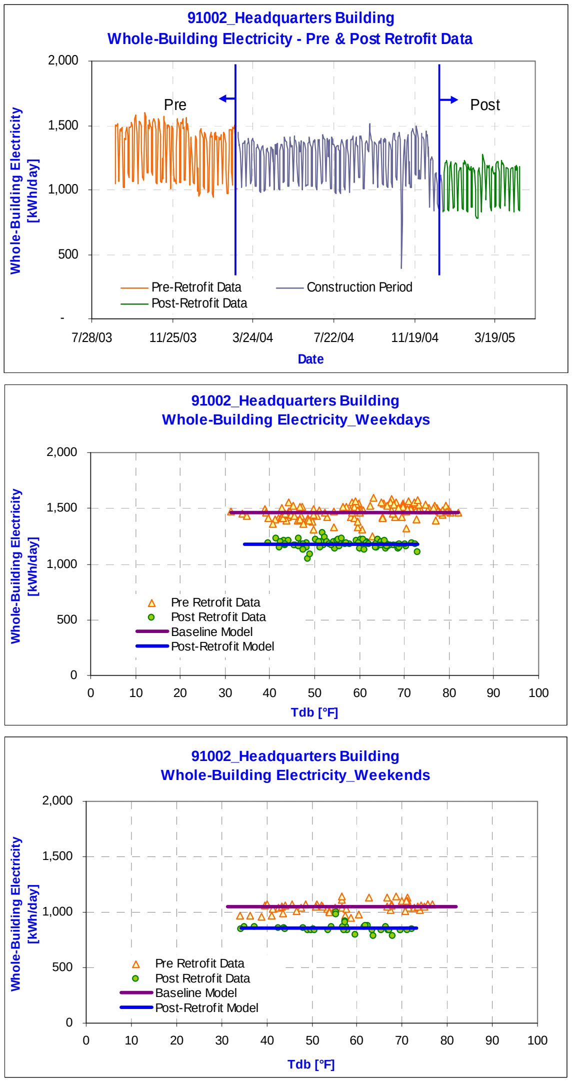


Figure 5: *Building 91002 Electricity Use Weekdays and Weekends Models from Portable Logger Data*

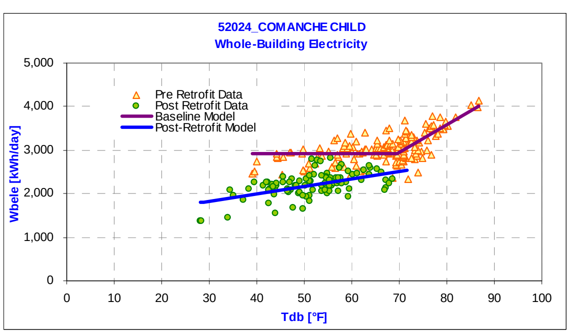


Figure 6: *Building 52024 Electricity Use Model from Portable Logger Data*

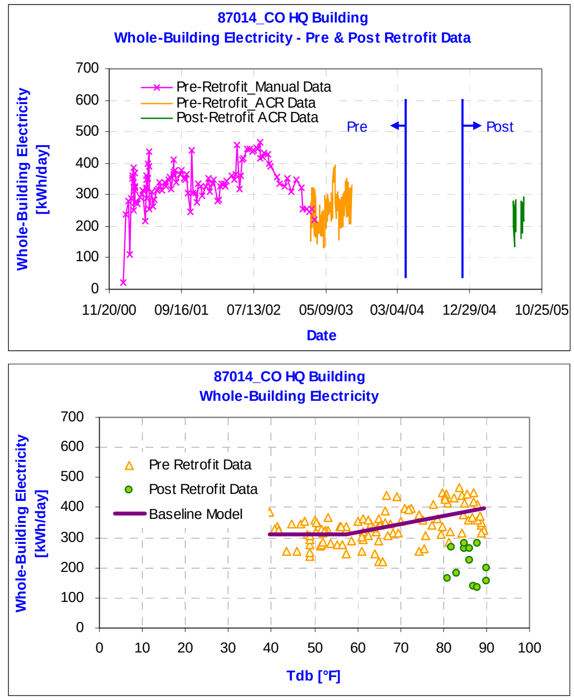


Figure 7: *Building 87014 Electricity Use Model from Manual Readings*

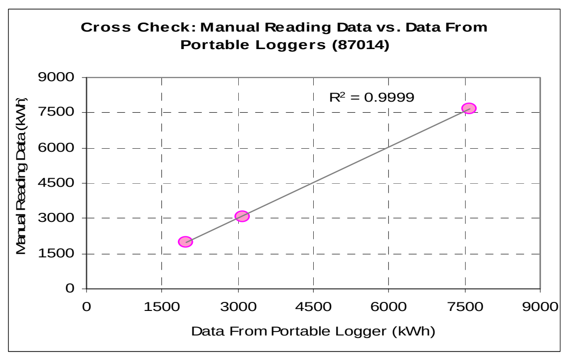


Figure 8: *Comparison of Manual Readings and Hourly Data from Portable Loggers*

Savings analysis for electrical demand

In the upper plot of Figure 5, data are shown from a portable logger that recorded the hourly electricity use from the Watt-hour meter installed in building 91002. These data represent six months of hourly data for pre-retrofit period and four months of hourly data for post-retrofit period that were used to develop the diversity factors models using ASHRAE's Diversity Factor Toolkit.

The 24-hour profiles for weekday and weekend of January 2004 (Pre-retrofit) and January 2005 (Post-retrofit), developed from measured data in building 91002, are displayed in Figure 9 and Figure 10, as an

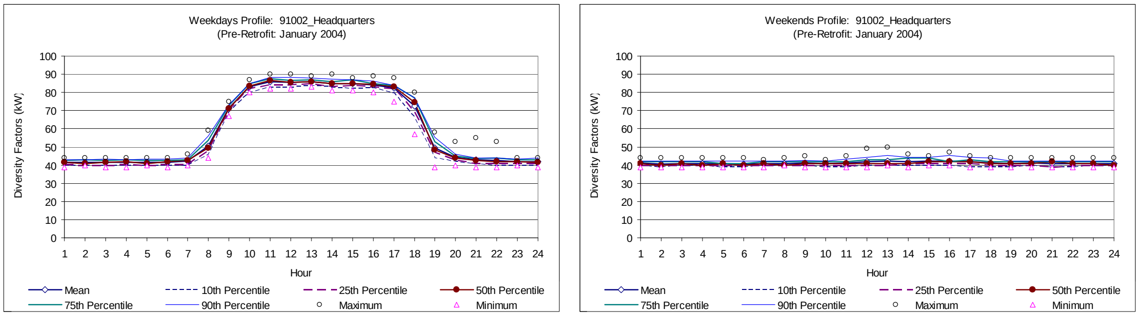


Figure 9: *Building 91002 Electrical Demand Model for Pre-retrofit Period (January 2004)*

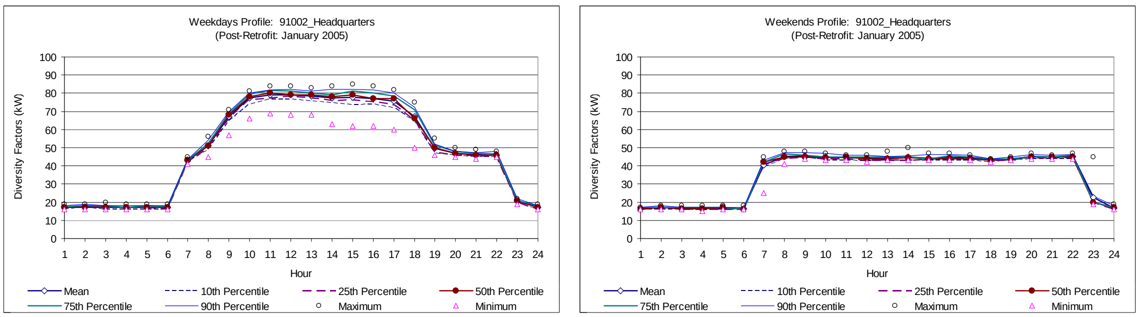


Figure 10: *Building 91002 Electrical Demand Model for Pre-retrofit Period (January 2005)*

example to show the demand savings analysis. The maximum kW use (90th percentile) is used to calculate the demand savings. In this example, the maximum demand for January 2004 (Pre-retrofit) and January 2005 (Post-retrofit) are 88 kW and 82 kW respectively. Therefore, the savings for January 2005 is 6 kW. Using the same method, the demand savings for February 2005 was calculated.

However, as previously mentioned, there were some difficulties calculating the demand savings for March 2005 and April 2005. This is because the demand models for March 2003 and April 2003 could not be developed due to missing data in the pre-retrofit period. To solve this problem, ASHRAE's IMT change-point linear models were applied to extend the demand prediction from the 1093-RP demand savings analysis to months where no demand was available. As shown in Figure 11, the maximum monthly demand (90th percentile) is plotted against the maximum average daily temperature of the month for the pre-retrofit period. For the 91002 building, a one parameter model (1P = average model) was chosen for the demand use model. Finally, the demand savings for March 2005 and April 2005 were calculated by comparing the maximum demand from these two months against the estimated demand from the 1P demand model for the same pre-retrofit months, that is, March 2003 and April 2003. Using the same method, the monthly demand savings for

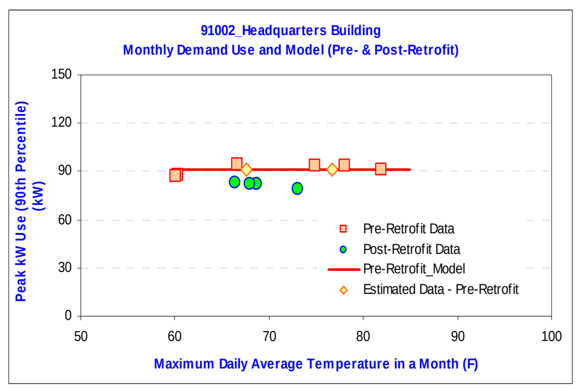


Figure 11: *Building 91002 Electrical Demand 1P Model for Pre-retrofit Period*

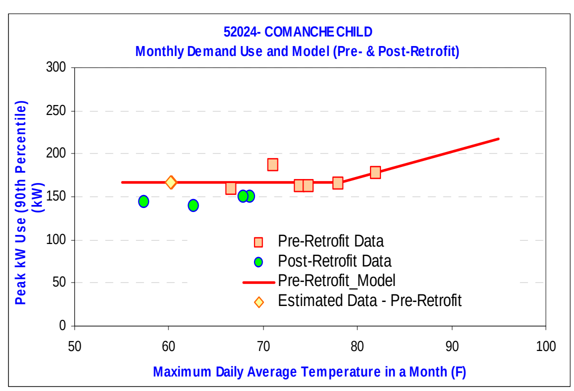


Figure 12: *Building 52024 Electrical Demand 1P Model for Pre-retrofit Period*

building 52024 for the post-retrofit period with measured data were calculated, using a three parameter model, as shown in Figure 12.

CONCLUSIONS

This paper has presented the procedures used for monitoring and verifying energy savings in selected buildings at the Fort Hood Army Base that received energy conservation retrofits, including buildings where hourly pre-retrofit and post-retrofit data were collected and buildings where weekly manual reading pre-retrofit data and hourly post-retrofit data were collected. New methods were developed to measure hourly demand savings from short-term data.

Lessons Learned

Applying linear, change-point linear and multiple regression models for the energy savings calculations and 24-hour profiles from diversity factor models for the demand savings calculation to commercial buildings requires careful planning of data collection and inspection of the data and the resultant regressions. When this is performed in a consistent manner, reliable results can be obtained that can be 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. Getting started with linear and change-point linear models using ASHRAE's IMT and 24-hour profiles using ASHRAE's Diversity Factor Toolkit requires less work than developing one's own models and the results can be linked to peer-reviewed publications.
2. 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.
3. Use of short-term hourly data collection using portable loggers is very helpful for trouble-shooting manual meter readings or detecting utility billing errors. It can also be used to evaluate the demand savings using the methods discussed in this paper.
4. Use of weekly meter readings or monthly utility billing data for analysis is useful for cases where the savings are expected to be greater than the CV(RMSE) error from the regression model.

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APPENDIX A: *Summary of Data Collection and Baseline Models*

Bldg. #	Const. Start Date	Const. End Date	GAS				ELECTRICITY				ELECTRICAL DEMAND				Manual Match ACR Data?	Savings Report Sent?
							Manual Reading Data or Logger Data				ACR Data					
			Baseline Model	Manual Reading Data Period	Pre-Retrofit Data	Post-Retrofit Data	Baseline Model	Data Available Period	Pre-Retrofit Data	Post-Retrofit Data	Baseline Model	Data Available Period	Pre-Retrofit Data	Post-Retrofit Data		
87017	May-04	Dec-04					3P	2/01-3/03	YES	NO	YES	3/03-8/03 6/26/05-7/09/05 7/31/05-8/13/05	YES	YES	YES	**YES**
87018	Apr-04	Apr-05	3P	12/00-3/03	YES	YES	YES	5/01-3/03	YES-Logger #938	YES-Logger #938	YES	Logger #938		YES-Need more data		**YES-Need more data to update it**
87008	Apr-04	Jan-05					1P	12/00-3/03	YES	NO	YES	3/03-8/03 6/26/05-7/09/05 7/31/05-8/13/05	YES	YES	YES	**YES**
87010	Apr-04	Dec-04					1P	2/01-3/03	YES	NO	YES	3/03-8/03	YES	NO	YES	
87003	Apr-04	Jan-05					1P	12/00-3/03	YES	NO	YES	1/03-8/03 7/31/05-8/13/05	YES	YES	YES	**YES**
87009	Apr-04	Jan-05					1P	12/00-3/03	YES	NO	YES	1/03-8/03 6/26/05-7/09/05 7/31/05-8/13/05	YES	YES	YES	**YES**
87006	Apr-04	Jan-05					1P	12/00-3/03	YES	NO	YES	3/03-8/03 6/26/05-7/09/05 7/31/05-8/13/05	YES	YES	YES	**YES**
87005	Apr-04	Jan-05					3P	12/00-3/03	YES	NO	YES	3/03-8/03 7/31/05-8/13/05	YES	YES	YES	**YES**
9212	May-04	May-04	3P	6/02-4/03	YES	NO	3P	6/02-4/03	YES	NO	NO Model		NO	NO		
52019	Feb-04	Nov-04														
42000	May-04	Mar-05					NO Model		YES	NO	YES	11/02-3/03	YES	NO	YES	
6602	Feb-04	Mar-05	3P	6/02-4/03	YES	NO	3P	6/02-4/03	YES	NO	YES	11/02-1/03, 8/03-5/04	YES	NO- Need data		
5485	Mar-04	Mar-05	3P	6/02-4/03	YES	NO	3P	6/02-4/03	YES	NO						
85018	May-04	Mar-05	3P	6/02-4/03	YES	NO	3P	6/02-4/03	YES	NO						
194	Feb-04	Feb-05	3P	6/02-4/03	YES	NO	2P	6/02-4/03	YES	NO	YES	11/02-1/03, 3/03-8/03	YES	NO	YES	
5764	Mar-04	Jun-04	3P	6/02-4/03	YES	NO	1P,2P	6/02-4/03	YES	NO	YES	11/02-1/03	YES	NO	NO- SF 0.405	
22020	Mar-04	Oct-04					NO Model				YES	12/02-3/03	YES	NO	NO	
52024	May-04	Nov-04					3P				YES	11/02-3/03, 8/03-3/05	YES	YES	NO	**YES**
1001	Apr-04	Apr-04	3P	6/02-4/03	YES	NO	1P, 2P	6/02-4/03	YES	YES	YES	5/03-8/03	YES	YES	Use Logger Data	**YES**
91002	Mar-04	Dec-04	NO Model	3/03-4/03	YES	NO	NO Model				YES	11/02-3/03, 8/03-4/05	YES	YES		**YES**
91014	Apr-04	Dec-04	3P	6/02-4/03	YES	NO	3P	6/02-4/03	YES	NO	YES	11/02-3/03, 8/03-11/04	YES	Need more data	YES	
91012	Mar-04	Dec-04	3P	6/02-4/03	YES	NO	3P	6/02-4/03	YES	NO	YES	12/02-4/05	YES	YES	NO - SF 30.39	**YES**
410	Mar-04	Sep-04	3P	6/02-4/03	YES	NO	3P	6/02-4/03	YES	NO	YES	11/02-1/03, 3/03-4/05	YES	YES	YES	**YES**
87016	Apr-04	Dec-04					3P	12/00-3/03	YES	NO	YES	3/03-8/03 7/28/05-08/15/05	YES	YES	YES	**YES**
87011	Apr-04	Dec-04					2P	1/01-3/03	YES	NO	YES	3/03-8/03 6/26/05-7/09/05 7/31/05-8/13/05	YES	YES	YES	**YES**
87019	May-04	Dec-04														
87004	Apr-04	**Dec-04**					NO Model	12/00-1/01	NO	NO	YES					
87014	Apr-04	Dec-04					2P	1/01-3/03	YES	NO	YES	3/03-8/03 6/26/05-7/09/05 7/31/05-8/13/05	YES	YES	YES	**YES**
4351	Feb-04	Apr-04	3P	6/02-4/03	YES	NO	NO Model	6/02-4/03	YES	NO						
30015	Feb-04	Apr-04														
38014	Apr-04	Apr-04														
38003	Feb-04	May-04														
35014	Feb-04	Apr-04														
30033	Feb-04	Apr-04														
35023	Feb-04	Apr-04														
30017	Feb-04	May-04														
15060	Feb-04	Mar-04					NO Model				YES	11/02-3/03	YES	NO		
19012	Feb-04	Apr-04														
9553	Mar-04	May-04														
9535	Feb-04	May-04														
9513	Mar-04	May-04														
9127	Feb-04	Apr-04														
9122	Feb-04	May-04					NO Model				YES	11/02-3/03	YES	NO		
9112	Feb-04	May-04					NO Model				YES	12/02-3/03	YES	NO		
87015	Apr-04	Jan-05					3P	2/01-3/03	YES	NO	YES	1/03-5/03 7/28/05-08/15/05	YES	YES	YES	**YES**
87012	Apr-04	Jan-05					2P	12/00-3/03	YES	NO	YES	3/03-8/03 7/28/05-08/15/05	YES	YES	YES	**YES**
87021	Apr-04	Jan-05									YES					
87007	Apr-04	Jan-05					4P	12/00-3/03	YES	NO	YES	3/03-8/03 7/28/05-08/15/05	YES	YES		**YES**
87013	Apr-04	Jan-05									YES					
87022	Apr-04	Jan-05									YES					
85020	Feb-04	Mar-05	1P	6/02-4/03	YES	NO	1P	6/02-4/03	YES	NO	YES	11/02-3/03, 5/03-4/05	YES	YES		**YES**
28000	Mar-04	**Oct-05**					1P, 3P				YES	11/02-3/03	YES	NO	NO- SF 0.6796	
33001	Mar-04	Dec-04					NO Model	1/04-7/05	Need More Data		NO	7/04-5/05	YES	YES		**YES**
33003	Dec-04	Dec-04					NO Model	1/04-7/05	YES		NO	7/04-4/05	YES	YES		**YES**
18010	Mar-04	Mar-04					NO Model				NO	7/04-5/05	Need data	YES		
36014	Dec-04	Dec-04					NO Model				NO	2/05-5/05	Need data	YES		
87020	Jan-05	Jan-05														
50012	Mar-04	Mar-05														