Energy Savings and Persistence from an Energy Services Performance Contract at an Army Base

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ABSTRACT

This paper examined persistence of energy savings from the application of the Monitoring and Verification (M&V) for the Fort Hood Energy Services Performance Contract (ESPC). The first and second ESPC Delivery Orders (DO) were implemented for 58 buildings in 2004-2005 and for 47 building in 2006-2008, respectively. To evaluate the long-term energy savings from the first and second ESPCs, ten sites where the hourly data in 2008-2010 were available were selected, and weather-dependent and weather-independent linear and change-point linear models were calculated with the ASHRAE's Inverse Modeling Toolkit (IMT). The results show there was a considerable difference in persistence of energy savings site-by-site: varying from −352% to 677% of the audit-estimated electricity savings for the six DO#1 and four DO#2 buildings. For all ten buildings, the long-term savings were 692,987 kWh, which corresponds to 40% of the audit-estimated electricity savings.

INTRODUCTION

The Fort Hood Army Base has selected an ESPC contractor to help achieve its energy reduction goals as mandated by Executive Order. The first and second ESPC Delivery Orders (DO#1 and DO#2) were implemented for 58 buildings in 2004-2005 and for 47 building in 2006-2008, respectively. The Energy Conservation Measures (ECMs) implemented include HVAC control system upgrades, lighting retrofits, vending machine controls, and cooling tower variable frequency drivers (VFDs).

To accomplish the Measurement and Verification (M&V), data monitoring equipment was installed in the early stages of the ESPC contractual process, and hourly electricity consumption data collected using the monitoring system. Baseline models were then developed (Haberl et al. 2002 and 2003b), and energy and demand savings were calculated and reported on a short term basis for twenty-three DO#1 sites (Liu et al. 2005; Cho et al. 2008) and ten DO#2 sites (Kim et al. 2008) just after the installation of ECMs.

This paper examines the persistence of energy savings from the application of M&V for the Fort Hood ESPC. To accomplish this, six DO#1 and four DO#2 sites where the hourly data in 2008-2010 were available were selected, and weather-dependent and weather-independent linear and change-point linear models were calculated with the ASHRAE's Inverse Modeling Toolkit (IMT) (Haberl et al. 2003a; Kissock et al. 2003) to satisfy the M&V requirements of the International Performance Monitoring and Verification Protocols (IPMVP) (DOE 2002) and ASHRAE's Guideline 14-2002 (ASHRAE 2002). The savings for the different periods were then calculated and compared with savings reported previously as well as audit-estimated savings.

METHODOLOGY

A total of ten buildings (six DO#1 and four DO#2) were selected among 58 DO#1 and 47 DO#2 sites where the ECMs had been installed. The selection was based on the availability of suitable hourly data for the pre- and post-retrofit periods. To access a long-term energy savings, 2008-2010 data were considered for the post-retrofit period. Table 1 lists the six DO#1 and four DO#2 sites for which measured long-term savings are evaluated in this paper, and includes the building size, implemented ECMs, and annual audit-estimated electricity savings. HVAC control system upgrades were implemented at all ten sites, and lighting retrofits were performed for nine sites. For two sites, vending controls were installed in the vending machines, and for the 87018 thermal plant, cooling tower VFDs were implemented.

To develop baseline models, the previously-collected hourly, whole-building or whole-plant electricity data were used. The hourly data collected in the pre-retrofit period were converted to daily

usage and then modeled with ASHRAE's IMT change-point linear models (Figure 1) for weekdays and weekends, separately. When the consumption on the weekdays and weekends were not significantly different, a combined, baseline model was developed. To compute savings, the hourly or 15-min

Table 1. Summary of DO#1 and DO#2 Sites

ID No. for Ten Sites Analyzed in this Paper	Bldg. #	Building/ Thermal Plant Name	DO#1/ DO#2	Building Size (ft^2)	Energy Conservation Measures (ECMs)				Annual Audit-Estimated Electricity Savings (kWh/year)
					HVAC Controls	Lighting	Vending Controls	Cooling Tower VFDs	
1	410	Headquarters Bldg.	DO#1	102,391	√	√	√		931,344
2	87007	Enlisted UPH Bldg.	DO#1	31,470	√	√			5,887
3	87012	Enlisted UPH Bldg.	DO#1	42,306	√	√			9,719
4	87017	Dining Facility	DO#1	15,695	√	√			41,390
5	87018	Physical Plant	DO#1	3,327	√	√		√	522,971
6	91012	Admin Bldg.	DO#1	86,292	√	√			391,136
Total for Six DO#1 Sites									**1,902,446**
7	13	Information Processing Ctr.	DO#2	22,000	√	√			71,392
8	113	Child Development Ctr.	DO#2	23,100	√	√			119,919
9	7051	Simulation Bldg.	DO#2	24,908	√		√		67,246
10	10041	Chapel Bldg.	DO#2	6,659	√	√			46,142
Total for Four DO#2 Sites									**304,700**

whole-building electricity data for post-retrofit period was converted to daily usage and then compared against the estimated daily usage calculated using the pre-retrofit baseline models.

SAVINGS ANAYLSIS FOR THE SIX DO#1 AND FOUR DO#2 SITES

Table 2 summarizes the audit-estimated savings and measured whole-building electricity savings calculated for six DO#1 sites during the analysis period of 2010 and for four DO#2 sites during the analysis period of 2008-2010. The audit-estimated electricity savings of the six DO#1 sites are 1,196,451 kWh. The total measured savings of −243,846 kWh correspond to −20.4% of the audit-estimated electricity savings, which indicates that the electricity consumption increased when compared to the pre-retrofit period. In contrast, the audit-estimated electricity savings of the four DO#2 sites are 556,854 kWh for the measured period, and the total measured savings of 936,833kWh correspond to 168.2% of the audit-estimated electricity savings, which indicates that the retrofits are generally working better than expected.

Figures 2 to 4 shows an example of one of the time-series plot and change-point linear models used to calculate savings for the 410-Headquarters Building at Fort Hood for the period of January 2010 - September 2010. Figure 2 shows the time series plot of the measured daily electricity use. The pre-retrofit period, construction period and post-retrofit period are also shown in the plot. The data for the period of November 2003 were excluded in the analysis because of unreasonably low energy use. The hourly data collected in the pre-retrofit periods were converted to daily usage and then modeled with ASHRAE's IMT change-point linear models for

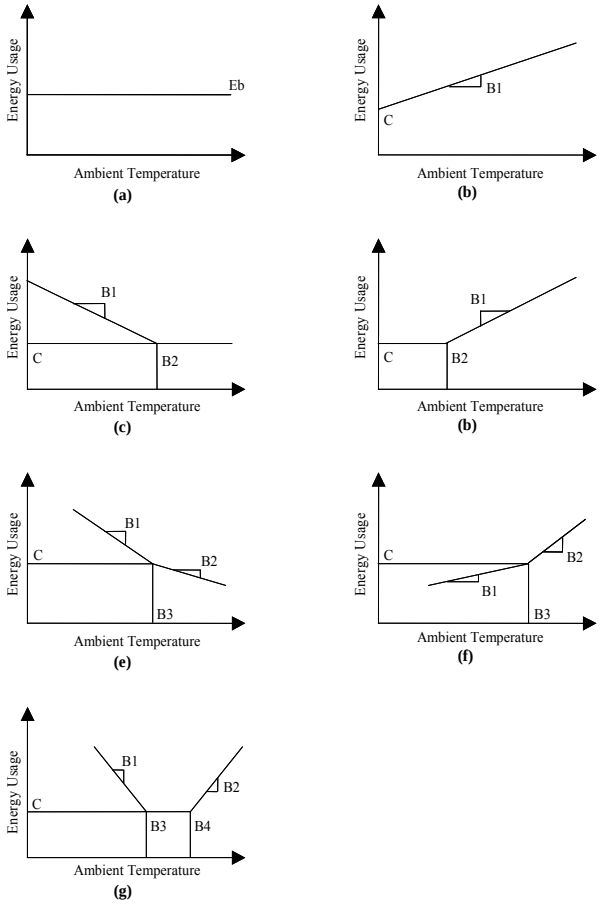

Figure 1. ASHRAE IMT Change-Point Models. (a) mean or 1 parameter (1P) model, (b) 2P model, (c) 3P heating model (d) 3P cooling model, (e) 4P heating model, (f) 4Pcooling model, and (g) 5P model

Table 2. Savings Summary of Six DO#1 and Four DO#2 Sites

ID No. for Ten Sites Analyzed in this Paper	Bldg. #	Building/ Thermal Plant Name	DO#1/ DO#2	Baseline Period	Pre-Retrofit Data	Post-Retrofit Data	Pre-Retrofit Model	Electricity Savings For the Measured Period (2010 for DO#1 and 2008-2010 for DO#2)			
								No. Of Days	Audit-Estimated Savings (kWh/period)	Measured Savings (kWh/period)	% of Audit-Estimated Savings
1	410	Headquarters Bldg.	DO#1	Mar. 2003-Feb. 2004	Hourly data from ACR logger	15-min data from Wattnode	3P Weekday and Weekend Models	251	640,458	-72,123	-11%
2	87007	Enlisted UPH Bldg.	DO#1	Dec. 2000-Mar. 2003	Weekly manual readings	15-min data from Wattnode	4P All data model	234	3,774	24,905	660%
3	87012	Enlisted UPH Bldg.	DO#1	Dec. 2000-Mar. 2003	Weekly manual readings	15-min data from Wattnode	2P All data Model	251	6,683	-8,347	-125%
4	87017	Dining Facility	DO#1	Feb. 2001-Mar. 2003	Weekly manual readings	15-min data from Wattnode	3P All data Model	253	28,689	-36,290	-126%
5	87018	Physical Plant	DO#1	Mar.-Nov. 2001; May-Nov. 2002; and Apr.-Dec. 2003	Hourly data from ACR logger	15-min data from Wattnode	4P All data model	173	247,874	170,867	69%
6	91012	Admin Bldg.	DO#1	Dec. 2002-Feb. 2004	Hourly data from ACR logger	15-min data from Wattnode	3P Weekday and Weekend Models	251	268,973	-322,858	-120%
Total for Six DO#1 Sites									**1,196,451**	**-243,846**	**-20%**
7	13	Information Processing Ctr.	DO#2	Nov. 2005-Oct. 2006	Hourly data from ACR logger	Hourly data from ACR logger	3P All data Model	518	101,318	-357,110	-352%
8	113	Child Development Ctr.	DO#2	Oct. 2005-Oct. 2006	Hourly data from ACR logger	Hourly data from ACR logger	3P Weekday and Weekend Models	744	244,438	178,318	73%
9	7051	Simulation Bldg.	DO#2	Nov. 2005-Aug. 2006	Hourly data from ACR logger	Hourly data from ACR logger	3P Weekday and Weekend Models	754	138,914	939,767	677%
10	10041	Chapel Bldg.	DO#2	Dec. 2005-Dec. 2006	Hourly data from ACR logger	Hourly data from ACR logger	3P All data Model	571	72,184	175,858	244%
Total for Four DO#2 Sites									**556,854**	**936,833**	**168%**
Total for DO#1 and DO#2 Sites									**1,753,305**	**692,987**	**40%**

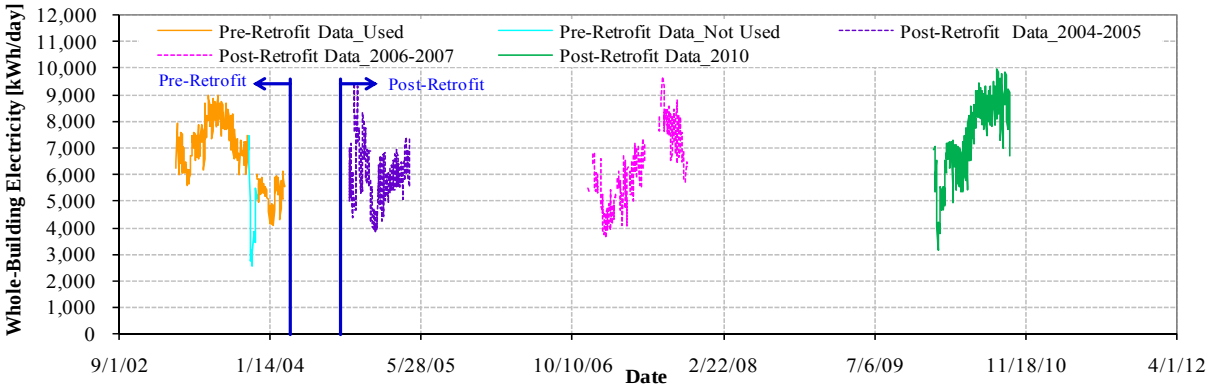

Figure 2. 410-Headquarters Building Daily Electricity Use

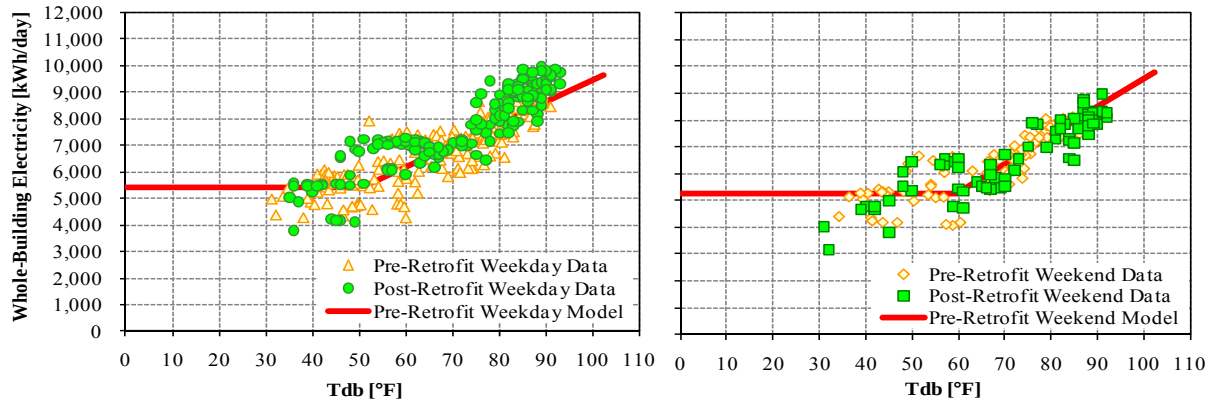

Figure 3.410-Headquarters Building Daily Electricity Models for Weekdays (Left) and Weekends (Right) for Pre- and Post-Retrofit Periods

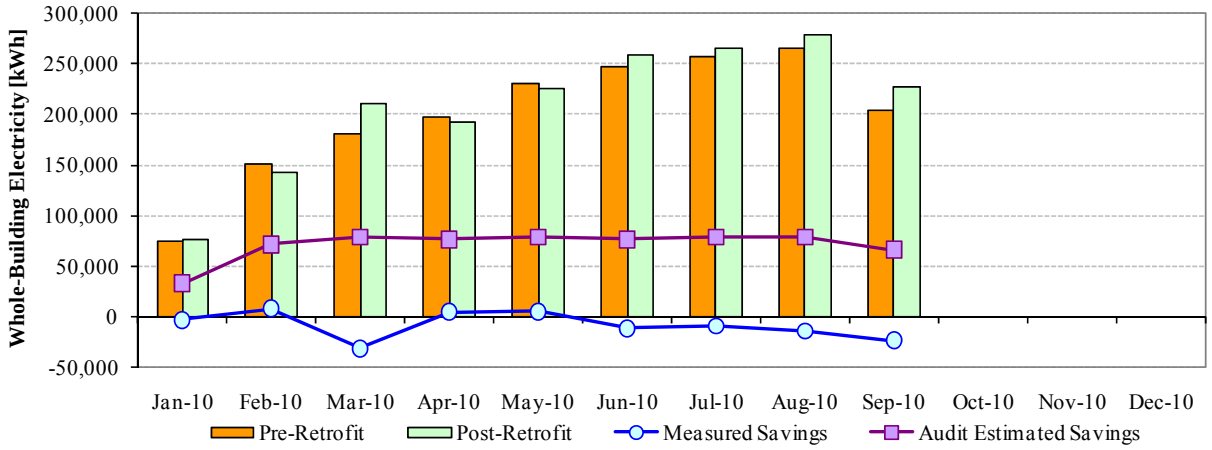

Figure 4.410-Headquarters Building Monthly Electricity Savings

weekdays and weekends separately, as shown in Figure 3. The 15-min data for post-retrofit period was converted to daily usage and then compared against the calculated, baseline daily usage from the three-parameter, pre-retrofit models to calculate the savings. The monthly electricity consumption for pre- and post-retrofit periods and the electricity savings are presented in Figure 4.

According to the information obtained from Fort Hood, lighting, HVAC controls, and vending controls were implemented at this site. The lighting and vending projects were completed in March 2004 and the HVAC controls project was completed in September 2004. The audit-estimated savings for electricity was 931,344 kWh/yr. Previously, the analysis on electricity savings for this building was reported twice: −11,190 kWh (increase) measured savings which corresponds to −2.2% of the audit-estimated savings of 515,429 kWh for the period of October 2004 to April 2005; and 129,611 kWh measured savings which corresponds to 15.2% of the audit-estimated savings of 854,795 kWh for December 2006 to October 2007. The measured electricity savings of −72,123 kWh corresponds to an increased usage of −11.3% of the audit estimated savings of 640,458 kWh for the analysis period[1]. This falls short of expectations.

Figures 5 to 7 show another example of the time-series plot and change-point linear models used to calculate savings for the 113-Child Development Center of Fort Hood for the period of September 2008 - September 2010. Figure 5 shows the time series plot of the measured daily electricity use. The pre-retrofit period, construction period and post-retrofit period are also shown in the plot. The data for the period of November 2002 - September 2005 was excluded in the analysis because there was adequate one-year data for the pre-retrofit model. Therefore, the most recent data from October 2005 to October 2006 were used in the analysis. The hourly data collected in the pre-retrofit periods was converted to daily usage and then modeled with ASHRAE's IMT change-point linear models for weekdays and

[1] The monthly audit estimated savings for electricity is proportional to the number of days per month.

weekends separately, as shown in Figure 6. The savings were calculated by comparing the daily usage for the post-retrofit period against the estimated daily usage from the three-parameter, pre-retrofit model. The monthly electricity consumption for pre- and post-retrofit periods and the electricity savings are presented in Figure 7.

According to the information obtained from Fort Hood, lighting and HVAC controls retrofits were implemented at this site. The lighting project was completed in April 27, 2007, and the HVAC controls project was completed in January 29, 2008. The audit-estimated savings was 119,919 kWh/yr for electricity. Previously, the analysis of the electricity savings for this building was reported for the period of January 2008 to September 2008: 60,295 kWh measured savings which corresponds to 85% of the audit-estimated savings of 70,966 kWh. For the analysis period of this study (2008-2010), the measured savings was 178,318 kWh for electricity which corresponds to 73.0% of the audit estimated savings of 244,438 kWh, which is about 27% lower than the estimated savings. The lower electricity savings observed during the summer time may indicate that the lighting retrofits have been generally working as expected while HVAC retrofits may not be performing as expected during the hot summer period.

ENERGY SAVINGS PERSISTENCE

The savings of DO#1 sites were previously reported for the periods 2004-05 (just after the

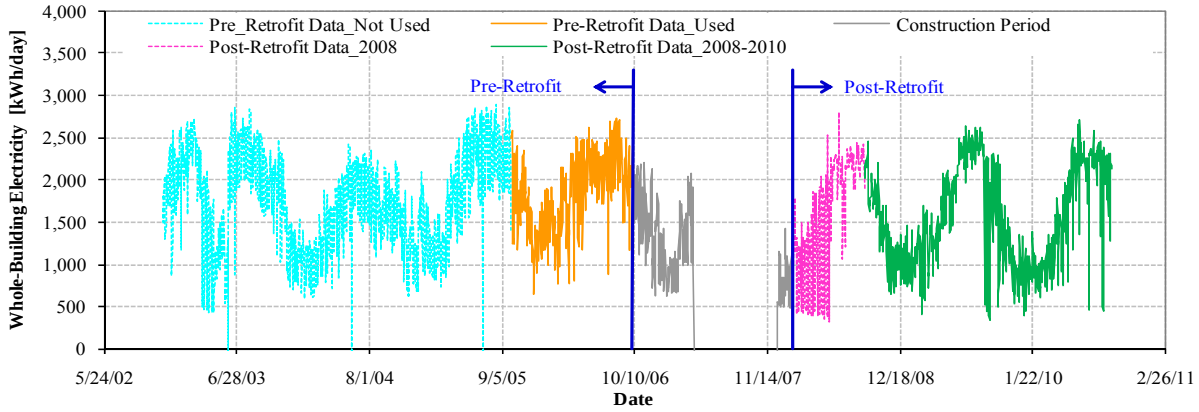

Figure 5. 113-Child Development Center Daily Electricity Use

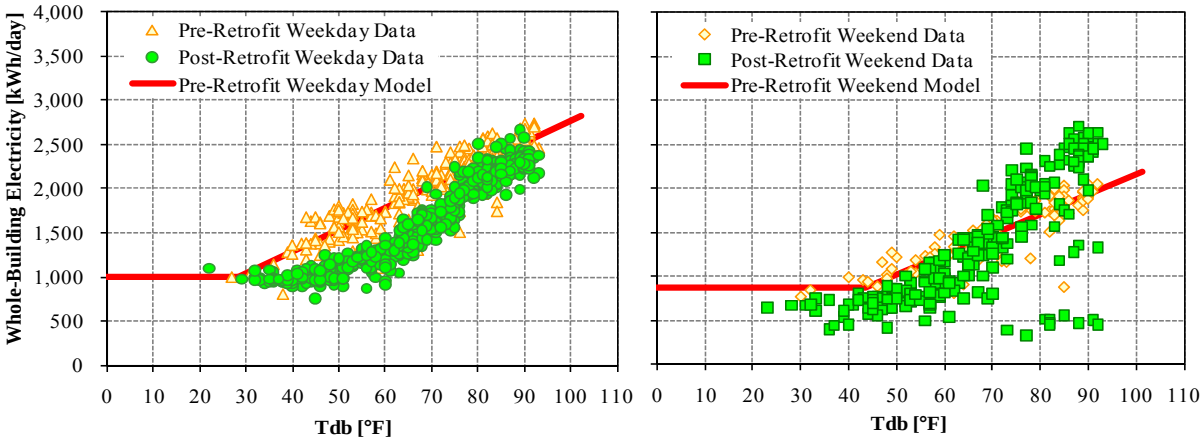

Figure 6. 113-Child Development Center Daily Electricity Models for Weekdays (Left) and Weekends (Right) for Pre- and Post-Retrofit Periods

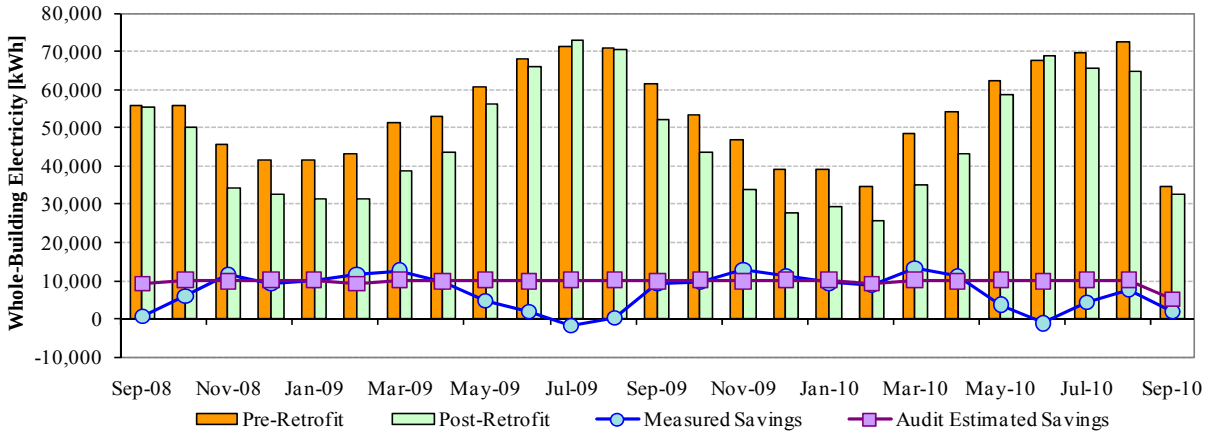

Figure 7. 113-Child Development Center Monthly Electricity Savings

installation of ECMs) and 2006-07 (Liu et al. 2005; Cho et al. 2008). For the DO#2 sites, the savings were previously reported for the period of 2006-07 just after the installation of ECMs (Kim et al. 2008). Table 3 presents the audit-estimated and measured electricity savings of the six DO#1 and four DO#2 sites with other DO#1 and DO#2 sites where the savings were previously reported[2]. For all DO#1 buildings, the savings were 867,239 kWh (51% of the audit-estimated savings) for 2004-05, 821,242 kWh (41% of the audit-estimated savings) for 2006-07, and −243,846 kWh (−20% of the audit-estimated

[2] Of a total 23 DO#1 and ten DO#2 sites where the savings were previously reported, the sites of which reporting period longer than 28 days were selected and plotted in this figure.

Table 3. Audit-Estimated and Measured Savings of the DO#1and DO#2 Sites for Each Reporting Period

ID No. for Ten Sites Analyzed in this Paper	Bldg. #	Building/ Thermal Plant Name	DO#1 / DO#2	Building Size (ft^2)	Electricity Savings (kWh/period) for 2004-2005				Electricity Savings (kWh/period) for 2006-2007				Electricity Savings (kWh/period) for 2010 (DO#1) and 2008-2010 (DO#2)			
					No. Of Days	Audit-Estimated Savings	Measured Savings	% of Audit-Estimated Savings	No. Of Days	Audit-Estimated Savings	Measured Savings	% of Audit-Estimated Savings	No. Of Days	Audit-Estimated Savings	Measured Savings	% of Audit-Estimated Savings
	194	NCO Club	DO#1	19,023					335	469,829	53,620	11%				
1	410	Headquarters Bldg.	DO#1	102,391	202	515,429	-11,190	-2%	335	854,795	129,611	15%	251	640,458	-72,123	-11%
	1001	Headquarters Bldg.	DO#1	312,800	365	821,700	787,465	96%								
	5764	Officers Club	DO#1	36,649					335	293,328	113,722	39%				
	33001	MEDAC	DO#1	20,240	212	22,307	68,660	308%	699	73,550	135,350	184%				
	33003	MEDAC	DO#1	20,240	212	21,928	-36,228	-165%								
	52024	Comanche Child Bldg.	DO#1	34,779	100	103,251	71,568	69%	212	218,892	164,917	75%				
	87003	BN HQ Bldg.	DO#1	12,314					74	10,405	15,839	152%				
	87006	Health Clinic	DO#1	4,073	28	847	740	87%	46	1,392	2,460	177%				
2	87007	Enlisted UPH Bldg.	DO#1	31,470					365	5,887	25,138	427%	234	3,774	24,905	660%
	87008	BN HQ Bldg.	DO#1	6,371	28	1,412	2,173	154%	46	2,320	5,949	256%				
	87009	BN HQ Bldg.	DO#1	12,381	28	3,773	2,760	73%								
	87011	CO HQ Bldg.	DO#1	25,618	28	4,271	2,645	62%								
3	87012	Enlisted UPH Bldg.	DO#1	42,306					881	23,458	80,981	345%	251	6,683	-8,347	-125%
	87014	CO HQ Bldg.	DO#1	14,162					335	30,189	40,856	135%				
	87015	Enlisted UPH Bldg.	DO#1	42,306					881	15,694	11,806	75%				
	87016	CO HQ Bldg.	DO#1	25,168					182	25,030	40,993	164%				
4	87017	Dining Facility	DO#1	15,695	28	3,175	4,755	150%					253	28,689	-36,290	-126%
5	87018	Physical Plant	DO#1	3,327									173	247,874	170,867	69%
	91002	Headquarters Bldg.	DO#1	38,462	115	68,728	31,010	45%								
6	91012	Admin Bldg.	DO#1	86,292	110	117,877	-57,119	-48%					251	268,973	-322,858	-120%
Total for DO#1 Sites						**1,684,700**	**867,239**	**51%**		**2,024,768**	**821,242**	**41%**		**1,196,451**	**-243,846**	**-20%**
7	13	Information Processing Ctr.	DO#2	22,000					215	42,053	-167,260	-398%	518	101,318	-357,110	-352%
8	113	Child Development Ctr.	DO#2	23,100					216	70,966	60,295	85%	744	244,438	178,318	73%
	7012	AC Maintenance Hanger	DO#2	54,706					262	67,332	1,291	2%				
9	7051	Simulation Bldg.	DO#2	24,908					216	39,795	142,711	359%	754	138,914	939,767	677%
10	10041	Chapel Bldg.	DO#2	6,659					189	23,893	44,513	186%	571	72,184	175,858	244%
	23001	Physical Fitness Center	DO#2	58,841					216	76,696	-2,343	-3%				
	50004	Exchange Main Store	DO#2	307,336					468	363,595	-17,769	-5%				
	88030	Repair Bays	DO#2	171,957					217	171,767	76,232	44%				
Total for DO#2 Sites										**856,097**	**137,670**	**16%**		**556,854**	**936,833**	**168%**
Total for DO#1 and DO#2 Sites						**1,684,700**	**867,239**	**51%**		**2,880,864**	**958,912**	**33%**		**1,753,305**	**692,987**	**40%**

savings) for 2010. For all DO#2 buildings, the savings were 137,670 kWh (16% of the audit-estimated savings) for 2006-07 and 936,833 kWh (168% of the audit-estimated savings) for 2008-10.

Site-by-site, there was a considerable difference in persistence of energy savings: varying from −352% to 677% of the audit-estimated electricity savings for the six DO#1 and four DO#2 buildings. Of the six DO#1 sites, only one site (87007 Enlisted UPH building, ID No. 2 in the figure) reported measured savings higher than the audit-estimated savings with the percent of audit-estimated savings calculated to be: 427% from June 2006 to May 2007 and 660% from Jan. to Sep. 2010. For one site (87018 Thermal Plant), a 69% of audit-estimated savings was observed from April to Sep. 2010, which means the measured savings were lower than the expectation. For the other four sites, negative savings were observed during the analysis periods of 2008-2010. For the 410 Headquarters building, the savings fell short of expectations throughout all the reporting periods with the percent of audit-estimated savings: −2% from Oct. 2004 to Apr. 2005, 15% from Dec. 2006-Oct. 2007, and −11% from Jan. to Sep. 2010. For the 91012 Admin building, negative savings were observed for both reporting periods with the audit-estimated savings: −49% from Jan. to Apr. 2005 and −120% from Jan. to Sep. 2010. For 87012, another Enlisted UPH building, 345% of audit-estimated savings were reported from Aug. 2005 to Dec. 2007, but a negative savings (−125%) were observed from Jan. to Sep. 2010. For the 87017 Dining Facility, a negative −126% of audit-estimated was observed from Jan. to Sep. 2010.

Of the four DO#2 sites, two sites (7051 Simulation building and 10041 Chapel) have the measured savings higher than the audit-estimated savings for both reporting periods. The percent of

audit estimated savings are 359% from Jan. to Sep. 2008 and 677% from Sep. 2008 to Sep. 2010 for the 7051 building; and 186% from Feb. to Sep. 2008 and 244% from Sep. 2008 to Sep. 2010 for the 10041 Chapel. For the 113 Child Development center, the measured savings were lower than the estimated savings for both reporting periods with the percent of audit-estimated savings: 85% from Jan. to Sep. 2008 and 73% from Sep. 2008 to Sep. 2010. The Information Processing center had negative savings for both reporting periods with the percent of audit-estimated savings: −398% from Jan. to Aug. 2008 and −353% from Apr. 2009 to Sep. 2010.

DISCUSSIONS

Figure 8 shows the measured daily electricity savings (Wh/ft^2-day) against their audit- estimated savings for the DO#1and DO#2 sites listed in Table 3. Group 1 buildings (light green triangle shape) are the sites that had higher savings than the audit-estimated savings, and Group 2 buildings (light blue triangle shape) are the sites that had lower savings than the audit-estimated savings. Group 3 buildings (light orange rectangle shape) are those sites where electricity consumption increased after the retrofits. The reasons that the savings did not meet expectations for Group 2 buildings and that the consumption increased for Group 3 buildings remain unknown. Even though conversations with the facility personnel at the Fort Hood revealed that there were no noticeable operational changes.

Three recommendations have been proposed to help with future analysis.

1) *Blink test*: A blink test is a quick way to identify the size of various loads for lighting, equipment and mechanical systems by performing a staged shut-down sequence for the systems of interests in the building (Bryant and Carlson 2001). The information collected using a blink test before and after retrofits can be used to help determine the changes to base loads of the building.

2) *Energy submetering*: Submetered energy data by major end-use (i.e., heating, cooling, fans, pumps, lighting and equipments, or water heating) are helpful to identify the reasons of improved or deteriorated energy performance of the buildings. For example, periodic submetering of the vending machines' energy uses before and after retrofits will help to verify the savings from installing vending controls, which are too small to identify using whole-building electricity data.

3) *Lab testing of individual measures*: Testing individual energy efficiency measures in an independent lab before applying them in the field will be helpful for a more accurate estimate of savings.

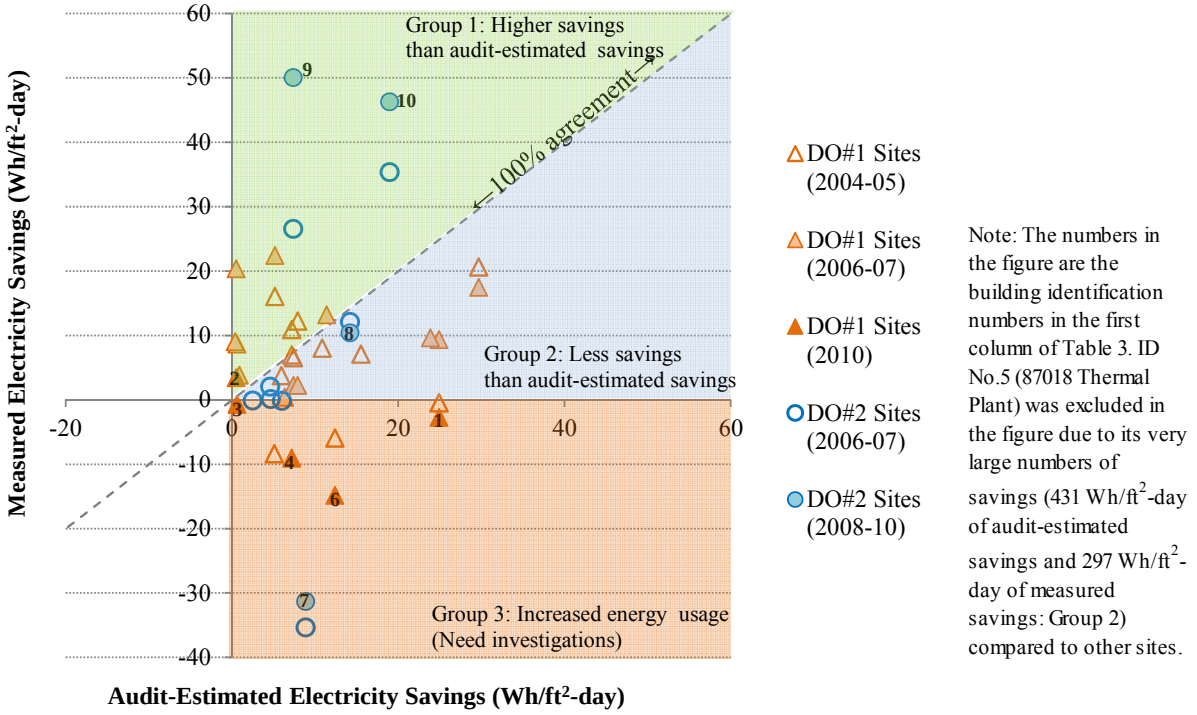

Figure 8. Measured Electricity Savings against the Audit-Estimated Savings for Each Reporting Period

SUMMARY

This paper presents the results of an analysis of long-term energy savings from the application of the M&V for the Fort Hood Energy Services Performance Contract (ESPC). For the ten sites where the hourly data in 2008-2010 were available, the weather-dependent and weather-independent linear and change-point linear models were calculated with the ASHRAE's Inverse Modeling Toolkit (IMT). The results show there was a considerable difference in persistence of energy savings site by site: varying from −352% to 677% of the audit-estimated electricity savings for the six DO#1 and four DO#2 buildings. Of a total ten buildings, the measured savings of three sites (87007, 7051, and10041) were higher than the audit-estimated savings for all analysis periods. For two buildings (87018 and 113), there were savings lower than the estimations. One building (410) showed little difference in the energy use between before and after retrofit. Another four buildings reported negative savings for this long-term analysis period (2010 for DO#1 sites and 2008-10 for DO#2 sites), which overwhelmed the total savings.

ACKNOWLEDGEMENT

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