DEVELOPMENT OF A MONITORING AND VERIFICATION (M&V) PLAN AND BASELINE FOR THE FORT HOOD ESPC PROJECT

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ABSTRACT

Fort Hood 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 56 buildings, and includes 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 IPMVP Options B and C for the first two years after the retrofits are installed, and Option A combined with annual performance verification for the remainder of the contract. This paper discusses the development the Measurement and Verification (M&V) Plan for the Fort Hood Energy Services Performance Contract, and includes results of the baseline calculations (Haberl et al. 2002, 2003b).

INTRODUCTION

Fort Hood has selected an Energy Services Performance Contract 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 56 buildings, and includes 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 IPMVP Options B and C 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 this, a cost-effective 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 using linear and change-point linear models as shown in Figure 1 and Table 1 for the whole-building weather-dependent and weather-independent models and component-level models for the thermal plant.

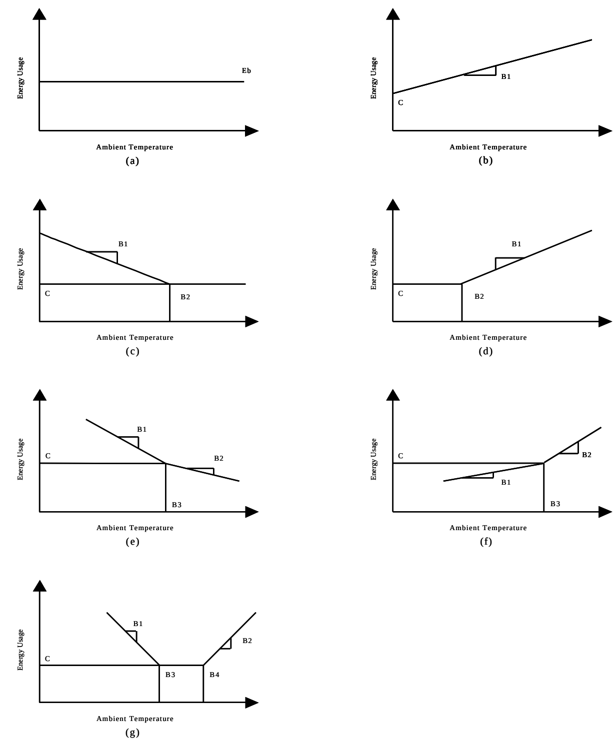

Figure 1: *Models used for the Whole-building Analysis. Included in this figure is: (a) mean or 1 parameter model, (b) 2 parameter model, (c) 3 parameter heating model (similar to a variable based degree-day model (VBDD) for heating), (d) 3 parameter cooling model (VBDD for cooling), (e) 4 parameter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

The weather-dependent and weather-independent regression models used for this effort were linear and change-point linear models calculated with ASHRAE's Inverse Model Toolkit (IMT) (Haberl et al. 2002; Kissock et al. 2002), to satisfy the requirements of the International

Name	Section	Independent Variable(s)	Form	Examples
No Adjustment /Constant Model	6.1.4.1	None	$E = E_b$	Non weather sensitive demand
Day Adjusted Model	6.1.4.2	None	$E = E_b \times \frac{day_b}{day_c}$	Non weather sensitive use (fuel in summer, electricity in summer)
Two Parameter Model	6.1.4.3	Temperature	$E = C + B_1(T)$	
Three Parameter Models	6.1.4.4	Degree days/Temperature	$E = C + B_1(DD_{BT})$ $E = C + B_1(B_2 - T)^+$ $E = C + B_1(T - B_2)^+$	Seasonal weather sensitive use (fuel in winter, electricity in summer for cooling) Seasonal weather sensitive demand
Four Parameter, Change Point Model	6.1.4.5	Temperature	$E = C + B_1(B_3 - T)^+ - B_2(T - B_3)^+$ $E = C - B_1(B_3 - T)^+ + B_2(T - B_3)^+$	
Five Parameter Models	6.1.4.6	Degree days/Temperature	$E = C - B_1(DD_{TH}) + B_2(DD_{TC})$ $E = C + B_1(B_3 - T)^+ + B_2(T - B_4)^+$	Heating and cooling supplied by same meter.
Multi-Variate Models	6.1.4.7	Degree days/Temperature, other independent variables	Combination form	Energy use dependent non-temperature based variables (occupancy, production, etc.).

Table 1: *ASHRAE Guideline 14 Regression Models(ASHRAE 2002).*

Performance Monitoring and Verification Protocols (IPMVP 2001), and ASHRAE's Guideline 14 (ASHRAE 2002), which were specified as part of this contract. These models include:

(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.

RETROFITS

The retrofits identified by the ESPC contractor covered 56 buildings on the Ft. Hood army base as shown in Table 2. 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. The retrofits were intended to save 7.4 million kWh/year in electricity ($312,390/year), 11.2 MW in electric peak demand ($49,214/year), and 8.6 million cubic feet of natural gas ($31,302/year), for a total project savings of ($392,906/year), which averaged $0.38/ft^2. As shown in Table 3 there were five primary types of retrofits, including:

1) upgrades to boiler insulation,
2) improved building controls with a Utility Management Control System (UMCS),
3) vending machine controls,
4) cooling tower retrofits, and
5) lighting retrofits.

DATA COLLECTION

As a first step in the data collection effort, existing hourly metering equipment at Ft. Hood were recalibrated[2] and new equipment were 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. Manual readings of these meters and other existing meters were taken weekly to develop a record of energy use (kWh/week), which was to be used to calculate energy savings for electricity use savings. Hourly demand readings (kW) were to taken with portable 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 were demand savings were anticipated.

In Table 2, the fourth column indicates the intended baseline data for each building, including buildings with permanently installed data loggers (indicated by "logger"), buildings with Watt transducers and portable data loggers (man & ACR), and buildings with manual weekly readings only (manual). All buildings in the 87000 block (87000 block) had Watt transducers installed to record the whole-buildings electricity use. The thermal energy use (i.e., heating and cooling), was also recorded for

[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.

Building Number	Building Name	Building Size (ft2)	Electricity Meter Status	Gas Meter Status	Type of Elec Metering Needed (kWh,kW)	Type of Gas Metering Needed	Annual kWH Savings	Total Annual kW Savings	Total Annual Gas Savings (MCF)	Total Annual Savings kWh, kW,	Total Annual Savings kWh,
			Type							& Gas/ft2	kW/ft2
194	NCO Club (Phant	19,023	Man & ACR	YES	WBE(kWh,kW)		511,903	47	-	$1.15	$1.15
410	Headquarters Bui	102,391	Man & ACR	YES	WBE(kWh,kW)	WBNG	931,344	1,025	1,376	$0.52	$0.47
1001	Third Corp Headq	312,800	Logger	YES	WBE(kWh,kW)		821,700	2,363	-	$0.18	$0.18
4351	Motor Pool	16,317	Manual	YES	WBE(kWh,kW)		25,314	75	-	$0.11	$0.11
5485	Pershing Youth C	17,519	Manual	YES	WBE(kWh,kW)	WBNG	34,329	68	51	$0.13	$0.12
5764	Officers Club	36,649	Man & ACR	YES	WBE(kWh,kW)	WBNG	319,596	152	533	$0.46	$0.40
6602	Bronco Youth Ce	22,100	Man & ACR	YES	WBE(kWh,kW)	WBNG	85,034	125	114	$0.23	$0.21
9112	Motor Pool	20,832	Man & ACR	NO	WBE(kWh,kW)		106,906	431	-	$0.40	$0.40
9122	Motor Pool	20,832	Man & ACR	NO	WBE(kWh,kW)		117,344	477	-	$0.44	$0.44
9127	Motor Pool	20,240	BLINK	NO	WBE(kWh,kW)		58,304	222	-	$0.22	$0.22
9212	Patton Inn	1,612	Manual	YES	WBE(kWh,kW)	WBNG	13,221	53	1	$0.64	$0.63
9513	Motor Pool	20,832	Man & ACR	NO	WBE(kWh,kW)		90,926	362	-	$0.34	$0.34
9535	Motor Pool	20,240	BLINK	NO	WBE(kWh,kW)		67,860	260	-	$0.25	$0.25
9553	Motor Pool	24,560	BLINK	NO	WBE(kWh,kW)		40,097	140	-	$0.12	$0.12
15060	Motor Pool	20,240	Man & ACR	NO	WBE(kWh,kW)		83,276	329	-	$0.32	$0.32
19012	Motor Pool	20,240	BLINK	NO	WBE(kWh,kW)			150	-		$0.03
22020	Admin	21,096	Man & ACR	YES	WBE(kWH)	WBNG	195,943	180	304	$0.52	$0.46
28000	Headquarters Bld	129,635	Man & ACR	YES	WBE(kWh,kW)	WBNG	300,217	0	501	$0.11	$0.10
30015	Motor Pool	20,240	BLINK	NO	WBE(kWh,kW)		63,486	218	-	$0.23	$0.23
30017	Motor Pool	20,240	BLINK	NO	WBE(kWh,kW)		58,581	219	-	$0.22	$0.22
30033	Motor Pool	20,240	BLINK	NO	WBE(kWh,kW)		69,343	256	-	$0.26	$0.26
35014	Motor Pool	20,480	BLINK	NO	WBE(kWh,kW)		52,109	191	-	$0.19	$0.19
35023	Motor Pool	23,040	BLINK	NO	WBE(kWh,kW)		41,741	135	-	$0.13	$0.13
38003	Motor Pool	20,240	BLINK	NO	WBE(kWh,kW)		64,908	247	-	$0.24	$0.24
38014	Motor Pool	20,240	BLINK	NO	WBE(kWh,kW)		50,299	183	-	$0.18	$0.18
42000	Sports USA	23,341	Man & ACR	YES	WBE(kWH)	WBNG	406,107	92	340	$0.82	$0.76
50012	Community Even	4,203	Manual	YES	WBE(kWh,kW)	WBNG	13,713	0	1	$0.14	$0.14
52019	Comanche Comm	13,450	Manual	YES	WBE(kWh,kW)	WBNG	196,510	108	196	$0.74	$0.68
52381	Golf Pro Shop	3,061	Manual	YES		WBNG			-		
52024	COMMAND Chi	34,779	Man & ACR	YES	WBE(kWh,kW)	WBNG	376,866	217	506	$0.56	$0.51
70005	Longhorn Saloon	5,718	Manual	YES	WBE(kWh,kW)		134,677	53	83	$1.12	$1.07
85018	Walker Youth Ser	15,652	Manual	YES	WBE(kWh,kW)		50,954	113	-	$0.20	$0.20
85020	Commissary	105,659	Man & ACR	YES	WBE(kWh,kW)		165,961	470	-	$0.11	$0.11
87003	BN HQ Building	12,314	87000 Block	STEAM	WBE(kWh,kW)		51,320	146	-	$0.28	$0.28
87004	CO HQ Building	18,818	87000 Block	STEAM	WBE(kWh,kW)		46,779	126	-	$0.16	$0.16
87005	BDE HQ Building	9,840	87000 Block	STEAM	WBE(kWH)		26,450	114	-	$0.22	$0.22
87006	Offices	4,073	87000 Block	STEAM	WBE(kWh,kW)		11,047	44	-	$0.21	$0.21
87007	Enlisted UPH	31,470	87000 Block	STEAM	WBE(kWh,kW)		5,887	0	-	$0.01	$0.01
87008	BN HQ Building	6,371	87000 Block	STEAM	WBE(kWh,kW)		18,412	70	-	$0.22	$0.22
87009	BN HQ Building	12,381	87000 Block	STEAM	WBE(kWh,kW)	WBNG	49,190	162	-	$0.28	$0.28
87010	Physical Fitness C	23,631	87000 Block	STEAM	WBE(kWh,kW)		98,108	172	344	$0.29	$0.24
87011	CO HQ Building	25,618	87000 Block	STEAM	WBE(kWH)		55,680	157	0	$0.15	$0.15
87012	Enlisted UPH	42,306	87000 Block	STEAM	WBE(kWh,kW)		9,719	5	0	$0.01	$0.01
87013	Enlisted UPH	31,740	87000 Block	STEAM	WBE(kWh,kW)		6,439	0	0	$0.01	$0.01
87014	CO HQ Building	14,162	87000 Block	STEAM	WBE(kWh,kW)		32,892	96	0	$0.16	$0.16
87015	Enlisted UPH	42,306	87000 Block	STEAM	WBE(kWh,kW)		6,502	3	0	$0.01	$0.01
87016	CO HQ Building	25,168	87000 Block	STEAM	WBE(kWh,kW)		50,197	157	0	$0.14	$0.14
87017	Dining Facility	15,695	87000 Block	STEAM	WBE(kWh,kW)	WBNG	41,390	89	0	$0.16	$0.16
87018	Physical Plant - 8	3,327	Logger	STEAM	WBE(kWh,kW)		522,971	15	2,120		
87019	CO HQ Building	18,818	BLINK	STEAM	WBE(kWh,kW)		33,628	126	0	$0.13	$0.13
87020	Enlisted UPH	42,306	BLINK	STEAM	WBE(kWh,kW)		38,111	79	0	$0.05	$0.05
87021	Enlisted UPH	87,021	BLINK	STEAM	WBE(kWh,kW)		6,523	1	0	$0.00	$0.00
87022	Enlisted UPH	42,306	BLINK	STEAM	WBE(kWh,kW)	STEAM	23,936	54		$0.03	$0.03
91002	Headquarters Bld	38,462	Man & ACR	YES	WBE(kWh,kW)	WBNG	218,137	121	560	$0.32	$0.27
91012	Admin/ Operation	86,292	Man & ACR	YES	WBE(kWh,kW)	WBNG	391,136	388	1,186	$0.28	$0.23
91014	Admin	26,224	Man & ACR	YES	WBE(kWH)	WBNG	162,590	184	385	$0.38	$0.32
	Total	1,858,390					7,455,614	11,269	8,600		
	Average	33,186					138,067	205	307	$ 0.28	$ 0.26

Table 2: *Metering Status of the Buildings in the ESPC Versus Estimated Savings.*

all buildings in the 87000 block at the thermal plant. (i.e., 87018 thermal plant). Buildings that did not have meters, and where the estimated savings were small, did not have meters installed (blink). In these buildings 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.

[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.

BASELINE ANALYSIS METHODOLOGY

In Table 3 the analysis methods are listed for each building, depending upon energy conservation retrofit measure (ECRM) and metering data available, including:

1) (Option Ch/A), which indicates Option C of the IPMVP (before/after whole-building method) to be assembled from hourly data for the first two years, to change to Option A (i.e., measured performance stipulated use) of the IPMVP in year three of the contract.

2) (Option Ch/D*), which indicates Option C of the IPMVP (before/after whole-building method)

Building Number	Building Name	Building Size (ft2)	Recommended M&V Option for Ft. Hood Energy Services Contract				
			1.2 Boil.Ins.	3.1 UMCS	3.3 Vend	4.2 Cool	5.1 Light
194	NCO Club (Phantom Warrior Club)	19,023	Option Ch/A	Option Ch/D*	Option Ch/A		Option Ch/A
410	Headquarters Building	102,391		Option Ch/D*	Option Ch/A	Option Ch/A	Option Ch/A
1001	Third Corp Headquarters	312,800					Option Cm/A
4351	Motor Pool	16,317			Option Cm/A		Option Cm/A
5485	Pershing Youth Center	17,519	Option Ch/A	Option Ch/D*	Option Ch/A		Option Ch/A
5764	Officers Club	36,649	Option Ch/A	Option Ch/D*		Option Ch/A	Option Ch/A
6602	Bronco Youth Center	22,100	Option Ch/A	Option Ch/D*	Option Ch/A		Option Ch/A
9112	Motor Pool	20,832		Option Ch/D*	Option Ch/A		Option Ch/A
9122	Motor Pool	20,832			Option Cm/A		Option Cm/A
9127	Motor Pool	20,240			Option Cm/A		Option Cm/A
9212	Patton Inn	1,612					Option Cm/A
9513	Motor Pool	20,832			Option Cm/A		Option Cm/A
9535	Motor Pool	20,240			Option Cm/A		Option Cm/A
9553	Motor Pool	24,560			Option Cm/A		Option Cm/A
15060	Motor Pool	20,240			Option Cm/A		Option Cm/A
19012	Motor Pool	20,240			Option Cm/A		Option Cm/A
22020	Admin	21,096		Option Ch/D*	Option Ch/A		Option Ch/A
28000	Headquarters Bldg	129,635		Option Ch/D*	Option Ch/A	Option Ch/A	
30015	Motor Pool	20,240			Option Cm/A		Option Cm/A
30017	Motor Pool	20,240			Option Cm/A		Option Cm/A
30033	Motor Pool	20,240			Option Cm/A		Option Cm/A
35014	Motor Pool	20,480			Option Cm/A		Option Cm/A
35023	Motor Pool	23,040			Option Cm/A		Option Cm/A
38003	Motor Pool	20,240			Option Cm/A		Option Cm/A
38014	Motor Pool	20,240			Option Cm/A		Option Cm/A
42000	Sports USA	23,341	Option Ch/A	Option Ch/D*	Option Ch/A	Option Ch/A	Option Ch/A
50012	Community Event Center	4,203		Option Ch/D*	Option Ch/A		
52019	Comanche Community Activity Center	13,450	Option Ch/A	Option Ch/D*	Option Ch/A		Option Ch/A
52381	Golf Pro Shop	3,061					
52024	COMMAND Child Care	34,779	Option Ch/A	Option Ch/D*		Option Ch/A	Option Ch/A
70005	Longhorn Saloon	5,718	Option Ch/A	Option Ch/D*			Option Ch/A
85018	Walker Youth Service Center	15,652		Option Ch/D*	Option Ch/A		Option Ch/A
85020	Commissary	105,659		Option Ch/D*	Option Ch/A		Option Ch/A
87003	BN HQ Building and Org Classroom	12,314		Option Ch/D*	Option Ch/A		Option Ch/A
87004	CO HQ Building	18,818		Option Ch/D*	Option Ch/A		Option Ch/A
87005	BDE HQ Building	9,840		Option Ch/D*			Option Ch/A
87006	Offices	4,073		Option Ch/D*			Option Ch/A
87007	Enlisted UPH	31,470		Option Ch/D*			Option Ch/A
87008	BN HQ Building	6,371		Option Ch/D*	Option Ch/A		Option Ch/A
87009	BN HQ Building and Org Classroom	12,381		Option Ch/D*	Option Ch/A		Option Ch/A
87010	Physical Fitness Center	23,631	Option Ch/A	Option Ch/D*	Option Ch/A		Option Ch/A
87011	CO HQ Building	25,618		Option Ch/D*	Option Ch/A		Option Ch/A
87012	Enlisted UPH	42,306		Option Ch/D*			Option Ch/A
87013	Enlisted UPH	31,740		Option Ch/D*			Option Ch/A
87014	CO HQ Building	14,162		Option Ch/D*	Option Ch/A		Option Ch/A
87015	Enlisted UPH	42,306		Option Ch/D*			Option Ch/A
87016	CO HQ Building	25,168		Option Ch/D*	Option Ch/A		Option Ch/A
87017	Dining Facility	15,695		Option Ch/D*			Option Ch/A
87018	Physical Plant - 87000 Block	3,327	Option Ch/A			Option Ch/A	Option Ch/A
87019	CO HQ Building	18,818		Option Ch/D*			Option Ch/A
87020	Enlisted UPH	42,306		Option Ch/D*	Option Ch/A		Option Ch/A
87021	Enlisted UPH	87,021		Option Ch/D*			Option Ch/A
87022	Enlisted UPH	42,306		Option Ch/D*	Option Ch/A		Option Ch/A
91002	Headquarters Bldg	38,462	Option Ch/A	Option Ch/D*			Option Ch/A
91012	Admin/ Operational Testing	86,292	Option Ch/A	Option Ch/D*			Option Ch/A
91014	Admin	26,224	Option Ch/A	Option Ch/D*			Option Ch/A

Table 3: *Proposed Analysis of the Buildings in the ESPC Versus ECRM Type.*

3) to be assembled from hourly data for the first two years, to change to Option D (i.e., calibrated simulation) of the IPMVP in year three of the contract[4].

[4] This is to be accomplished by using data from the UMCS that tracks the changes in the control settings with differences tracked

4) (Option Cm/A), which indicates Option C of the IPMVP (before/after whole-building method) to be assembled from manual data for the baseline period, and hourly data after the retrofit recorded by the UMCS, to change to Option A (i.e., measured performance stipulated use) of the IPMVP in year three of the contract.

For the entire project, annual savings are to be measured during the first year according to the following equation

Annual Measured Cost Savings Fort Hood Task Order #1 = $kWhsavings + $kWsavings +$NGsavings ± $Adjustments

Equation 1

Where savings for electricity use (kWh), electric demand (kW), and natural gas use (NG) are to be measured separately and the dollar values added into a total annual project savings. For electricity use savings, which are estimated to be 7.4 million kWh/year in electricity ($312,390/year), savings are to be calculated using whole-buildings models of the individual buildings, using the following equation:

kWh_{savings}$ = $kWh-194 + $kWh-410
+ $kWh-1001 + $kWh-4351 + $kWh-5485
+ $kWh-5764 + $kWh-6602 + $kWh-9112
+ $kWh-9122 + $kWh-9127 + $kWh-9212
+ $kWh-9513 + $kWh-9535 + $kWh-9553
+ $kWh-15060 + $kWh-19012 + $kWh-22020
+ $kWh-28000 + $kWh-30015 + $kWh-30017
+ $kWh-30033 + $kWh-35014 + $kWh-35023
+ $kWh-38003 + $kWh-38014 + $kWh-42000
+ $kWh-50012 + $kWh-52019 + $kWh-52381
+ $kWh-52024 + $kWh-70005 + $kWh-85018
+ $kWh-85020 + $kWh-87003 + $kWh-87004
+ $kWh-87005 + $kWh-87006 + $kWh-87007
+ $kWh-87008 + $kWh-87009 + $kWh-87010
+ $kWh-87011 + $kWh-87012 + $kWh-87013
+ $kWh-87014 + $kWh-87015 + $kWh-87016
+ $kWh-87017 + $kWh-87018 + $kWh-87019
+ $kWh-87020 + $kWh-87021 + $kWh-87022
+ $kWh-91002 + $kWh-91012 + $kWh-91014

Equation 2

Similar expressions were developed for the electric demand savings, and natural gas savings. Each year, for the first two years after the retrofit, the energy use of the buildings will be measured, and the savings calculated using whole-building, weather normalized models (Haberl et al. 2002; 2003b). In years 3 thru the end of the contract equipment performance will be verified using on-site inspections, usage and savings will be stipulated using savings calculated in year 2. In the case that suitable baseline models cannot be developed before the end of year 2 (i.e., where the model uncertainty is greater than the savings), or cannot be developed due to inadequate baseline data, savings will be calculated using Option A of the IPMVP (i.e., equipment performance will be verified using on-site inspections, usage and savings will be stipulated using the ESPC contractor's estimated savings for each individual building as calculated by the contractor).

RESULTS

Table 4 contains the results of the baseline modeling efforts for the whole-building electricity and natural gas models. Column 3 lists the type of model chosen to represent the baseline energy use for the energy type indicated by column 14 (electricity use: kWh/day, natural gas use kBtu/day), column 4 shows the predicted annual energy use for the building, and column 5 shows the model uncertainty expressed in similar units for each fuel type, with the model uncertainty shown in column 5 as energy use per day, and as a annual uncertainty in column 15.

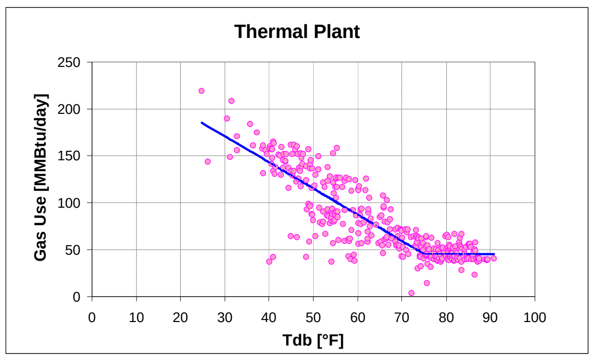

Figure 2: *Thermal Plant Natural Gas Weather-dependent Daily Model From Hourly Data Logger.*

<u>Linear and change-point linear models of whole-building electricity use (kWh).</u> As previously discussed, weather-dependent and weather-independent regression models were developed for the buildings that were scheduled to be retrofitted. These models used linear and change-point linear models calculated with ASHRAE's Inverse Model Toolkit (IMT) (Haberl et al. 2002; Kissock et al. 2002), to satisfy the requirements of the International Performance Monitoring and Verification Protocols (IPMVP 2001), and ASHRAE's Guideline 14 (ASHRAE 2002), which were specified in the contract.

with a calibrated simulation.

Building Number	Building Name	WBE -Consumption (kWh) or Natural Gas												
		model	Predicted Ann 9/2002-8/2003	Model Uncertainty kWh/day	Model Uncertainty %	Npre	RMSEpre or STdDevpre	CV-RMSE or CV-StdDev	Ymean or Ycp	LS	RS	Xcp	Units	Yearly Uncertainty
194	Phantom Warrior Club	2P	788,038	2,187	0.28%	23	1070	51.68%	448	25.9			kWh/day	5.30%
194	Phantom Warrior Club	3P	13,538,592	33,290	0.25%	31	16462	36.12%	12716	-1577.8	0.0	80.6	kBtu/day	4.70%
410	Headquarters Building	3P	2,789,054	2,926	0.10%	20	1424	19.28%	6694	0.0	63.7	57.7	kWh/day	2.00%
410	Headquarters Building	3P	8,479,200	26,390	0.31%	31	13050	40.63%	3002	-1755.3	0.0	74.8	kBtu/day	5.95%
1001.2	Third Corp Headquarters	1P	2,948,317	10,490	0.36%	24	5137	63.64%	8072				kWh/day	6.80%
1001.3	Whole-(MCC+Wbcool) week	2P	3,029,893	1,981	0.06%	253	958	8.20%	10372	19.4			kWh/day	1.19%
1001.4	Whole-(MCC+Wbcool) week	2P	891,092	1,383	0.16%	103	699	9.24%	7728	11.4			kWh/day	2.97%
1001.5	MCC	3P	879,097	594	0.07%	356	302	12.55%	1973	0.0	10.9	26.1	kWh/day	1.28%
1001.6	Chiller	3P	2,245,076	1,251	0.06%	356	637	10.36%	4164	0.0	106.8	48.6	kWh/day	1.06%
1001.7	Gas	3P	17,328,519	14,412	0.08%	354	7332	15.38%	34737	-786.0	0.0	81.6	kBtu/day	1.59%
1001.8	Third Corp Headquarters	3P	16,358	34	0.21%	31	17	33.25%	28	-0.9	0.0	82.6	kBtu/day	3.93%
4351	Motor Pool	3P	1,285,079	2,453	0.19%	31	1213	24.31%	295	-295.0	0.0	74.0	kBtu/day	3.65%
5485	Pershing Youth Center	3P	217,521	671	0.31%	31	332	67.07%	318	0.0	29.4	60.8	kWh/day	5.90%
5485	Pershing Youth Center	3P	219,134	769	0.35%	31	380	46.91%	122	-41.5	0.0	74.9	kBtu/day	6.71%
5764.1	Officers Club	1P	468,315	1,094	0.23%	31	541	42.33%	1278				kWh/day	4.48%
5764.2	Officers Club	2P	487,063	2,557	0.52%	24	1253	125.18%	-1384	41.1			kWh/day	10.03%
5764.3	Officers Club	3P	22,942,385	33,007	0.14%	31	16322	23.44%	46662	-1318.7	0.0	75.9	kBtu/day	2.75%
6602	Bronco Youth Center	3P	466,315	613	0.13%	24	301	36.15%	572	0.0	65.4	71.1	kWh/day	2.51%
6602	Bronco Youth Center	3P	329,931	1,108	0.34%	31	548	45.38%	321	-133.8	0.0	60.8	kBtu/day	6.41%
9212	Patton Inn	3P	188,398	563	0.30%	30	278	63.35%	258	0.0	36.7	65.4	kWh/day	5.68%
9212	Patton Inn	3P	422,878	988	0.23%	30	488	30.99%	186	-93.9	0.0	73.0	kBtu/day	4.46%
28000	Headquarters Bldg	1P	3,928,322	28,630	0.73%	22	13985	129.91%	10765				kWh/day	13.92%
28000	Headquarters Bldg	3P	770,868	3,773	0.49%	30	1864	57.06%	-1	-227.8	0.0	71.1	kBtu/day	9.35%
50012	Community Event Center	3P	318,032	460	0.15%	29	227	32.21%	452	0.0	33.5	56.8	kWh/day	2.78%
50012	Community Event Center	3P	305,593	992	0.32%	31	490	42.74%	270	-110.7	0.0	62.5	kBtu/day	6.20%
52024	COMMAND Child Care	3P	7,804	16	0.20%	22	8	39.00%	13	0.0	0.5	50.1	kWh/day	3.81%
52024	COMMAND Child Care	3P	1,716,769	5,874	0.34%	23	2875	43.67%	1504	-675.8	0.0	61.5	kBtu/day	6.54%
52381	Golf Pro Shop	3P	376,020	851	0.23%	31	421	44.94%	733	0.0	48.7	67.3	kWh/day	4.32%
52381	Golf Pro Shop	3P	297,280	950	0.32%	31	470	39.94%	153	-129.1	0.0	62.5	kBtu/day	6.11%
70005	Longhorn Saloon	3P	272,733	338	0.12%	30	167	24.43%	548	0.0	57.6	73.0	kWh/day	2.37%
70005	Longhorn Saloon	3P	848,252	1,674	0.20%	31	828	28.57%	1278	-164.1	0.0	65.4	kBtu/day	3.77%
85018	Walker Youth Service Center	3P	300,881	591	0.20%	30	292	39.97%	455	0.0	95.4	72.0	kWh/day	3.75%
85018	Walker Youth Service Center	3P	28,029	63	0.22%	31	31	37.22%	67	-0.9	0.0	78.7	kBtu/day	4.17%
85020	Commissary	1P	28,470	42	0.15%	11	20	25.37%	78				kWh/day	2.83%
85020	Commissary	1P	3,885,755	8,651	0.22%	31	4278	40.18%	10646					4.25%
87000.1	MCC	3P	1,238,149	249	0.02%	176	126	3.67%	3314	0.0	10.3	64.5	kWh/day	0.38%
87000.2	Chiller	3P	2,243,730	3,349	0.15%	176	1699	24.77%	5051	0.0	269.4	71.6	kWh/day	2.85%
87000.3	Gas	3P	28,340,328	42,223	0.15%	341	21480	28.35%	45299	-2792.2	0.0	75.0	kBtu/day	2.85%
87003	BN HQ Building and Org Cl	1P	188,930	128	0.07%	117	65	12.63%	512				kWh/day	1.31%
87005	BDE HQ Building	3P	160,804	187	0.12%	114	95	21.28%	406	0.0	50.5	81.7	kWh/day	2.22%
87006	Offices	1P	47,522	41	0.09%	117	21	15.94%	130				kWh/day	1.64%
87007	Enlisted UPH	4P	307,002	136	0.04%	81	69	8.06%	729	-3.7	9.1	59.0	kWh/day	0.85%
87008	BN HQ Building	1P	131,272	94	0.07%	117	47	13.18%	360				kWh/day	1.36%
87009	BN HQ Building and Org Cl	1P	237,153	343	0.14%	116	174	26.72%	650				kWh/day	2.76%
87010	Physical Fitness Center	1P	375,705	380	0.10%	106	192	18.66%	1029				kWh/day	1.93%
87011	CO HQ Building	2P	191,261	176	0.09%	107	89	16.97%	343	2.7			kWh/day	1.76%
87012	Enlisted UPH	2P	438,961	236	0.05%	117	119	9.99%	903	4.5			kWh/day	1.03%
87014	CO HQ Building	2P	122,668	118	0.10%	108	59	17.71%	182	2.3			kWh/day	1.83%
87015	Enlisted UPH	3P	143,475	105	0.07%	105	53	13.57%	371	0.0	5.9	72.5	kWh/day	1.40%
87016	CO HQ Building	3P	178,675	237	0.13%	117	120	24.87%	433	0.0	4.9	57.9	kWh/day	2.53%
87017	Dining Facility	3P	504,954	331	0.07%	106	167	12.18%	1292	0.0	13.0	65.5	kWh/day	1.25%
87018	REFA-C Building	3P	3,337,348	5,409	0.16%	79	2726	31.98%		-280.9	0.0	79.7	kBtu/day	3.10%
91012	Admin/ Operational Testing	3P	2,684,248	3,491	0.13%	22	1706	23.51%	6878	0.0	407.4	79.7	kWh/day	2.48%
91012	Admin/ Operational Testing	3P	52,430,699	118,074	0.23%	29	58266	33.11%	67638	-4895.8	0.0	81.8	kBtu/day	4.30%
91014	Admin	3P	814,329	1,714	0.21%	21	838	40.51%	1648	0.0	39.8	53.0	kWh/day	4.02%
91014	Admin	3P	568,995	2,103	0.37%	28	1037	46.89%	303	-103.1	0.0	75.9	kBtu/day	7.09%
1001.1	Third Corp Headquarters	1P	4,149,246	7,007	0.17%	31	3465	30.48%	11368				kWh/day	3.23%

Table 4: *Weather Dependent Models Calculated for the ESPC Baseline.*

Figure 2 shows an example of one of the change-point linear models used to measure the daily natural gas use of the boiler in the thermal plant in the 87000 block. The data for this model used measured hourly data from the permanently installed logger in the thermal plant, 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.

Figure 3 and Figure 4 show the data that were collected through manual readings of the existing gas meters in the Community Event Center (building 50012). These meters were read each week over a series of months, and then were regressed against the average weekly temperature as shown in Figure 4. 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.

<u>Diversity factor models for whole-building electric demand (kW).</u> In Figure 5 and Figure 6 data are shown from a portable logger that recorded the hourly electricity use from the Watt-hour meter installed in the 87000 block Headquarters building (building 87009) for a short period. These data represent 7 months of hourly data that were used to develop the diversity factors models using ASHRAE's Diversity Factor Toolkit, developed as part of Research Project 1093- RP (Abushakra et al. 2001). The 24-hour profiles from the diversity factor analysis are to be used to assess the demand savings

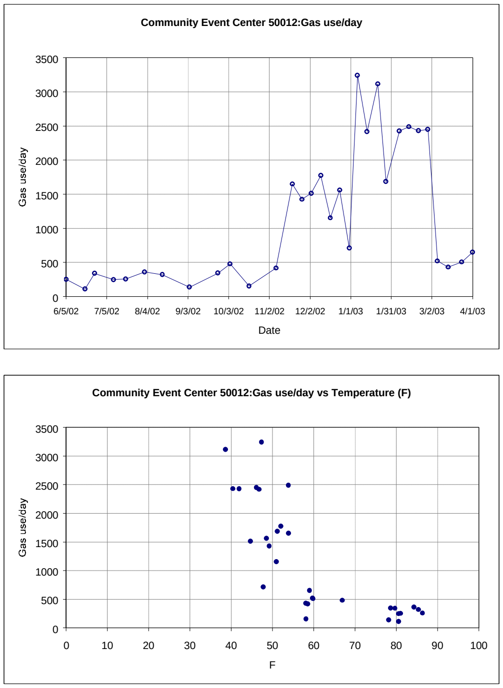

Figure 3: *Natural Gas Use for Building 50012 From Manual Weekly Readings.*

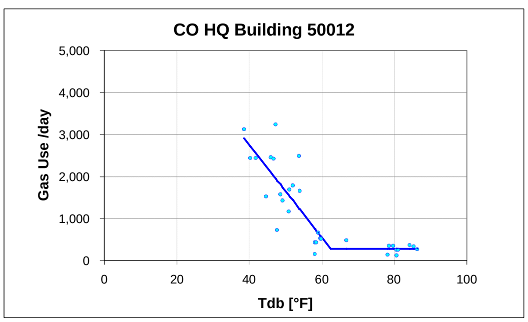

Figure 4: *Weather-dependent Model for Building 50012 From Manual Readings.*

in weather-independent buildings. Diversity factor models were developed for those buildings where significant electric demand savings were expected.

Chiller performance models. To model the boilers and chillers in the 87000 block thermal plant, special purpose models needed to be developed. As a first step, for the chillers, data were first separated into performance data for periods when each chiller was running separately, as shown in Figure 7. This was accomplished by sorting the hourly chilled water production data into groups that corresponded to the electricity use for each chiller, which included periods when both chillers were running, when

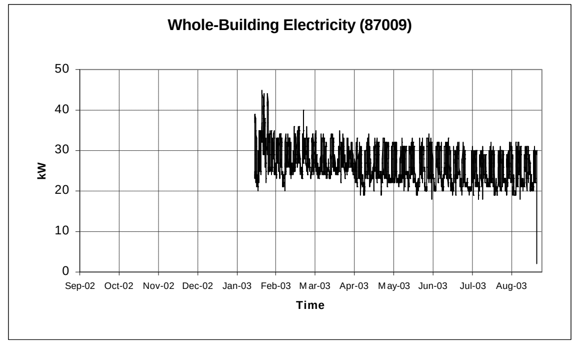

Figure 5: *Building #87009 Electricity Usage From Portable Watt-hour Meter.*

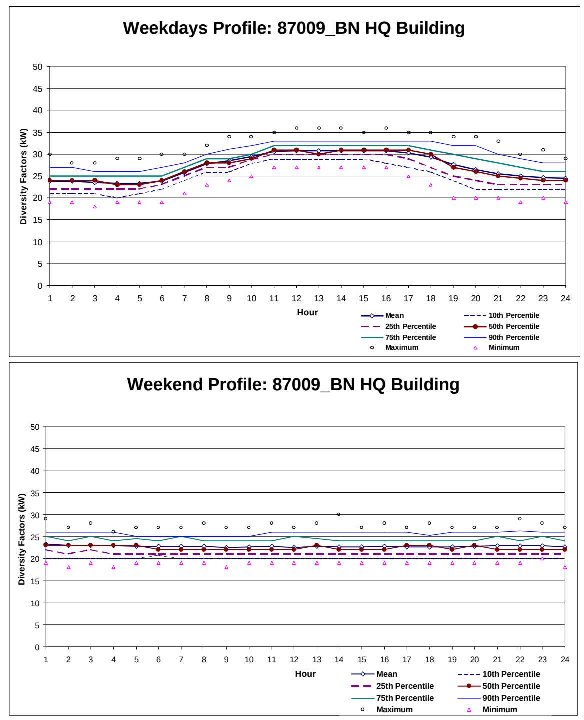

Figure 6: *1093-RP Diversity Factor Analysis for 87009 Building.*

chiller #1 was running and when chiller #2 was running. Next, for periods when one chiller was running, tri-quadratic models were used to model the performance of the chillers (Haberl et al. 1997, LBNL, 1980, 1981, 1982, 1989), which have the following format:

Quadratic: kW/ton = a + b x Tons + c x Tcond + d x Tevap + e x Tons^2 + f x Tcond^2 + g x Tevap^2 + h x Tons x Tcond + I x Tevap x Tons + j x Tcond x Tevap + k x Tons x Tcond x Tevap.

Equation 6

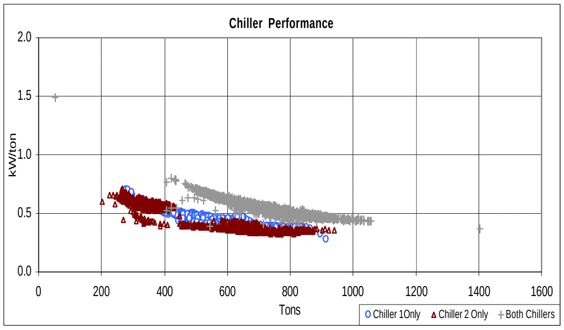

***Figure 7**: Chiller Performance Data From 87000 Block Thermal Plant.*

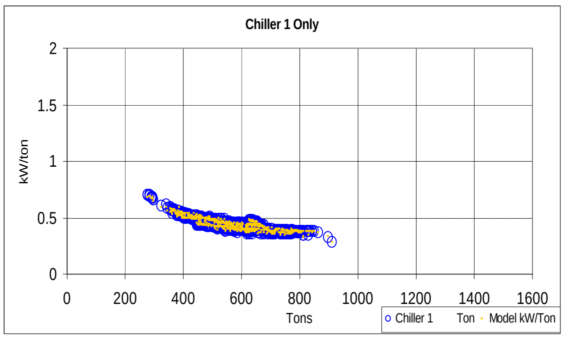

***Figure 8:** Tri-quadratic Model for Chiller 1 in 87000 Block Thermal Plant.*

An example of the tri-quadratic model is shown in Figure 8. These non-linear models normalized the chiller performance for the load on the chiller (tons), evaporator temperature supply temperature, and condenser temperature return. Similar performance models were developed for the boilers.

Model uncertainty. An important aspect of the baseline modeling was the accuracy or uncertainty of the baseline models. Since the baseline models are statistical models, there is always some degree of statistical uncertainty associated with the model's ability to represent the data upon which it was regressed. In the case that the uncertainty of the model is greater than the estimated energy savings, then the usefulness of the model to calculate energy savings comes into question. On the other hand, if the uncertainty of the model is quite low, when compared to the estimated savings, then the model can be considered a reliable predictor of savings.

These uncertainties in Table 4 were calculated using the formulas defined by Kissock et al. (1998)[5] as shown in the following equations:

$$Error_{savings} = (Error_{pred}^{2} + Error_{meas}^{2})^{1/2} \quad \text{Equation 3}$$

$$Error_{pred} = 1.96 \times RMSE_{pre} \times (1 + 2/N_{pre})^{1/2} \times (N_{post})^{1/2} \quad \text{Equation 4}$$

$$Error_{meas} = Measured \times Measured_{error} \quad \text{Equation 5}$$

Where

$Error_{pred}$ = prediction error for the pre-retrofit regression model,
$Error_{meas}$ = prediction error for the post-retrofit measured data,
Measured = Measured data for the post-retrofit period,
$Measured_{error}$ = 2%, recommended by Kissock et al. (1998).

These uncertainties were used to determine whether or not the baseline model is suitable for calculating savings. In cases where the uncertainty is greater than the expected savings, then the savings are to be calculated using the ESPC contractor's estimates. These formulas are calculated with the goodness-of-fit indicators available with ASHRAE's IMT.

SUMMARY

Fort Hood has selected an Energy Services Performance Contract 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 56 buildings, and includes boiler insulation, control system upgrades, vending machine controls, cooling tower variable frequency drives (VFDs), and lighting retrofits. This paper has presented the development the Measurement and Verification (M&V) Plan for the Fort Hood Energy Services Performance Contract, and includes results of the baseline calculations.

In the Spring of 2004, the ESPC contractor will begin implementing the performance contract, with savings expected to follow shortly thereafter. An independent evaluation of the ESPC contract at Ft. Hood is expected to be completed one year after the completion of the retrofits. This evaluation will utilize the baseline modeling presented in this paper, which represents one of the first efforts to actually independently measure energy savings from an ESPC contract using measured data and procedures that are

[5] Kissock, K., Reddy, A., and Claridge, D. 1998. "Ambient Temperature Regression Analysis for Estimating Retrofit Savings in Commercial Buildings", Journal of Solar Energy Engineering, ASME, Vol. 120.

compatible with the USDOE's IPMVP and ASHRAE's Guideline 14.

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REFERENCES

ASHRAE 2002. "Guideline 14: Measurement of Energy and Demand Savings", ASHRAE, Atlanta Georgia.

Haberl, J. S., Reddy, T. A., Figueroa, I., Medina, M. 1997. "Overview of LoanSTAR ` Monitoring and Analysis of In-Situ Chiller Diagnostics Using ASHRAE RP827 Test Method", Proceedings of the PG&E Cool Sense National Integrated Chiller Retrofit Forum (September).

Haberl, J., Baltazar-Cervantes, J-C, Sung, Y-H, Claridge, D., Turner, D. 2002. "Baseline Report for the Fort Hood Army Base: September 1st, 2001 to August 31st, 2002", Energy Systems Laboratory Report No. ESL-TR-02/12-02, (December).

Haberl, J., Claridge, D., Kissock, K. 2003a. "Inverse Model Toolkit (1050RP): Application and Testing, ASHRAE Transactions-Research, Vol. 2 (June).

Haberl, J., Baltazar-Cervantes, J-C, Liu, Z., Claridge, D., Turner, D. 2003b. "Baseline Report for the Fort Hood Army Base: September 1st, 2002 to August 31st, 2003", Energy Systems Laboratory Report No. ESL-TR-03/12-02, (December).

IPMVP 2001 "International Performance Measurement and Verification Protocols - IPMVP", United States Department of Energy.

Kissock, K., Reddy, A., and Claridge, D. 1998. "Ambient Temperature Regression Analysis for Estimating Retrofit Savings in Commercial Buildings", Journal of Solar Energy Engineering, ASME, Vol. 120.

Kissock, K., Haberl, J., Claridge, D. 2003. "Inverse Model Toolkit (1050RP): Numerical Algorithms for Best-Fit Variable-Base Degree-Day and Change-Point Models", ASHRAE Transactions-Research, Vol. 2 (June).

LBL. 1980. DOE-2 User Guide, Ver. 2.1. Lawrence Berkeley Laboratory and Los Alamos National Laboratory, Rpt No. LBL-8689 Rev. 2; DOE-2 User Coordination Office, LBL, Berkeley, CA.

LBL. 1981. DOE-2 Engineers Manual, Ver. 2.1A, Lawrence Berkeley Laboratory and Los Alamos National Laboratory, Rpt No. LBL-11353; DOE-2 User Coordination Office, LBL, Berkeley, CA.

LBL. 1982. DOE-2.1 Reference Manual Rev. 2.1A. Lawrence Berkeley Laboratory and Los Alamos National Laboratory, Rpt No. LBL-8706 Rev. 2; DOE-2 User Coordination Office, LBL, Berkeley, CA.

LBL. 1989. DOE-2 Supplement, Ver 2.1D. Lawrence Berkeley Laboratory, Rpt No. LBL-8706 Rev. 5 Supplement. DOE-2 User Coordination Office, LBL, Berkeley, CA.