DEMAND-SIDE MANAGEMENT IMPLEMENTATION AND VERIFICATION AT FORT DRUM, NEW YORK

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ABSTRACT

Through the Facility Energy Decision Screening (FEDS) process, the U.S. Army Forces Command (FORSCOM) has identified present value savings of nearly $47 million in cost-effective energy conservation measures (ECMs) at Fort Drum, New York. With associated costs of more than $16 million (1992 $), the measures provide a net present value of $30.6 million for all identified projects. By implementing all cost-effective ECMs, Fort Drum can reduce its annual energy use by more than 230,000 MBtu (11% of its fossil energy consumption) and more than 27,000 MWh (32% of its electric energy consumption). The annual cost of energy services will decrease by $2.8 million (20%) at current energy rates.

The servicing utility (Niagara Mohawk Power Corporation) has informally agreed to finance and implement cost-effective ECMs and to participate in the verification of energy savings. Verification baselining is under way; implementation of retrofit projects is expected to begin in late 1994.

The utility-administered financing and contracting arrangements and the alternative federal programs for implementing the projects are described. The verification protocols and sampling plans for audit, indirect, and direct measurement levels of verification and the responsibilities of Fort Drum, the utility, the energy service companies (ESCOs), and Pacific Northwest Laboratory (PNL) in the verification process are also presented. A preliminary weather-normalized model of baseline energy consumption has been developed based on a full year's metered data.

INTRODUCTION

Fort Drum is a 107,000-acre U.S. Army base situated 60 miles north of Syracuse, New York, at 44°N and 76°W. The Fort has 6.4 million ft^2 of commercial floor space plus 4.2 million ft^2 of on-post and 2.9 million ft^2 of off-post family housing floor area. Life-cycle-cost-effective conservation, fuel-switching, and peak-shaving measures with a net present value of $30.6 million have been identified [1-3]. An implementation plan addressing construction phasing, budget and finance, contracting, and administration has been developed. A verification plan has also been developed to determine, as accurately as practicable, the energy and dollar savings realized by the implementation.

The Facility Energy Decision Screening (FEDS) process is a method of energy resource identification, quantification, and prioritization used at Fort Drum and many other federal sites. FEDS applies engineering analysis and available metered and characteristics data to assess cost-effectiveness through appropriate economic parameters [4].

The use of this process at Fort Drum began in September 1991 with a preliminary assessment of total site energy use and broad estimates of energy savings potential. A more detailed, complete baseline of all energy use at the site [2] was completed in June 1992. This analysis provided a previously unavailable complete allocation of all energy supplied to buildings and processes throughout the site. In December 1992, the assessment of specific energy resource opportunities [3] was completed. This assessment identified the type and magnitude of potential energy retrofit projects and placed them in order of priority for effective use of funding. In March 1993, a plan for implementation of potential energy projects was defined. A verification process for assessing the effectiveness of energy projects was developed in January 1994.

IMPLEMENTATION PLAN

The initial implementation plan sought by Fort Drum was a turnkey program that would be partly or wholly subsidized or financed by the local utility, Niagara Mohawk Power Company (NMPC). This program would use, as a base or starting point, the findings of the comprehensive site energy resource assessment performed in 1991-92 [1-3]. The site assessment project identified energy conservation, peak-shaving, and fuel-switching opportunities and estimated savings. It also estimated the costs associated with each. The assessment then ranked the opportunities and provided economic parameters such as net present value (NPV), levelized energy cost (LEC), and savings-to-investment ratio (SIR) for use in determining effective use of funds.[1]

Figure 1, derived from the integrated resource planning (IRP) results [3], shows LEC values by energy conservation measure (ECM) category. ECM categories are disaggregated beyond end-use category in cases where there is a wide range of LEC within the end-use category. LEC is the figure of merit often used by utilities to rank demand-side management (DSM) measures because the LEC of a project reflects its value with respect to marginal energy purchase or production. The codes used to identify ECM categories are defined in Table 1.

Negotiations with the utility toward a utility-managed program are (as of mid-1994) still in progress and have been for some time. The negotiators are nevertheless confident at this point that a utility DSM contract covering a majority of the projects identified at the Fort will soon be in place. The utility is expected to provide 100% financing of DSM projects; Fort Drum will pay the debt as part of its monthly utility bill. The Fort will not start paying for a given project until it is completed and generating utility bill savings. This scheme allows the Fort to pay for DSM through its normal utility budget process in the near term and to enjoy the savings after the DSM debt has been paid off. The utility will use prequalified energy service companies (ESCOs) to install, replace, or retrofit lights, motors, controls, and other equipment identified in the FEDS process.

Faced with uncertainty about the duration and outcome of utility DSM negotiations, however, a segmented approach to project implementation has evolved as negotiations on the turnkey program progress. This segmented approach includes military and other federal sources of funding. Timing of project requests is critical, however, to seizing specific federal funding opportunities. Three sources of funding were identified: Energy Conservation Investment Program (ECIP), Operations and Maintenance (OMA), and Federal Energy Management Program (FEMP).

ECIP funding is provided for use in implementing energy conservation projects in new facility construction. It is intended for large projects exceeding $300K.

A pilot phase will involve four prototypical buildings on the newer portion of the Fort (New Post): a barracks, dining hall, headquarters building, and motor vehicle shop. This group comprises about 10% of the New Post commercial floor area.

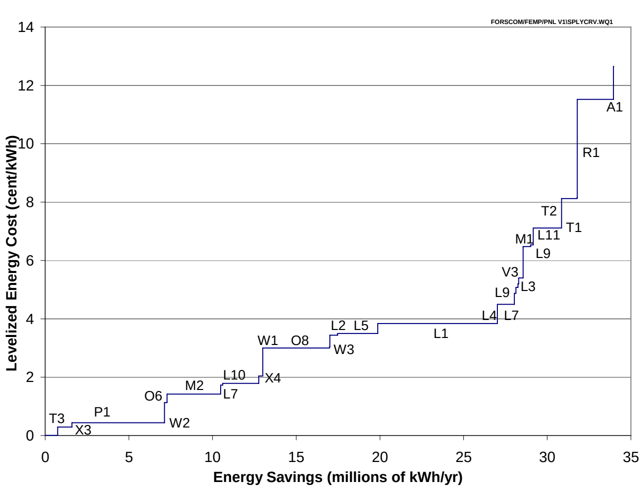

Figure 1. Resource Curve: savings potential of each ECM category ranked by cost-effectiveness expressed in terms of LEC threshold

TABLE 1. LEC THRESHOLDS AND SAVINGS

ECM Category	LEC	Savings (MWh/yr) Each	Cum.	Code
Conservation Voltage Reduction	0.01	740	740	T3
Combined Delamp and Rezone	0.29	850	1,590	X3
Peak Shaving	0.44	5500	7,090	P1
Down-Sized Lift Pump	0.66	34	7,124	W2
Switch Shop Exterior Bay Light	1.13	158	7,282	O6
Two-Speed Motors	1.42	3200	10,482	M2
Exterior Incandescent to CF	1.73	124	10,606	L7
Incandescent to CF (on-post AFH)	1.79	2160	12,766	L10
Mercury Street Lights to HPS	2.04	227	12,993	X4
Energy-Efficient Lift Pump Motors	2.86	4.2	12,997	W1
Occupancy Sensors	3.00	4000	16,997	O8
Two-Speed Lift Pump Motor	3.05	10.7	17,008	W3
Large Incandescent to HPS	3.44	456	17,464	L2
Interior Incandescent to CF(nonAFH)	3.50	2400	19,864	L5
Upgrade Fluorescents (commercial)	3.84	7160	27,024	L1
Exit Signs to LED	4.50	1010	28,034	L4
AFH Attic Insulation	4.88	98	28,132	E7
Upgrade Fluorescents (on-post AFH)	5.08	120	28,252	L9
Mercury Street Lights to HPS	5.20	33	28,285	L3
CO^2-Based Ventilation Control	5.40	270	28,555	V3
Efficient Motors	6.48	450	29,005	M1
Upgrade Fluorescents (off-post AFH)	6.54	160	29,165	L9
Incandescent to CF (off-post AFH)	7.11	1690	30,855	L11
Efficient Transformers (ROF)	8.12	925	31,780	T1
Power Factor Correction	8.15	20	31,800	T2
Refrigerators	11.5	2160	33,960	R1
Window A/C	12.6	19	33,979	A1

CF=compact fluorescent; ROF=replace on failure; AFH=Army family housing; HPS=high-pressure sodium lamp/fixture; LED=light-emitting diode

OMA funds are provided for operational, maintenance, and related retrofit projects in existing facilities and systems. These funds are generally intended for smaller projects less than $300K.

FEMP funding is the newest of the three sources. Offered through the U.S. Department of Energy (DOE) as a supplement to the OMA program, it can be used for a variety of energy reduction options. The funds can be used for retrofits as well as for design and small energy studies leading to implementation of energy reduction strategies.

Each of the funding source programs is governed under specific criteria for the disbursement of funds. In addition, funds are sometimes available on short notice. All branches of the military must, in effect, compete for these funds. All three of the funding sources rely on SIRs as a primary determinant of where funding should be applied for maximum cost-effective energy savings. To date, three Fort Drum projects have been approved under the 1994 fiscal year budget. These projects involve exterior building and entrance lighting and street lighting. The first is a project to rezone exterior building lighting at a cost of $42.8K, a SIR of 11.5, and a simple payback (PB) of 1.06 years. The second project is an upgrade of exterior entrance lighting at $24.3K, SIR of 4.33, and PB of 2.74 years. The final 1994 project is a change to high-pressure sodium (HPS) exterior lighting at $60.9K, SIR of 3.25, and PB of 3.64 years. Twenty-three projects have been submitted to the funding sources indicated in Table 2 for fiscal year 1995.

TABLE 2. FY 1995 DSM PROJECT PROPOSALS

Program Category	Description	Cost ($K)	SIR	PB[a]
	Commercial Building Projects			
ECIP	Upgrade fluorescent lighting--14,839 fixtures	970.5	2.39	4.75
ECIP	Upgrade fluorescent lighting--15,000 fixtures	981	2.39	4.75
ECIP	Upgrade fluorescent lighting--15,500 fixtures	1013.7	2.39	4.75
ECIP	Upgrade fluorescent lighting--16,000 fixtures	1046.4	2.39	4.75
OMA	Retrofit incandescent exit lights with LEDs	189.1	8.34	1.97
ECIP	Occupancy sensors--large rooms	1556.9	2.39	4.7
ECIP	Occupancy sensors--small offices, dayrooms, bathrooms	333.3	3.57	3.14
FEMP/ Const	HVAC upgrade: setback T-stat, insulate attics	269	3.37	4.85
FEMP/ Const	Expand EMCS--P-173,174, 175 barracks complex	711	3.48	3.43
FEMP/ Const	Selected Lighting projects New & Old Post	246	2.08	6.93
FEMP/ Const	Heat rcvry & EMCS expansion in Wilcox Clinic (building P-36)	24	3.6	2.53
FEMP/ Const	Repair HTHW distribution	298	3.91	4.39
FEMP/ Const	Convert P-10785,10790 from HTHW to gas	38	5.23	3.31
FEMP/ Const	Warehouse lighting	204.9	2.25	5.02
FEMP/ Const	Replace interior lighting with hardwired fluorescent	1102	2.53	4.5
FEMP/ Design	Insulate & Rehab--Bldg P84, heavy equipment shop	92	TBD	
FEMP/ Design	Insulate attics--16 buildings	80	TBD	
FEMP/ Study	Window & wall insulation--P-173,174,175 brks complex	1713	TBD	
FEMP/ Study	Convert 8000 Area housing from electric heat to gas	1820	TBD	
	On-Post Family Housing Projects			
OMA	T-8 lighting--compact fluorescents	218.3	3.57	3.14
OMA	T-8 lighting—compact fluorescents	218.3	3.57	3.14
OMA	T-8 lighting—compact fluorescents	218.3	3.57	3.14
OMA	Increase attic insulation--8000 Area (electric heated) housing	62.3	2.4	5.61

[a] Simple payback used here as required by ECIP

VERIFICATION PLAN

Verification helps to satisfy a number of utility, regulatory, Department of Defense (DoD), and site concerns and requirements about the DSM implementation. These concerns reflect the technical (design and operations and maintenance [O&M]) policies and nontechnical (financial and administrative) climates under which customers' DSM plans are developed and implemented.

The concerns of the participants under the Fort Drum implementation plan can be summarized in the following statements. The utility wants to be sure that the customer realizes sufficient savings to pay off the loan and to satisfy the cognizant regulatory agency that the customer--in this case, the largest commercial customer to elect the recently approved DSM subscription option[2]--is making near-optimal use of scarce capital, energy, material, and labor resources. The customer wants to know that the measures paid for have been installed and properly commissioned, that predicted savings are being realized, and that savings are documented so that morale, welfare, and recreation (MWR)[3] and energy programs will receive (after the DSM loan is paid off) the savings retention shares to which they are entitled [5]. The U.S. Army Corps of Engineers has an interest in verification methodologies that can be applied to energy performance as well as conventional energy project contracts. FORSCOM wants to know that the realized savings are reasonably close to the predicted savings and wants to demonstrate the Fort Drum verification procedures and transfer the procedures to other sites. By pooling the verification resources of the participants and making efficient use of their capabilities, it should be possible to meet all of these objectives cost-effectively.

Verification Method

The FEDS process of improving energy efficiency in the federal sector is very different from the standard DSM approach. The characteristics of federal facilities also differ from the characteristics of typical communities with active DSM program participation. Compared to a private-sector community, the stock of military buildings of a given type tends to be homogeneous, the number of types at a given site is manageable, the variety of end-use technologies is limited, the community boundaries are well defined, and population and operations usually follow regular patterns and are well defined, even when unusual operations occur. In the case of Fort Drum, the implementation will be relatively short in duration, large in scale, and highly controlled and trackable. Consequently, the appropriate mix of data collection and analysis activities for impact assessment is different and the confidence with which predicted savings potential and realized savings can be estimated is expected to be relatively high.

For large sites, relatively small samples of one-time unit load and operating hours measurements will suffice to validate or correct assumptions that had to be made in the assessment process about operating hours and load factors of aggregate loads. In addition, long-term end-use measurements in small samples of the dominant building types will suffice to validate or correct the time-of-use and load diversity assumptions. Finally, a community energy model driven by weather, population, and active floor area time-series data will provide accurate weather-, population-, and building stock-normalized estimates of energy use before and after the implementation. Because the model uses data (total gas, thermal and electric energy, weather, and population and building activity) already being monitored, it provides a low-cost (albeit end-use-blind) way to detect savings. The model will provide estimates, in future years, of the energy that would have been used had no DSM program been undertaken; it will also predict the effects of changes in population or operations.

Utilities are often required by regulators to evaluate the energy impacts of their private-sector DSM programs through a process called *impact evaluation*. To distinguish the data collection and analysis activities proposed for Fort Drum from the mix of impact evaluation activities in which utilities have traditionally engaged, we use the term *energy savings verification* instead of *impact evaluation*. One significant difference between these activities is that verification addresses only the effects of changes in unit loads, their controls, and their interactions; impact evaluation is a broader activity that has to address a variety of potential sources of uncertainty and statistical bias. The likely federal site impact of occupant behaviors and other sources of uncertainty and bias considered important in private-sector DSM programs and impact evaluations are assessed in the Appendix.

After considering the unique aspects of the FEDS approach and characteristics of typical FEDS sites, it became clear that the best approach to verification of a large, basewide DSM implementation would be a multilevel approach. This approach combines four basic complementary methods of estimating savings:

- engineering estimate (facility/process audit)
- indirect end-use measurement
- direct end-use measurement
- total energy measurement.

Any one of these methods will give a savings estimate; any of the first three will estimate savings by end use. However, a properly coordinated mix of data will result in more robust estimates and lower verification costs.

The first method is usually applied to 100% of the individual (e.g., light fixture or motor) end-use loads. The second and third methods are usually applied to a sample of the population. The fourth method inherently covers all loads. While direct end-use measurement is generally considered the most accurate approach, it is not perfectly accurate, even if applied to 100% of end-use loads, because occupant behavior, weather, and interaction with other fuels will affect the difference between before and after energy use. The essential principles and some of the possible variations are outlined below for each method.

<u>Engineering Estimate</u>. The engineering estimate (or audit) can be applied to all loads that operate at constant power. This includes such end uses as lighting and single-speed fans or pumps. Annual energy use is taken to be the product of operating power and annual operating hours. Hours (or full-load-equivalent hours) of operation before and after implementation are estimated, and full-load power is measured (or taken from nameplate ratings) before and after implementation. Variations that reduce cost are possible in some cases. For example, full-load power can be measured on a dedicated light circuit at the switch or breaker panel, provided that all fixtures are functioning. Some measures require additional assumptions or analysis. For example, the annual operating hours of two-speed motors must be estimated at both high and low speed.

This approach is identical to that used in PNL's energy resource assessment [3] except that the reliability of savings estimates should be better[4] as a result of knowing exactly the number and model of each fixture or piece of equipment involved in each building type. However, we do not expect much improvement in the hours of operation estimates obtained in a re-audit.

The engineering estimate approach has low incremental cost and is generally applied to 100% of the individual loads involved in a project as part of the construction[5] and acceptance activities.

<u>Indirect end-use measurement</u>. Low-cost monitoring techniques can be used to measure operating hours. The product of measured operating hours and measured or nameplate load provides an indirect measurement of annual energy use. For DSM measures that reduce load but have no effect on operating hours, it is not necessary to monitor operating hours both before and after implementation--a distinct advantage. The measured hours of operation for a given indirect measurement sample can be applied to the entire population.

<u>Direct end-use measurement</u>. Direct measurement is important when the constant load assumption is a concern. The per-load cost is much higher than for the indirect measurement approach because a kilowatthour meter must be installed in each dedicated circuit to measure the loads before and after the retrofit. Direct measurement can be applied to a subset of the loads to which indirect measurement is applied to obtain a correction factor for the indirect measurement sample. This is especially useful for variable loads, such as variable lighting controls (used in conjunction with daylighting) and variable speed drives (for fans, pumps, and compressors), for which the engineering estimate and indirect end-use measurement approaches are not well suited. It is important to have at least a small sample of end-use metered loads, even if they are nominally constant loads, to confirm the one-time power measurements.

<u>Total energy measurement</u>. The total energy approach costs little but has generally not been used by utilities because of signal-to-noise ratio (SNR)[6] problems. The SNR for civilian communities is high because DSM implementation is slower-paced, penetration rates are generally lower, and occupancy and building stock effects are not as accurately trackable. The SNR for individual buildings is high because there is insufficient diversity to mask noise. Large-scale application of DSM on a military base will result in better SNRs because the signal is large and the effects of occupancy, building stock, and weather can be accurately tracked.

Verification Pilot Plan

Fort Drum will use a combination of all four measurement methods. Sparse sample plans will be used at the direct end-use measurement level because use of the (low-cost) audit and indirect metering methods will provide fixture counts for applying direct end-use data to over 50% of the commercial floor space.

Each end use requires different verification data. The data applicable to each end use involved in the pilot phase of the Fort Drum implementation are presented below. End-use sampling rates will be assessed, based on statistical and cost-effectiveness tests applied to the pilot phase data, and appropriately revised sampling rates applied to subsequent phases of the implementation. (However, most of the pilot phase automatic

metering equipment will be left active regardless because the cost per unit data from existing autonomous loggers is low.)
Lighting data collection procedures include the following:

· (100%) audit - Record bulb, ballast, and fixture type, quantity, and application by building (real property facility number); record and certify replacement/retrofit for each existing fixture. Record hours of use reported by building monitor. Also break out fixture type inventory by circuit and wall switch in the subset of buildings where indirect measurement is performed (2% to 5% of light fixtures). A sample lighting retrofit certification report (electronic form) is presented in Figure 2.

· (2% to 5%) indirect measurement - Use lighting loggers and before/after power measurement at switch to determine savings in one (or more) each of prototypical buildings and other buildings selected at random. (Note that indirect measurement will not be applied in all rooms; instead, a set of prototypical rooms will be selected in each prototypical building.) The resulting experimental design is expected to involve 2% to 5% of all light fixtures in the project. A sample lighting load and time-of-use report is presented in Figure 3.

· (0.2 to 0.5%) direct measurement - Install end-use power loggers in subset of prototypical buildings that are subjected to indirect measurement. Where feasible, pick up circuits that do not have lighting loggers as well as those that do, but keep separate. Also pick up other end uses.

Street lighting verification data procedures include

· (100%) audit - Record bulb, ballast, and fixture type and quantity by circuit. (Also document street name and pole number or other description that uniquely defines location.) Record and certify replacement/retrofit for each existing fixture. Record time-clock parameters for each circuit controlled by a time clock.

· (2%) indirect measurement - Make one-time power factor measurement before and after the retrofit. Use current transformers (CTs) and pocket loggers to record ampere-hours on selected circuits. Stratify sample by ECM (technology upgrade, delamp, reduced hours) according to expected energy savings.

Motor verification data will be collected as follows:

· (100%) audit - Record motor nameplate data, quantity, and application by building real property facility number); record and certify new motor data for each existing motor that is replaced. Make one-time power and power factor measurement for each 2-hp or larger motor targeted for replacement by a two-speed motor and of each 5-hp or larger motor targeted for replacement by an energy-efficient motor. This measurement will support motor downsizing, which is expected to result in significant additional energy savings not addressed in the high-level resource assessment project [3]. Record hours of use reported by building monitor, heating shop, or energy engineer designee. Also break out motor inventory by circuit for the buildings where direct measurement is to be performed (0.5% of all motors in the project). A sample motor retrofit certification report is presented in Figure 4.

· (5%) indirect measurement - Install run-time meters (note that two-speed motor requires two run-time meters) to determine savings in one (or more) of each prototypical building and other buildings selected by stratified sampling plan. Use same buildings that have lighting loggers to the maximum practical extent. A sample motor run-time and load measurement report is presented in Figure 5.

· (0.5%) direct measurement - Monitor motor circuits using the end-use power loggers installed in the direct measurement task for lighting. Where feasible, pick up circuits that do not have run-time meters as well as those that do, but keep separate.

Power factor correction will be verified as follows:

· (100%) direct measurement - It is cost-effective to measure the power factor correction effect directly at the New Post substation because it is just a matter of adding three CTs to existing end-use power logger channels. One-time measurements will be made at the substation situated in the older section (Old Post) of the Fort; this, together with continued monitoring of total power and reactive power at Substation 1, is equivalent to continuous direct measurement.

Total energy verification data involves long-term monitoring at the building service entrance, at the feeder or feeder tap (housing area or building complex) levels, and at the site service entrance.

The total energy data collection plan is outlined below.

· building meters - Pulse recorders may be installed in some of the ~180 existing meters to provide pre- and post-implementation measurements of energy consumption by building and housing area. The purpose of these measurements is to provide a model-based estimate of savings in buildings that have no direct or indirect-measurement-based verification activity. One-day time resolution is needed. An extra pulse channel and a register-pulse adapter are needed for each housing area and for each building (e.g., dining hall) that has natural gas service and an existing gas meter.

· site meters - The existing feeder metering and weather station equipment [2] have been upgraded to record global radiation from below as well as from above (to estimate albedo effects) and aspirated air temperature and wind speed at 10 m above grade. The data from this metering activity, along with time-series data from the Fort Drum property management and manpower management offices, are being used to model daily electrical, thermal loop, and natural gas energy use. Measurement of energy use from all fuels is necessary to model the interactive effects of electric conservation measures on consumption of other fuels as well as the other-fuel ECM impacts.

· thermal loop - Pulse recording channels have been installed to monitor the three existing PNL Btu meters at Barracks P10522. Fort Drum is installing remote telemetry units to record thermal loop heat rates at the central heating plant. Recorders at the commissary and retail store (PX)[7] Btu meters are planned because these are significant nonprototypical buildings that will not be subjected to end-use metering.

· natural gas - The utility installed a dedicated communications line in March 1993 to record daily New Post gas meter totals.

Reconciliation of Savings Estimates

The indirect and direct measurement activities will give percentage savings distributions for each building type, end use, and, in some cases, end-use technology. The direct and indirect sample distributions can be compared to see if they represent the same parent population. If they compare favorably, the direct and indirect measurement results can be used to correct the hours-of-operation estimates which, in combination with audit and one-time measured load data, provide a corrected engineering estimate of total annual energy savings. The corrected engineering estimate can then be statistically compared to the savings estimate based on total energy measurement. If these estimates are not statistically comparable, further comparisons will be made using energy models for individual feeders or individual buildings. In this way, it may be possible to isolate and explain sources of error such as model inadequacy or sampling error.

Verification Work Assignments

An effort is being made to fund the verification tasks in such a way that utility, ESCO, consultant, and Fort Drum in-house skills and resources are used most cost-effectively. The distribution of tasks believed to best serve this objective is outlined below.

The audit tasks will be performed by the ESCO because the ESCO can perform audits at low cost as part of developing a bill-of-materials for each project. PNL has prepared audit formats for approval by the utility and the Fort. Audit quality checks (QC)[8] will be provided by Fort Drum.

Indirect measurement tasks will be performed by the ESCO, utility, or other utility contractor. PNL will provide audit formats. Sample selection will involve collaboration of PNL, the utility, and the Fort. Fort Drum will provide QC with PNL support.[9]

Most of the direct end-use measurement tasks are being performed by PNL. Additional direct measurement may be performed by the ESCO, utility, or other utility contractor. PNL is providing monitoring protocols[10] and data formats. Sample selection will be reviewed by PNL, the utility, and the Fort.

Total energy measurement at the feeder level will be performed by PNL. Fort Drum will perform thermal loop monitoring. Installation of, and downloading from, whole-building pulse recorders will be performed by the Fort or the utility.

Fort Drum will provide QC of unit load audits. Fort Drum will also maintain site-owned metering equipment and will continue to collect meter, building deactivation, family housing vacancy, and similar population, operations, and building inventory data.

BASELINE MODELING

Daily sitewide energy consumption is currently monitored for electric, gas, and high-temperature hot water (HTHW) service. (Fuel oil and coal use are recorded by delivery only.) Daily total radiation, air temperature, sol-air temperature, and wind speed are record`ed continuously. Building activation and deactivation are recorded to the nearest day. Site population and occupancy by building are monitored with monthly resolution. These data make daytype- and weather-normalized empirical modeling feasible. Preliminary results from natural gas use modeling are discussed below. Occupancy-normalization terms will be added to the models as data become available.

Daily Gas Use Model

Daytype and temperature dependence of gas consumption are illustrated in Figure 6. The daytype effect may be insignificant (formal statistical tests will be applied later in the modeling effort). The temperature effect follows the classic mode of decreasing heating load with increasing outdoor temperature, followed by a transition to a constant "warm-day" gas consumption rate that corresponds to the site's aggregate gas-fueled cooking, domestic water heating, and other non-seasonal process loads. The temperature effect is quite clear in this simple model; however, some of the apparent scatter can be explained by deterministic effects involving measurable conditions besides temperature. Also, the daily use/temperature relation appears to be nonlinear. This is probably due to one or more of the following three effects: 1) occupants tend to use their window quilts in colder weather; 2) roof and perimeter ground losses go down as snow depth increases; and 3) cycling losses from the heating equipment are reduced.

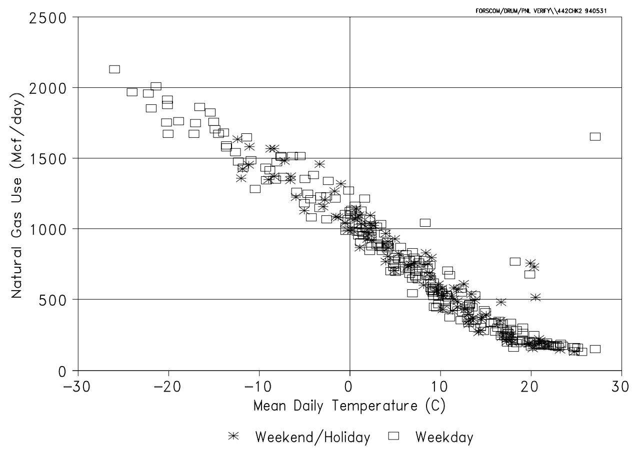

Figure 6. Daily Basewide Gas Use vs Mean Daily Temperature

A second-order linear model involving daily average outdoor temperature (T and T^2) and daily total horizontal solar radiation (S) was fit to the data for all days with T < 15°C. The model residuals, shown in Figure 7, have seasonal and distributed lag components. Time-series modeling eliminates most of the residual error as shown in Figure 8.

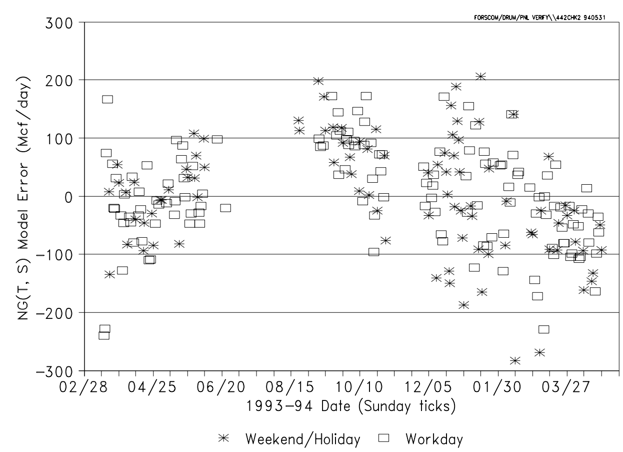

Figure 7. Residuals (measured-predicted) of Daily Gas Use Model based on Mean Daily Temperature and Solar Radiation

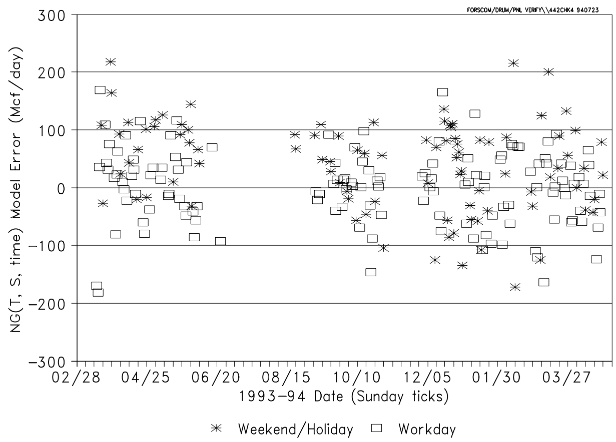

Figure 8. Residuals (measured-predicted) of Daily Gas Use Time-Series Model

Monthly and Annual Gas Use

The ultimate goal of sitewide energy baselining is to model monthly and annual energy use before and after the implementation of DSM measures. One way to obtain the monthly and annual estimates is to accumulate the output of the daily energy model over time. This process has benefits beyond its simplicity and straightforward physical interpretation.

Figure 9 shows the effect of time aggregation. The weekly and monthly gas consumption estimate errors are expressed as daily rates (million cubic feet/day) to facilitate comparison with Figure 8. The weekly model estimates of gas consumption are seen to deviate from measured gas consumption much less than the daily estimates, and the monthly model estimates are seen to deviate even less. This is fortuitous because it is generally the *annual* occupancy-, weather-, and building stock-normalized energy use that is of interest to the participants. Use of a daily model provides, in effect, a large sample size. The deviation (from the true value) of the mean of n = 365 daily savings numbers will be, on the average, about one-twentieth of the deviation of a single daily savings number. The variances shown in Figure 9 bear out the theoretical expectation that mean-squared deviation is proportional to 1/n.

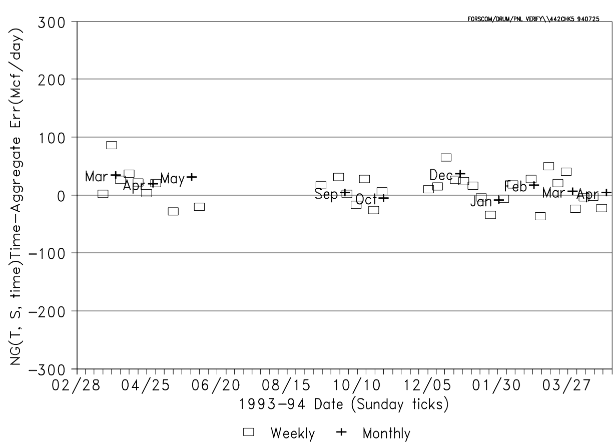

Figure 9. Weekly and Monthly Residuals of the Daily Gas Use Time-Series Model

The one-day time step is short enough to 1) account for daytype/occupancy effects; 2) account for the nonlinear relation between energy and weather conditions; and 3) provide a large sample (i.e., 365 days per year). The one-day time step, on the other hand, is long enough to 1) avoid the need to model most high-order dynamics (i.e., thermal storage effects in the building envelope) and 2) yield a dataset that is not so large as to be unmanageable.

The natural gas daily energy model is being extended to cover the T > 15°C range and to account for population and active building floor area changes over time. Daily models of electric and high-temperature hot water energy use will also be developed.

CONCLUSION

The FEDS approach to identifying and procuring energy efficiency at large federal installations is being applied at Fort Drum. The FEDS assessment, an IRP process that identifies all cost-effective efficiency, conservation, and fuel-switching measures at a site, has been completed with the identification of DSM investments of $16 million. The implementation and verification phases are currently under way.

A segmented, multiprogram-based implementation plan has evolved at Fort Drum. It is based on the competition for funds allocated by various military and federal agencies and does not constitute a unified course of action to implement all cost-effective measures.

A multilevel measurement- and empirical-model-based savings verification program has commenced. This verification plan will be used to estimate DSM savings and persistence at Fort Drum. Preliminary modeling of natural gas use indicates that annual natural gas use can be estimated from weather data with a root mean square error of better than 1%.

ENDNOTES

1. Life-cycle cost (LCC) is the total cost to own and operate a building (or facility or subsystem) including the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value. LCC is usually expressed as a present value and evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV() denotes "present value of"
IC is the installed cost
EC is the annual energy cost
OM is the annual nonenergy O&M cost
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0)-PV(EC_1)) + PV(OM_0)-PV(OM_1)) + PV(REP_0)-PV(REP_1)) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where PV() denotes "present value of"
subscript 0 denotes the existing or baseline condition
subscript 1 denotes the energy cost saving measure
IC is the installation cost of the alternative
(note that the IC of the baseline is assumed zero)
ECS is the annual energy cost savings
OMS is the annual nonenergy O&M savings
REPS is the future replacement savings.

Levelized energy cost (LEC) is the effective or blended energy price at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr).

Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC)$$

2. In the case of Fort Drum's servicing electric utility, NMPC, a DSM subscriber is defined as a commercial customer who has elected to forego standard NMPC DSM program benefits. Subscribers are served under a modified rate that eliminates the DRAM charge (~$0.002/kWh); the utility may still be involved in DSM implementation but implementation cost is borne directly by the customer.

3. As motivation to implement energy efficiency, one-third of savings is retained by the site for additional energy programs and one-third is retained for morale, welfare, and recreation (MWR) programs.

4. It is possible for the new estimate to be less accurate, even though the new fixture count data are more accurate, if the old fixture count errors and hours of operation errors are large but opposite in sign in such a way that they largely cancel.

5. The ESCO is expected to inventory existing lights and motors in order to 1) determine which unit loads can be cost-effectively replaced or modified and 2) minimize disruption at a given building by directing the correct quantities and models of parts and fixtures to said building very close to the construction start day. Having the ESCO gather additional information to document room, circuit, and switch locations of the unit loads in a mutually agreeable format will add very little to the project cost.

6. In this context, the change in average load resulting from DSM implementation is the signal of interest and the change due to all other effects is the noise.

7. The commissary and PX must be monitored because the interactions of DSM savings with heating energy will differ from the interactions in barracks or other prototypical buildings.

8. Cost-effective QC can be provided by Fort Drum personnel replicating the ESCO's measurement activity on a few percent of the full audit sample. The required subsample size will vary depending on sample variance and will therefore be initially set to a high value and later reduced as better estimates of variance become available. However, if staffing resources for in-house QC are not available, third-party QC *must* be provided for in the turnkey contract with NMPC.

9. The ESCO will provide a schedule of run-time meter and lighting logger installations by location. Fort Drum contract office or DEH personnel will check a subsample of the installations and log the operating hours readings near the start and end of the monitoring period.

10. Quality assurance (QA) features are built in to the direct measurement and total energy monitoring protocols. Two forms of QA are being used: redundant measurement and energy balance reconciliation.

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APPENDIX - Sources of Uncertainty and Bias

The sitewide integrated resource planning (IRP) approach has been rapidly adopted as the approach of choice by DoD and a number of other federal agencies because it minimizes lost opportunities and cream skimming while taking maximum advantage of economies of scale in planning and implementation. An unanticipated side benefit of the sitewide IRP approach is that it eliminates many of the difficult problems usually associated with impact evaluation of utility DSM programs.

The amount and cost of data needed to determine the savings achieved with a given confidence in private-sector DSM activity results largely from customer choice and behavior effects. There are over a dozen widely recognized effects [A1]. However, the relative magnitude of most of these effects is small at most federal facilities, as outlined below.

The effect of *aggregation bias* is low due to homogeneity within building types and the relative ease of aggregating within, but not across, building types.

The *appliance saturation* effect is small because the inventory of equipment and appliances in a federal facility is generally well characterized and the distribution of equipment in a given building type is generally uniform.

Although little-used in the federal sector, reliable *control groups* are more easily identified than in the private sector because 1) self-selection bias is not a factor and 2) the people or organizations embodied in the control and noncontrol groups have nothing to gain or lose by the selection.

Cream skimming is minimal because a large fraction of the life-cycle cost-effective measures have already been identified through the FEDS IRP process. The ESCO may be given some leeway in--and appropriate performance-based incentives for--selecting or rejecting measures to be implemented, but only when deviation from the IRP can be justified on a life-cycle cost basis.

Little is currently known about *demand diversity factors* in the federal sector. The mix of existing technologies and end uses, the behavior of occupants, the mix of DSM measures, and so on are all characteristics that affect demand diversity factors--and are characteristics with respect to which the federal and private sectors differ. Since dynamic diversity has a real economic effect and since the demand diversity effects of conservation, control, and efficiency measures interact strongly with peak-shaving measures, it is important to monitor all peak-shaving equipment in the course of post-retrofit end-use and total energy monitoring.

Evaluation ethics effects are low because the verification roles have been defined in a way that eliminates conflicts of interest for the roles where verification results are susceptible to analyst bias.

Free driver and *free rider* phenomena affect only programs that involve many customers, each of whom can choose a level of program participation and a level of nonprogram conservation actions. This is not the case at federal sites where the FEDS approach is implemented.

The difference between *gross change* and *gross impact* is smaller at a FEDS site than in the private sector because *all* energy contracts and work orders are considered part of the program. In addition, the impact due to most nonprogram effects (e.g., Central Supply changing to a more efficient lamp or ballast technology) can be better tracked and quantified than in the private sector.

At Fort Drum, *interactive effects* are very low for cooling because of low air-conditioning saturation and moderately low for heating because the buildings are well insulated.

Natural change and *natural conservation* effects are small due to 1) rapid implementation and 2) low building stock turnover.

Persistence effects may be large relative to private-sector persistence effects because there is currently no motivation or feedback about energy use at the building or O&M level at most federal sites. To track persistence at Fort Drum, the direct end-use and total energy monitoring equipment will be left in place and active, and annual or biannual savings analysis will be performed.

The bias error resulting from use of *prototype models* is nil because the Fort Drum plan relies on measurement and empirical modeling rather than theoretical (engineering) models.

Rebound/snap-back/take-back effects are very low because occupants do not pay the utilities; only a small snap-back effect is expected at the command level because measures have to be paid for at the rate of savings based on engineering estimates that assume these effects are zero and, in the long term, because of Executive Order pressure [A2] and continued tracking. Additional effects may occur, however, if occupants react to a perceived lower level of service.

Response bias is small because response to surveys, where used, will be required, not voluntary.

Sample bias is small because of occupant, operation, and building stock homogeneity.

Sectional variation is small because of occupant, operation, and building stock homogeneity, and accountable--at least across building types.

Self-selection bias effects are nil since participation is not self-determined.

Weather effects can be modelled with relative ease because of homogeneity within building types and HVAC plants. At large sites, an autonomous weather station that measures more weather variables and provides data that are more location-specific and accurate than the data typically available to utility evaluation programs is likely to prove a worthwhile verification investment.

APPENDIX REFERENCES

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