ENERGY USE ANALYSIS FOR THE FEDERAL ENERGY MANAGEMENT PROGRAM

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ABSTRACT

Recent congressional legislation allows federal agencies new authorities to contract for energy savings by sharing the acquired savings with an energy service company. As part of its charter to make the federal government more energy-efficient, the Federal Energy Management Program (FEMP) endeavors to improve the technical basis for such performance-based contracting. Specific tasks include the development of improved energy use baselining methods, refinement of a simplified energy analysis method and support to users, preparation of guidelines and procedures for energy savings initiatives, and publication of a manual to guide identification and analysis of energy conservation measures. This paper describes the current status and planned progress in each of these areas, and how these relate to several planned shared savings projects.

INTRODUCTION

Many federal buildings were constructed with little attention to energy efficiency during an era of low energy prices. Consequently, they generally consume substantially more energy than justified on a life-cycle cost basis in light of current and projected energy prices. Although cost-effective energy conservation measures exist in public buildings, federal agencies are often incapable of shifting multiyear operating funds to capital improvement funds to pay for these measures.

In recognition of this "Catch-22" situation, the U.S. Congress has authorized federal agencies to enter into multi-year contracts with energy service companies (ESCOs) to up-grade efficiency in return for a share of the realized energy savings. These shared savings agreements typically make use of third-party financing to identify, procure, install, and maintain energy conservation measures. The third party then receives a calculated or derived portion of the resultant energy cost savings for a specified period of time.

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A technical challenge is confronted when entering into these agreements to determine the actual level of energy savings resulting from the efficiency improvements. This is complicated by the fact that building energy consumption is known to be a complex function of building microclimate, usage, and operations, as well as by the efficiency of its construction and energy-using systems. These various determinants of building energy use may need to be characterized, to develop an accurate and contractually enforceable estimate of achieved energy savings.

Where the efficiency improvements affect only one end use, say exterior lighting, the resulting energy savings can be determined directly by sub-metering the affected devices or by conducting one-time measurements before and after the efficiency improvement, then calculating savings based upon the hours of equipment use. In most instances, however, there will be significant interactions among energy end uses, climate, and building operations and use, so that a more sophisticated approach is required to accurately determine energy savings resulting from a retrofit.

In the more complex cases, an energy use baseline is developed to establish what the costs of energy for a specific facility would have been if no investment were made to improve its efficiency. By subtracting the actual energy costs following an efficiency improvement from this baseline quantity, the value of the energy savings attributable to the effort is determined. The shared-savings contractor can then be paid an agreed-upon portion of this savings for an agreed-upon period of time. This performance-based approach provides an incentive for the ESCO to ensure that measures are properly specified, installed, and maintained for the duration of the contract, and protects the government from paying for ineffective projects.

BASELINING STRATEGIES

A basic approach to developing and evaluating baselining strategies is to consider of the signal-to-noise ratio, where the signal is the acquired energy savings and the noise is the uncertainty in the baseline projection. If the anticipated energy savings is small relative to the baseline, accuracy of the baseline

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is very important but may not be affordable in light of the magnitude of potential savings. Thus, a preliminary assessment of the baseline signal-to-noise ratio for a specific project should be made before committing substantial resources to the project.

The best baselining method is easy to understand, inexpensive to implement, accurate, sensitive to known determinants, and contractually acceptable. To determine the best baselining methods for specific projects, the U.S. Department of Energy (DOE) is sponsoring research to develop and evaluate various baselining techniques (1). The most promising methods will be demonstrated in several pilot shared savings to stimulate widespread application.

For discussion purposes, three categories of baseline methods are defined: statistical approaches, simulation models, and end-use monitoring. The statistical approaches may make use of utility billing data, local climatological measurements, and some proxy for production levels to develop a regression model. Simulation models attempt to explain the energy flows of a building based upon the laws of thermodynamics and may provide an estimate of potential energy savings. Energy end-use monitoring entails the collection of submetered energy consumption and determinant data to isolate the changes in energy use directly attributable to specific efficiency improvements and may support the development of an empirical model of the building energy flows.

The statistical models can be inexpensive to develop and sufficiently accurate if the signal-to-noise ratio is high. Typically, monthly billing data are regressed against outdoor temperature and a proxy for building use (such as sales, man-hours, or meals served) to explain the variation in the utility bills. With a long billing record and stable operations, the statistical model can be derived with part of the time series record and tested against its ability to predict the balance of the record. Alternatively, various goodness-of-fit statistics can be derived to indicate what percentage of the historical variation is explained by each parameter added to the model, and whether each parameter is statistically significant.

Table 1 indicates the results of a simple statistical analysis of energy consumption for the U.S. Army. Utility meter readings reflecting monthly use of base-wide electricity, central steam plant gas, and other gas were analyzed over a 3-year period. The ratio of the parameter estimates to the standard error indicates the significance of the independent variables to explain variation in the dependent measurements. The predictive power of these models is presently being evaluated for potential application for a base wide shared savings contract.[2]

Another, more complex statistical approach makes use of daily meter readings and indoor and outdoor temperature measurements. Figure 1 depicts daily total electrical consumption for an all-electric office building as a function of indoor-outdoor temperature differences for approximately 300 days. The numbers correspond to the day of the week, with a 1 for Monday and a 7 for Sunday. Two predominant day types emerge, weekdays and weekend/holidays. A curve is then fit to these day types to provide an estimate of energy use as a function of indoor-outdoor temperature difference and daytype. Examination of such curves, and the equations that best represent them, will reveal comparative efficiency for base loads (the minima of the curve) the balance point temperature difference (the horizontal position of the minima), and the performance of the heating and cooling systems (the slope of the curves to the right and left of the balance point, respectively). These depictions can be used to evaluate the effectiveness of efficiency improvements by comparing the placement and shape of the pre- and post-retrofit curves as shown in Figure 2.

The second type of baselining method is to use a thermodynamic simulation model. Various engineering models are available that estimate building loads based upon weather data and building characteristics and simulate the performance of the energy using systems to meet these loads. For use in performance based contracting, the models must be calibrated to metered data to ensure that the model inputs are correct and that the model can properly simulate the types of loads and systems in the building under study. Once calibrated, these models can be used to identify and assess energy conservation opportunities, as well as provide a basis for the energy use baseline. The model is run with the pre-retrofit characteristics and the post-retrofit weather and building use data to estimate the amount of energy the building would have consumed without efficiency improvements.

This approach has several advantages. As mentioned above, the model can be used to identify and assess conservation opportunities by taking into account major end-use interactions. Another advantage is

[2]Darwin, R.F., and R.P. Mazzucchi, "Evaluating and Monitoring Energy Conservation Measures in Multi-Building Clusters with Statistical Models." To be pbulished in: Proceedings Fifth Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates, Houston, Texas, September 13-14, 1988.

Independent Variables and Miscellaneous Statistics	Parameter Estimates[1] for Models with the Following Dependent Variables:		
	Electricity (mwh)	Gas at Central Heating Plant (therms)	Other Gas (therms)
Independent Variables			
Intercept	332.64	20488.66	-9363.75
	(278.23)	(40040.39)	(25920.18)
Time Trend	11.54	-1371.59	-112.45
	(1.29)	(549.89)	(356.84)
Total Hours in Billing Period	1.31	30.18	83.19
	(0.41)	(54.66)	(35.65)
Nighttime Hours in Billing Period	1.33	-212.23	-192.11
	(0.44)	(170.95)	(101.44)
Heating Degree Days[2]	0.15	165.64	191.18
	(0.06)	(19.93)	(14.55)
Cooling Degree Days[3]	1.07		
	(0.13)		
Miscellaneous Statistics			
Number of Observations	36	34	35
Degrees of Freedom	30	31	31
Standard Error of Y Est	75.54	29670.33	19255.47
R-Squared	0.8934	0.8975	0.9468

1 Standard errors in parentheses.
2 Heating degree day bases were derived using the PRISM method and are as follows: for electricity - base 63; for gas at the central heating plant - base 75; for other gas - base 60.
3 The cooling degree day base is 57 and was derived using the PRISM method.

Table 1. Models of energy consumption at Fort Sheridan.

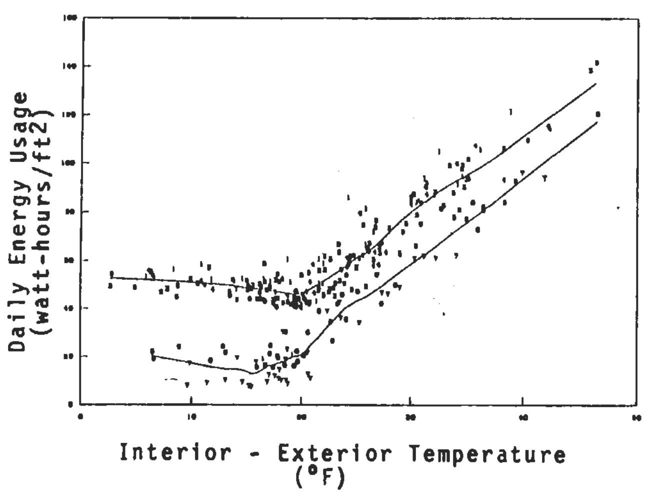

Fig. 1 Total daily energy use for an all-electric office building as a function of average daily indoor-outdoor temperature differences.

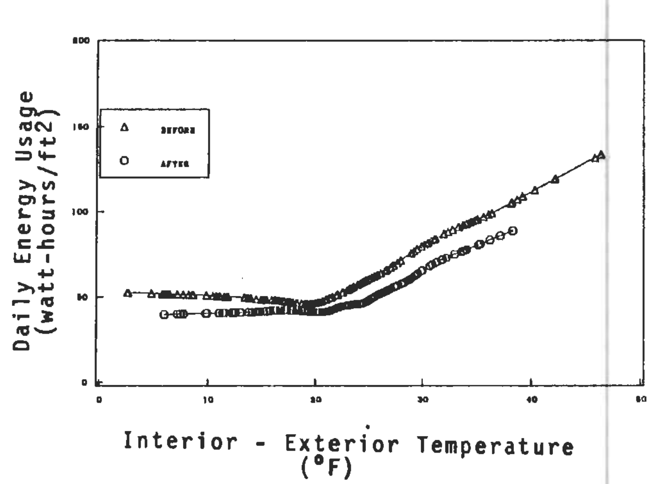

Fig. 2 Comparison of pre- and post-retofit weekday energy use as a function of average daily indoor-outdoor temperature differences.

that both weather and building use changes can be corrected for by altering the inputs accordingly. The principal shortcoming of this approach is that the baseline and conservation estimates are only as good as the inputs and the algorithms in the model, and assessment of these factors can be highly technical. For this reason, FEMP is using submetered energy consumption and determinant data to refine and demonstrate the accuracy of the models.

The third type of baselining method is to collect and analyze submetered energy end-use and determinant data. These data can be used to refine the statistical and simulation methods described above, used directly, or used to initialize an empirical model. Protocols for the collecting metered data and a core set of building characteristics data are currently being developed to guide this approach (2). Typically, energy for heating, ventilation, and air conditioning, lighting, major process loads, and other uses is measured and compared to the building total energy use to ensure data quality. Such data can reveal the amount of energy savings in each of these systems and the interactions that may occur. Use of time-series data recorders can effectively indicate the hourly profiles of energy consumption before and after building retrofit. Using these data, any significant changes in how the building is used and operated can be identified and accounted for in the energy savings calculations.

Recent research has focused on the development of empirical modeling approaches that use these time-series measurements and core characteristics. Dynamic data over a few days from several channels can be based to determine the as-built parameters of a dynamic building load on system model. One method, called equivalent thermal parameters (ETP), models the building as a simple electrical network with resistors for conduction paths, capacitors for mass effects, and nodes indicating the temperatures at various locations (3). Through complex, yet mathematically elegant procedures, the parameters of such a model can be determined and used to develop an equation expressing building energy. A benefit of this approach is that the parameters of the model have physical significance, in that they relate to the various heat flows in the modeled building. By recalculating the parameters of the model after an efficiency improvement, some insight is gained as to the nature of the retrofit and the significance of end-use interactions.

ASEAM MODEL DEVELOPMENT

A Simple Energy Analysis Method (ASEAM) has been developed for DOE using the American Society of Heating, Refrigerating, and Air Conditioning Engineers' bin-temperature calculation method (4). This model is in the public domain, operates on most personal computers, and has many user-friendly features. The entries for the program are menu driven, and once entered, can be automatically varied to conduct parametric sensitivity analyses. Actual run time calculations can be observed, and several graphical depictions of the results of these analyses can be viewed as the program runs.

Run times are dependent on the building complexity and features of the computational environment. On state of the art personal computers with a math co-processor, annual simulations for a five zone building require less than one minute to execute. A batch parametric processor is available to queue up multiple runs for unattended execution. Finally, the output can be tailored for direct entry into popular spreadsheet programs for data analysis and plotting.

The energy simulation model is coupled to the National Bureau of Standards life-cycle costing model to provide savings-to-investment ratios for energy-efficiency improvements (5). These ratios are calculated using the current DOE regional fuel prices and escalation rates as well as user selected discount rates. Thus, tables similar to Table 2 can be developed for a specific type of facility, to indicate the cost-effectiveness of building retrofits according to climate type and prototype configuration.[3]

The FEMP is now funding efforts to evaluate and enhance this model, and is providing training workshops for federal users. An engineer/programmers guide will be developed next year to document the inner workings and technical basis of the code, to assist those wishing to review or refine various features of the public domain code. Other planned enhancements include the development of a hard-disk version with added capabilities, definition of standard defaults for various types of existing buildings, and the development of an ASEAM to DOE-2 model input file generator to facilitate examinations of energy conservation opportunities for which bin-temperature modeling may be inadequate.

GUIDELINES AND PROCEDURES

The FEMP is developing guidelines for project evaluations and procedures for contract execution, to facilitate use of the new contracting authorities for shared savings projects in the federal sector.

[3] Mazzucchi, R.P. et al, Prototype Energy Efficiency Dining Hall Study, Prepared for the U.S. Air Force Engineering & Services Center, Tyndal AFB, Florida, 1988, by Pacific Northwest Laboratory.

Conservation Measure Description	Savings-to-Investment Ratio by Climate Type COLD	COOL	WARM	HOT
10% FOOD PREP CAPACITY REDUCTION	1.4	1.6	2	2.4
10% FOOD PREP DIVERSITY REDUCTION	1.1	1.3	1.6	2.1
LOW TEMPERATURE DISH MACHINE	0.3	0.8	1.6	2.8
WATER COOLED REFRIGERATION CONDENSERS	2.4	2.6	3	3.4
CURTAIN ON WALK-IN REFRIGERATOR DOORS	1.4	1.7	2.2	2.9
MOTION DETECTOR FOR DINING LIGHTS	1.8	3.7	7.6	11.7
HIGH EFFICIENCY FLUORESCENT LIGHTS	2.1	2.5	2.9	3.1
PARBOLIC REFLECTORS FOR LIGHTS	2.8	3.4	3	4.2
ELECTRONIC BALLASTS FOR FLUORESCENT FIXTURES	1.6	2	2.1	2.4
R-11 WALL INSULATION	8	8.2	5.1	5.1
R-11 TO R-19 WALL INSULATION	5.5	4.3	4	3.2
R-19 TO R-30 WALL INSULATION	1.7	3.2	3.5	2.3
R-11 ROOF INSULATION	5.8	5.3	3.6	4.1
R-11 TO R-19 ROOF INSULATION	5.6	4.5	5.6	3.3
R-19 TO R-30 ROOF INSULATION	1.7	1.5	0.8	1.9
R-30 TO R-38 ROOF INSULATION	0.5	0.4	0.4	0.3
R38 TO R-49 ROOF INSULATION	0.8	0.2	0.6	0.5
TINTED WINDOW GLAZING	0.2	0.8	1.2	1.7
DOUBLE PANE WINDOWS	7.1	6.4	3.3	3.3
DOUBLE TO TRIPLE PANE WINDOWS	15	11.5	6.9	20.2
EFFICIENT AIR CONDITIONERS	3.5	5.5	7.9	11.7
ECONOMIZER CYCLE COOLING	11.4	6.8	9.3	8.5
AIR TO AIR HEAT PUMP	11.5	8.2	3	1.6
VARIABLE AIR VOLUME SYSTEM	1.8	2.7	1.9	2
GROUND SOURCE HEAT PUMP	11.9	8.5	3.5	1.6
MAKE-UP AIR EXHAUST HOODS	14.5	10.9	6	1.6
NIGHT SETBACK THERMOSTATS	60.5	44.6	23.8	3.5
HOT WATER HEAT PUMP	9.7	8.5	7.3	6.1

Table 2. Summary of Savings To Investment Ratios for Energy Efficiency Opportunities Applicable to U.S. Air Force Dining Halls

The guidelines provide a roadmap for identifying and designing successful shared savings projects. This starts with an objective analysis of the potential for cost-effective energy savings and consideration of the signal-to-noise ratio of the baseline.

The first step entails the assembly and verification of utility billing records, collection of key facility characteristics, and acquisition of climatological data. From the resulting information, energy use intensities are calculated, and compared with those of similar facilities. These consumption levels can also be compared to the energy budgets established for new building construction as an indication of the technical limit of efficiency improvements. This work will yield a first-order indication of the potential magnitude of energy efficiency improvements.

The next step is to select and test the appropriate baselining methods. The uncertainty of the baseline is compared to the potential energy savings levels to determine the signal-to-noise ratio of the baseline strategy. Various approaches are tested and evaluated to confirm if end-use monitoring will be required and cost-justified. If necessary, end-use measurements are made according to a monitoring protocol.

At this point the viability of the project is reviewed by cognizant parties and potential ESCOs to ensure that a Request for Proposal (RFP) will be responded to and that a legally valid contract can be consummated. The stability of building use and operations over the anticipated term of the contract should be addressed. If major changes are scheduled or likely, a shared savings contract may be inappropriate unless the impacts of such changes on energy usage can be quantified.

After the viability of the potential project has been determined, efforts shift to the development of the RFP and supporting documentation. Further study and development of the energy consumption baseline may be conducted at this point or may be deferred to consider strategies that may be proposed by the ESCOs. One reason for assembling supporting documentation such as building plans, utility billing records, and other technical information is to minimize the inconvenience to facility managers by repeated requests for information from potential bidders.

Typically, a pre-bid conference is convened to describe the project and address any issues raised by the potential bidders before the RFP is released. Review of previously developed RFPs for similar projects may provide a pro-forma for the subject project and significantly reduce project development costs. Criteria are established for evaluating the proposals. These include the firm's technical capabilities, financial resources, key staff, proposed efficiency improvements, and, if applicable, the proposed baselining method.

Once a source is selected, relatively extensive contract negotiations will follow. The method to determine energy savings and payments to the contractor must be agreed upon. Arrangement for access, coordination with onsite maintenance personnel, and familiarization of utility and contracts personnel must be attended to. Provision for unpredictable circumstances, such as loss of tenancy or building damage, during the term of the contract should be considered in the event of such occurrences.

THE ARCHITECT AND ENGINEER'S GUIDE TO ENERGY CONSERVATION

The Architects and Engineers Guide to Energy Conservation in Existing Buildings was prepared for FEMP in 1980 (6). This manual was originally intended to enhance and simplify the work of those architects and engineers whose practice includes analyzing and modifying existing buildings to reduce both fuel consumption and operating costs. In effect, the manual offers a field-tested approach to identifying, analyzing, and recommending action on the full range of opportunities and options available to reduce energy use in most existing buildings. Besides a review of the principles of energy use and conservation, the manual provides a step-by-step methodology for assessing and improving the year-round energy performance of buildings, as well as a series of forms, charts, and nomographs designed to serve as day-to-day tools in the energy professional's toolbox.

Because of the significant advancement in energy conservation technology and analysis methods during the decade, a major update to this publication is nearing completion. A total of 129 generic energy conservation opportunities are described with respect to their operating principle, how to collect data for performance assessment, appropriate analysis methods, and implementation procedures. These measures fall into the following categories: lighting systems, building envelope, distribution systems, HVAC equipment, domestic water heating, and power systems.

A new chapter on building energy analysis methods will be added to help the user identify the most appropriate tools for a specific investigations. The applicability of degree-day, bin-temperature, and hourly simulation for modeling generic conservation opportunities is indicated. Because the bin-temperature simulations are relatively easy to conduct on personal computers, and are considered to be useful to analyze most of the ECOs, the manual is being updated to provide specific guidance with respect to the use the ASEAM 2.1 model. In comparison to the existing manual methods, this model offers the advantages of accounting for ECO interactions and automating the assessment of energy conservation opportunities and associated sensitivity analyses. The model also facilitates automated application of the FEMP approved life-cycle costing methods to determine cost-effectiveness.

SAMPLE PROJECTS

As the FEMP is action-oriented, the tools and manuals described above are useful to the program only insofar as they are applied to actual projects. For this reason, the technology base support components of the program are driven by the needs of current and planned shared energy savings projects in the federal sector. This section briefly describes some of these projects.

The first shared-savings project authorized by the federal government was a lighting retrofit for the U.S. Postal Service. This involves the replacement of the existing fixtures with more efficient luminaries in mail- handling facilities. The savings to the government and proceeds to the contractor were easily calculated because the lights are operated 24 hours per day, the building is not cooled, and heating is provided by fossil fuels. Annual savings per fixture were established based on a side by side monitoring and comparison of an existing and new fixture. The contractor will be paid on an annual cost-savings-per-fixture basis over a specified time period.

A project is currently being negotiated to retrofit daylighting controls to the U.S. Housing and Urban Development offices in Washington, DC. The energy use of this large office building was simulated using ASEAM 2.1 and found to match the historical billing records for electricity remarkably well. Hence, the ASEAM model is being put forward as the baselining method for this building. The model will make use of climate data collected onsite during the contract period to determine what the air-conditioning requirements would have been without the lighting system improvements.

Another project under consideration involves the retrofit of a DOE operated laboratory building. This building contains 56 offices, 56 laboratories, and a high bay area with a 10-ton crane. The retrofits being considered include updating HVAC controls, altering provisions for low-conductivity water, use of variable speed pumps, and cogeneration. The energy use of this building has been submetered since November 1987, and additional 15-minute data has been obtained on building microclimate and interior temperatures. These data are being used to better develop the energy conservation opportunities and provide a benchmark to test various baselining approaches. In light of the magnitude and mission-driven nature of the building process loads, the end-use metering will be continued to provide the baseline performance data for this building. Study of the signal-to-noise ratio of various baselining methods will continue as the energy conservation opportunities are clarified.

A fourth type of project is being considered for an entire military base. The facility has significant energy conservation potential and relatively stable mission requirements, making it a good candidate for a shared-savings initiative. A statistical analysis of the utility supply meter readings against climate data revealed that most of the month-to-month variation in energy use could be explained. However, a general trend of increasing electrical use detected must be better understood before a base-wide baseline can be established. For natural gas consumption the statistical analysis resulted in very good models for the steam plant and the balance of the base. It is hoped that further evaluation will reveal that the potential for cost-effective energy savings is sufficiently great that the noise associated with a base-wide baseline will be small in comparison.

CONCLUSIONS

The FEMP has made significant progress over the past year to develop methods and tools for improving the efficiency of federal facilities. Key issues surrounding the implementation of shared-savings projects in the federal sector have been identified, and action-oriented research has been initiated to demonstrate effective approaches to using this new authority. In light of the complexity of the issues, and the need for data from actual field experience, a multiyear program has been planned to provide tested "turn-key" guidance to federal agencies wishing to initiate such contracts.

Along with this guidance, the FEMP is enhancing tools and reference materials for use by federal agencies and contractors involved in building energy efficiency improvement. The public domain ASEAM 2.1 simulation model is being tested and refined, and classes and user-support services are being provided for federal users. The Architect and Engineers Guide to Energy Conservation in Existing Buildings, is being updated to include new conservation technologies and analysis methods. Finally, specific advice and assistance is being provided to various federal agencies involved with energy savings initiatives to stimulate use of the new contracting authorities and to streamline the process for future applications.

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