USE OF METERING FOR FACILITY AND WHOLE BUILDING ENERGY ANALYSIS BY THE U.S DEPARTMENT OF ENERGY FEDERAL ENERGY MANAGEMENT PROGRAM

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ABSTRACT

This paper details how the U.S. Department of Energy, Federal Energy Management Program (FEMP) is applying metering technology to conduct empirically based analyses of energy use by federal agencies. Continuing developments in sensors, data acquisition systems, microcomputers and monitoring protocols are reducing the costs of metering to the point that it is becoming "too cheap not to meter" energy and the determinants of energy use at federal facilities. This has widespread consequence for FEMP if one accepts the axiom that "one can't manage what one doesn't measure."

Several recently completed and ongoing activities being managed by Pacific Northwest Laboratory[a] for FEMP are highlighted in this paper. This includes the metering of energy end-uses for a research laboratory building to support a shared energy savings contract, analysis of utility billing records, climate, and characteristics data for entire military bases to prioritize energy use testing requirements, and enhancements to simplified energy analysis tools to help federal energy decision-makers identify and evaluate cost-effective energy savings opportunities.

INTRODUCTION

The U.S. Department of Energy (DOE), Federal Energy Management Program (FEMP) mission is to provide leadership to make the federal government more energy efficient. This mission is accomplished through a broad-based program of research and development coordination, information dissemination, and interagency cooperative development ventures. Commercially available technologies, emerging technologies, and experimental technologies are among the options that FEMP encourages other agencies to consider, as appropriate, to help meet energy efficiency goals. Coordination of energy management activities among federal agencies is an important element of FEMP, including the education and training of federal energy decision makers with regard to energy-efficient technologies.

To accomplish this mission and achieve these goals, the FEMP has supported several applied research and development activities at Pacific Northwest Laboratory (PNL), one of the DOE multipurpose research facilities. This paper summarizes significant research efforts and provides sample applications of various tools and methods appropriate for widespread application. These efforts include advanced energy use metering techniques, energy use baselining and forecasting approaches, and energy use simulation and conservation measure evaluation methods.

A focus of FEMP efforts has been to support the development and application of low-cost metering and energy analysis approaches for use in the federal sector. Metering is used to identify and characterize energy end-uses, develop cost-effective energy cost reduction strategies, and evaluate the performance of energy efficiency improvements. Important aspects of this work include the development of guidelines and procedures for the selection and instrumentation of metering points as well as the collection and analysis of the available data.

ENERGY USE METERING FOR FEDERAL FACILITIES

Although most federal facilities use energy in complex and diverse ways, energy is usually metered only for utility billing purposes. These measurements are often much too aggregated to be of direct use for identification and assessment of specific efficiency improvement opportunities. Nonetheless, the careful examination of these data can provide insights to help determine the fuels, facilities, systems, and seasons of greatest significance, and to provide overall indices of comparative energy performance.

One of the most insightful methods of studying utility billing data is to plot the daily average energy use levels for each period versus the average outdoor temperature. Care must be exercised to ensure that the climate data is averaged over the exact billing periods, and that the daily average energy consumptions are calcu-lated accurately. Depictions for steam and chilled water production data from the central plant records of the National Naval Medical Center in Bethesda, MD are presented in Figure 1. The month and year label for each monthly average data point is positioned to immediately identify outliers while showing central tendencies. Examination of these plots indicates the sensitivity of the various fuels and systems to outdoor temperature, and provides a quick visual means to verify data quality and to compare historical energy consumption levels. The plots are useful to identify anomalous data points for further investigation, such as steam production in August 1988. During this month the otherwise idle absorption chillers at the central plant were activated, significantly increasing steam and fuel oil consumption during a period of relatively high outdoor temperature.

Where time-of-use demand meters are utilized for electrical billing, it is useful to prepare these plots using daily consumption totals. In this way the effects of building occupancy on

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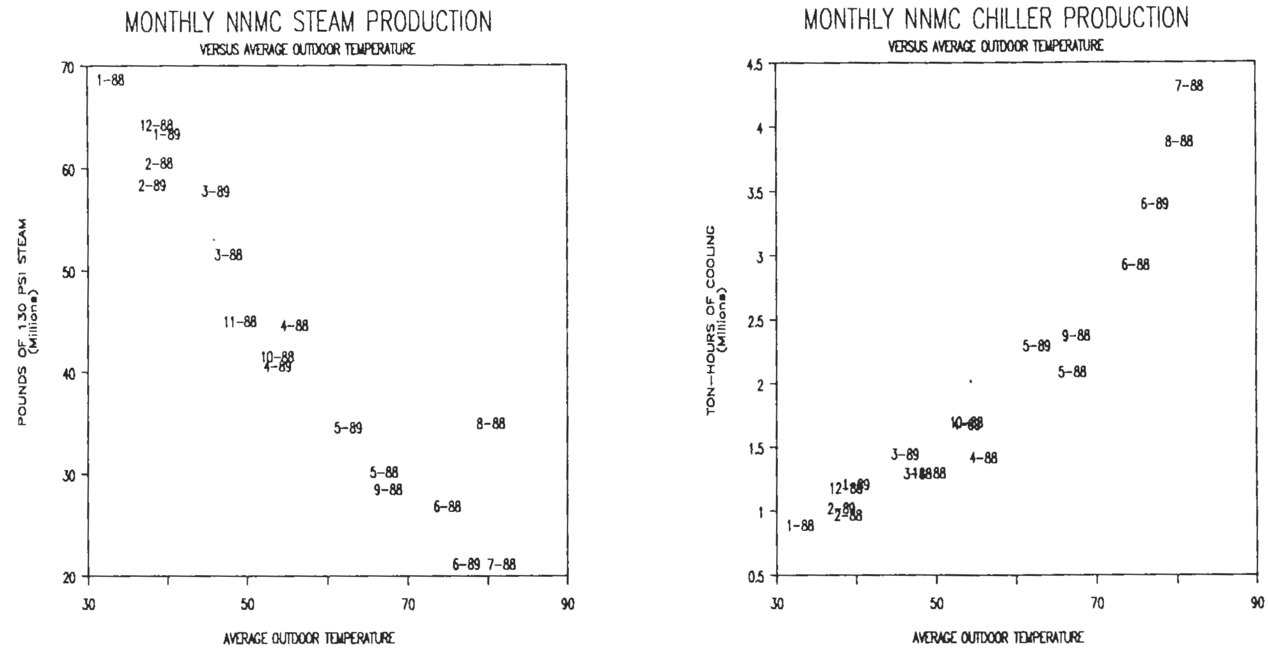

FIGURE 1: STEAM AND CHILLED WATER PRODUCTION VERSUS AVERAGE OUTDOOR TEMPERATURE FOR THE NATIONAL NAVAL MEDICAL CENTER (NNMC) CENTRAL PLANT IN BETHESDA, MD

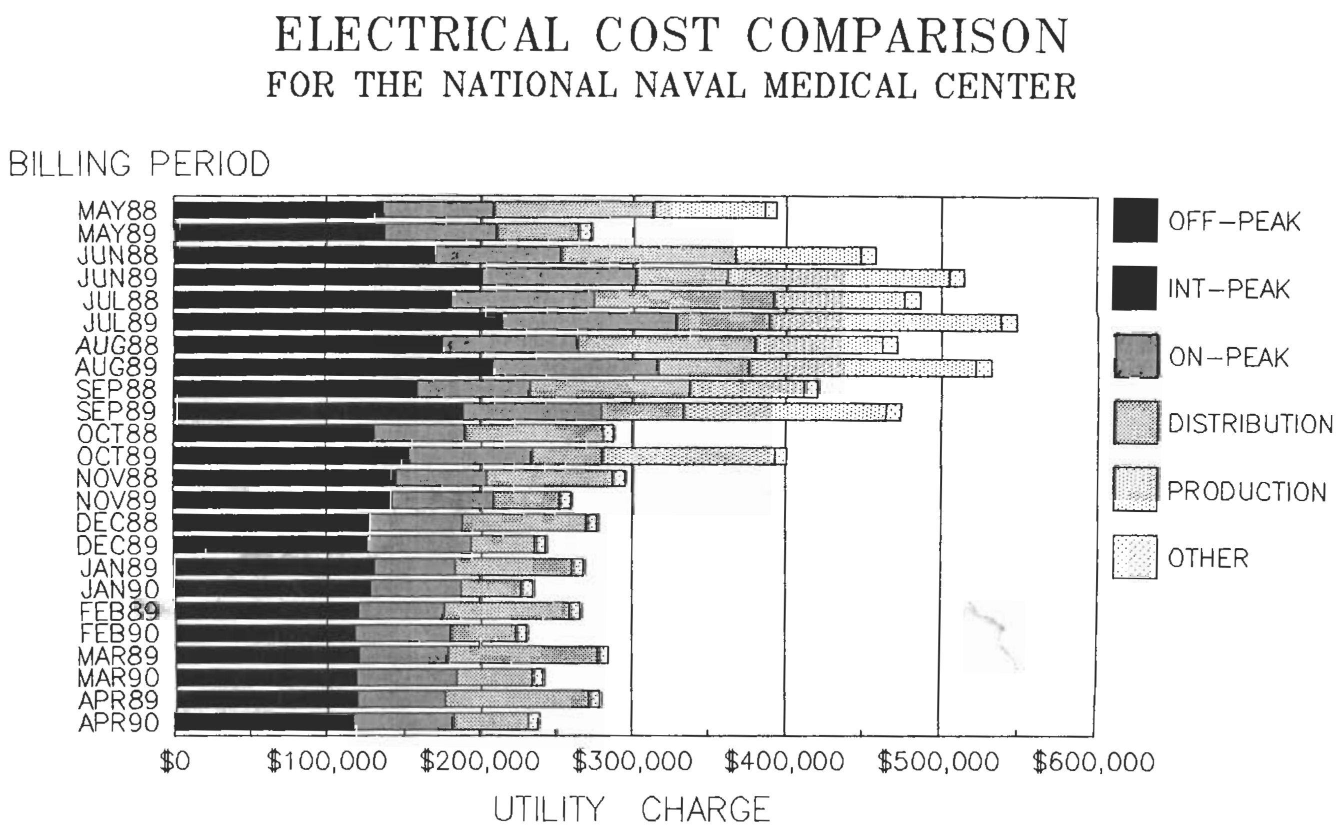

FIGURE 2: ELECTRIC UTILITY CHARGES FOR A MILITARY FACILITY – COMPARISON OF PREVIOUS AND CURRENT TARIFFS

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energy use can be distinguished for working and non-working days. It is also useful to examine electrical use according to billing components that may include peak demand, and consumption during off-peak, on-peak, and intermediate periods. This yields additional insight of the nature of electrical energy use and the impact of potential conservation and load management measures on utility costs. Because energy costs are a function of utility tariffs, it is important to examine past and anticipated utility rates. Figure 2 depicts the monthly charges for electricity at the National Naval Medical Center facility under the actual rates in 1988 and early 1989, as contrasted with what the charges will be if consumption is identical in the coming year. The monthly distribution and production charges are assessed based upon the peak 30-minute demand, and the highest 30-minute demand during the on-peak period of the summer months, respectively. The change in the utility tariff commencing in May of 1989 significantly increases electricity costs during the summer with a commensurate reduction during the winter months (also the 5 "summer" months have been shifted to begin in June rather than May). While the overall impact on the annual electrical cost is small, this change significantly affects the cost-effectiveness of individual energy conservation measures.

While much is learned from careful analysis and presentation of the utility billing data, supplemental measurement is often cost justified to better understand energy end-uses and conservation potentials. Consequently, FEMP supports the development and application of new energy metering technologies and analysis methods for federal facilities. As new tools and methods are developed, the FEMP supports applied research to evaluate and refine them before promoting more widespread applications.

PNL administers four FEMP Mobile Energy Laboratories (MELs) for use by federal agencies to conduct energy use measurements and efficiency tests. The laboratories are customized 56 passenger busses outfitted with sophisticated metering and test equipment. They are configured to provide equipment storage and work space for specially trained technicians to conduct energy efficiency tests in conjunction with on-site operations personnel. These laboratories are made available to federal agencies through interagency agreements with the Department of Energy, that provide funding for PNL technicians or subcontractors to conduct tests and maintain the test equipment.

PNL is presently preparing a catalog of standardized energy efficiency testing procedures for common investigations such as combustion efficiency measurement, electrical or steam distribution system evaluation, and heating, ventilation, and air conditioning system testing. These procedures follow guidelines established by the American Society for Testing and Materials (ASTM), and will be submitted for ASTM approval as they are finalized.

The MELs have sophisticated portable computers with removable cartridge hard drives for general data assembly and analysis, insertion turbine flow computers for steam and hot water measurement, electrical power analyzers and a family of clamp on current transformers and voltage transducers for electrical circuit analysis, and digital combustion gas analyzers for combustion efficiency measurements. Field data acquisition systems based upon DOE specifications for multichannel data logging of electrical consumption, climate conditions, and equipment status are also now available. Remote measurement of temperatures is also provided by small self-contained data recorders. With the exception of the combustion gas analyzer, all of this equipment is configured to generate electronic records for subsequent analysis using desk-top computer analysis packages.

Examples of the types of measurements available from this equipment are provided in Figure 3. This includes combustion gas analysis results for two boilers, and power measurements for a large motor vehicle maintenance facility. The boiler efficiency measurements were made to evaluate the adequacy of boiler maintenance and controls, and the power measurements revealed the effectiveness of a campaign to turn off lights at night and on week-ends. While these measurements are of great value to the facility energy manager, they probably would not be considered or cost-justified if the specialized equipment and skilled technicians were not available to them on a cost-shared basis. The coordinated application of the equipment on-board the MELs among all federal agencies makes it practicable to collect these types of data for short periods of time and identify where opportunities for efficiency improvements and dedicated metering justify follow-up action by the facility management.

ENERGY USE BASELINING AND FORECASTING APPROACHES

An important element of any energy management program is the ability to determine progress toward energy efficiency goals. This is made difficult where buildings and people are involved because of the complex interactions of energy consumption with climate and building use. Means of accounting for these affects or isolating system components not influenced by them are necessary to accurately quantify energy use efficiency. To this end the FEMP has employed end-use energy measurements and conducted tests of various approximation methods to adjust consumption for uncontrollable changes.

When energy consumption baselines are established, it is possible to test their accuracy by comparing forecasted levels of energy consumption with actual energy use. Deviations from expectations must be studied to determine if energy use efficiency changed or if unexplained factors are affecting the baseline and resultant forecast. Work is ongoing to help determine the best mix of measurements and approximation methods for particular facilities.

Another benefit of baselining energy consumption is to facilitate the implementation of performance-based shared energy savings contracts. Under these contracts, which are now permitted by the federal government, an energy service company can reap the benefits of capital investments they make to improve energy use efficiency of federal facilities. The benefits are determined by comparison of the current measured energy consumption levels with the pre-retrofit baseline as adjusted for current conditions. The success of these agreements hinges largely upon the credibility (perceived accuracy) and simplicity of the energy

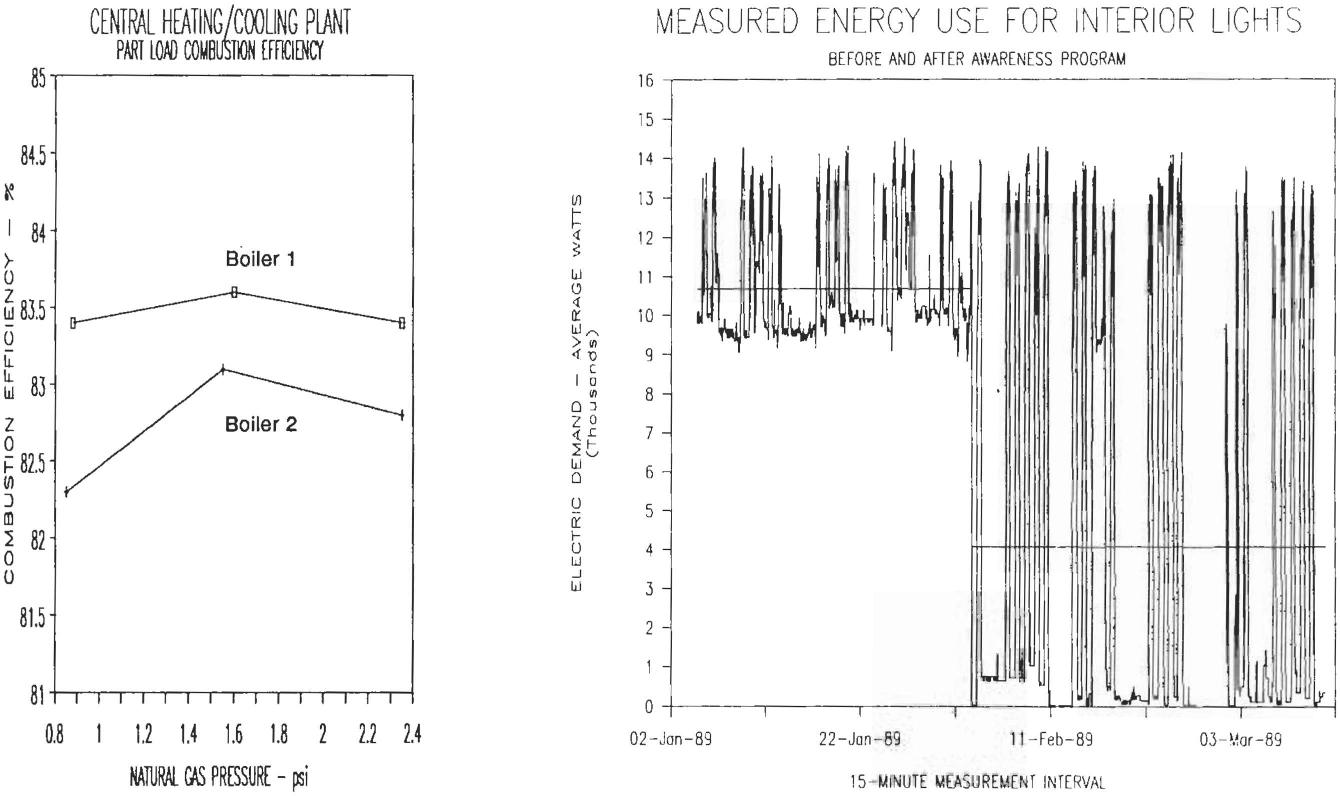

FIGURE 3: SAMPLE MEASUREMENTS PROVIDED BY FEMP MOBILE ENERGY LABORATORY EQUIPMENT

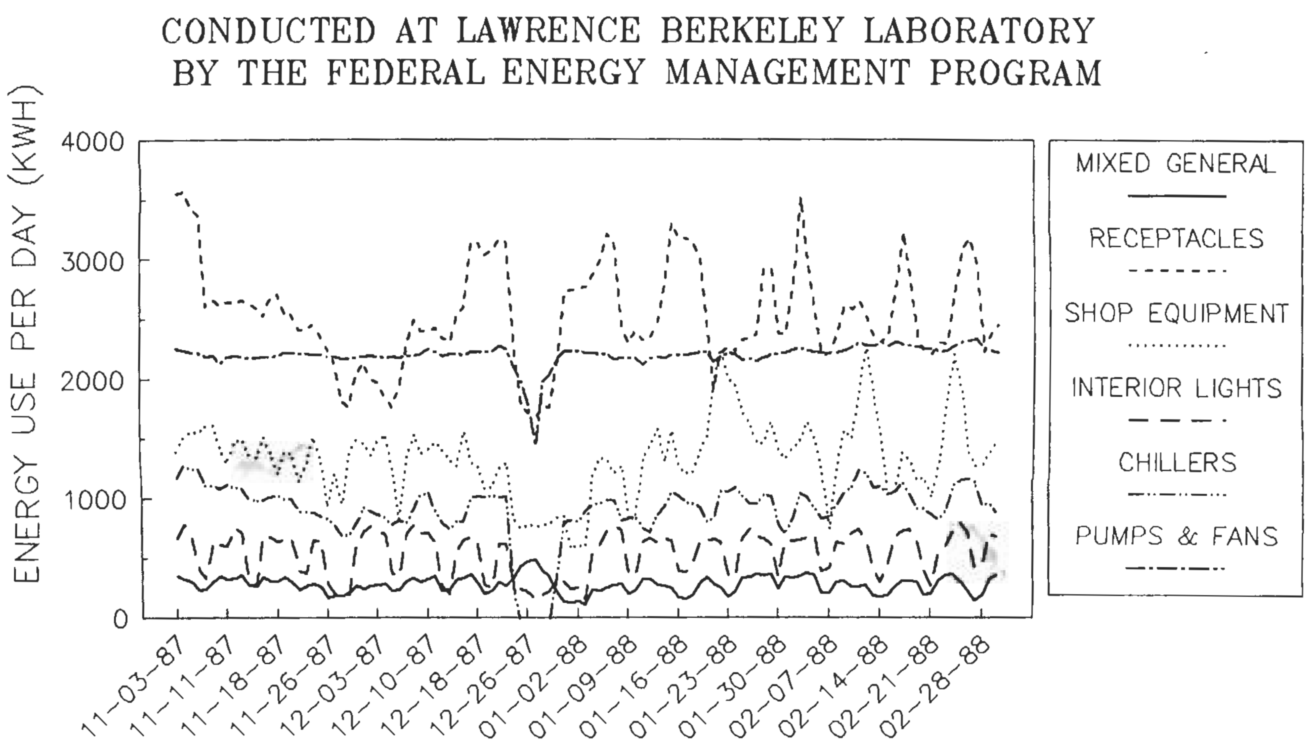

FIGURE 4: ENERGY USE SUBMETERING FOR A SYSTEMS ISOLATION BASELINE AT A MULTI-PURPOSE LABORATORY

use baseline, two seemingly conflicting requirements.

FEMP activity in this area has progressed along three parallel paths. The first was alluded to above, where utility billing data is carefully analyzed with consideration of climate data. A previous paper (1) describes this approach in some detail, where a set of electronic spreadsheet macros have been developed to guide the normalization and statistical analysis of utility billing data. Such data may be sufficient for an acceptable baseline if the potential conservation measures significantly exceed the "noise" or uncertainty associated with the baseline predictions.

The second path employs energy end-use measurements to isolate the components of energy use that can be reliably baselined from those that cannot. This may be necessary where the baseline uncertainty would otherwise be too great in relation to the potential savings. An example of data for this systems isolation approach is depicted in Figure 4 where a set of end-use measurements are made for a multipurpose laboratory building to baseline the energy using systems that will be affected by a shared energy savings project. Because no retrofits are anticipated for the scientific equipment and methods to forecast their use would be futile, the energy they consume is measured and subtracted from the building energy use to derive a more reliable baseline. Other sensors measure the interior and exterior climate conditions to adjust the baseline for changes in key parameters that are beyond the control of the energy savings contractor.

A third pathway to baselining is described below, where a calculated baseline is developed based upon an energy use simulation model. Once the model is calibrated to measured data, it can be used not only to identify cost-effective energy efficiency improvement opportunities, but may also serve as the energy use baseline. The FEMP is improving the capabilities of public domain energy analysis programs while conducting applied research to evaluate and refine this baselining approach (2).

In light of the various approaches to energy use baselining, and their critical importance to evaluate energy management programs, the FEMP is exploring the most acceptable and cost-effective techniques with interested federal agencies. Typically, a preliminary investigation of energy savings potential and each of the three baselining approaches described above is carried out for a particular facility, before significant resources are expended for metering, modelling, or the sophisticated analysis that may be required.

ENERGY USE SIMULATION AND CONSERVATION MEASURE EVALUATION

With the advent of inexpensive and widely available desk-top computers, FEMP is supporting the development and enhancement of public domain energy use analysis software. This software facilitates detailed analysis of the complex and diverse energy uses of building systems by modelling energy use cause and effect relationships. All software developed by the FEMP is placed in the public domain to facilitate widespread use and to provide an open architecture for educational purposes and customization as may be desired.

Presently, the FEMP is continuing development and user support for "A Simplified Energy Analysis Method" (ASEAM) that uses bin temperature data and the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) approved calculation methods to estimate building energy end-use intensities (3). This tool uses the life cycle costing procedure developed by the National Bureau of Standards to determine the savings-to-investment ratios of potential energy efficiency improvements (4). The output of this menu driven software can be read directly, or formatted for input to popular spreadsheet programs and analysis packages.

This simplified method was originally developed to operate on IBM personal computers with only 256K of random access memory. Now that most energy analysts have access to computers with enhanced capabilities the software is being upgraded to take advantage of these capabilities and improve ease of use, flexibility, and accuracy. However, even with these improvements the simplified calculations are not adequate for sophisticated energy control simulations and utility load management options investigations.

Consequently, the FEMP is embarking on a project to integrate the ASEAM and DOE-2 hourly simulation programs into a common computing environment. The objective is to slightly modify the ASEAM program inputs and develop an interface to accommodate use of the more sophisticated and computationally intensive DOE-2 program. The public domain DOE-2 program can presently be run on enhanced desk-top computers only by using proprietary software. It is FEMP's goal to release an integrated public domain program, thereby permitting the federal energy analyst to quickly examine a wide number of potential conservation measures using ASEAM and then readily use the DOE-2 program to more fully investigate the most promising energy efficiency improvements.

An important caution is required to ensure effective use of these tools. The output estimates are only as good as the input data and to a lesser degree the software algorithms. Without well informed users, these tools can be incorrectly applied and the results can be easily misinterpreted. As a check on this the FEMP is continuing efforts to measure the actual end-use consumption of building energy systems and developing methods by which independent users under certain stable conditions may apply metered data to calibrate the baseline for their building and improve retrofit options analysis. By documenting these experiences, and supporting user training, the FEMP hopes to provide guidance and low-cost approaches to calibrate the simulation models and check the validity of their estimates against accumulated measurements.

SUMMARY

This paper has described several applications of metering for facility and whole building energy analysis, and identified areas of ongoing investigation by the FEMP. Our experiences with field data collection have been particularly valuable, providing an empirical basis to evaluate energy analysis methods, and revealing the measurement complexities and capabilities of metering hardware. When coupled with the increasing sophistication and affordability of energy metering systems and computational environments, the future is particularly bright for improving the understanding and efficiency of energy use.

However this paper also identifies areas where additional research and applications testing is necessary to achieve the goals of optimal energy use efficiency. Specifically, improved energy use metering technologies must be investigated, software to efficiently apply the data and computers now available must be maintained and enhanced, and more scientifically sound energy use baselining and forecasting methods must be developed. All this requires funding and institutional support that is challenging to obtain in this era of energy complacency and focus on sources of new energy supply. It is hoped that the increasing awareness of the environmental impacts of energy production, and the indisputable merits of energy efficiency improvement to reduce these impacts, will compel public and private sources to continue and accelerate this applications-oriented research. Ultimately, these investments will be small in relation to the value of the energy savings that will be realized as the methods are put into practice.

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