Establishing Baselines and Measuring Performance on Military Installations

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ABSTRACT

This paper provides a methodology to determine annual changes in military installation energy use or verify savings from large, base-wide energy efficiency projects. The method uses monthly utility bills and weather data for a military installation. This method conforms to the guidance provided in the two recognized protocols for measurement and verification (M&V) of energy projects. DoD Utility Energy Reporting System (DUERS) data is used for consumption data and the National Climatic Data Center for weather data. The EModel program from Texas A&M University is used as the software tool to develop multi-parameter models.

There are several approaches to assessing progress or energy savings based on a spectrum of project complexities. Factors that determine the choice and cost of M&V are the magnitude of savings, the complexity of energy conservation measures, the interaction of the measures, and the allocation of risk. Progress is measured by statistically comparing one year against another, normalizing the data for weather and square footage. Other issues about applying these methods to large installations are multiple fuels, dual fuel heating plants, billing month data skewing, and selection of proper building selection are discussed.

Installations have the responsibility to verify savings and ensure payment to performance contractors is accurate. With increased emphasis on alternative financing and energy efficiency, it is imperative that a consistent and effective methodology be used to assess progress towards energy reduction goals and to verify project energy savings. The methods may also be applied to any other large complex of buildings, such as a college campus.

Introduction

The Department of Defense (DoD) is the largest single user of energy in the nation. The United States Army leads the DoD in real estate assets held. With 903 million square feet in 171,000 buildings and 1,897 individual installations and sites, the annual facility energy bill exceeds $797 million. Additionally, the Army purchases $188M worth of mobility fuels, mostly gas, diesel, and jet fuel. Though significant progress has been made in reducing overall energy use, the trend has been one of growing electrical energy use corresponding with the explosion in electronic and automation requirements and increased demand for comfort air conditioning systems. During the period from 1991 until the present, the Army has spent about $400 million on energy saving projects. Private contractors have invested an additional $65 million through Energy Saving Performance Contracts on Army installations. Ensuring that projected energy savings have been achieved is an imperative.

This paper provides guidance and methodology to determine annual changes in installation energy consumption and to verify savings from large, base-wide energy efficiency projects. The method uses monthly utility bills and weather data for an installation. The methods defined are based by the Energy Systems Laboratory, Texas Engineering Experiment Station, Texas A&M University System, for the Construction Engineering Research Laboratory (Reddy et al. 1996) and the 1997 ASHRAE Handbook of Fundamentals (ASHRAE 1997). In order to use the procedures, the user is expected to have some basic statistical expertise and be familiar with spreadsheet techniques.

This method conforms to the guidance provided in the two recognized protocols for measurement and verification of energy projects. These are the Federal Energy Management Program M&V Guidance for Federal Projects (Steven R. Schiller 1996) and the International Performance Measurement and Verification Protocol (IPMVP) (DOE 1997). The purpose of this document is to simplify conformance with the protocols by providing military installations with straightforward procedures. The methods may be applied to any large complex of buildings, such as a college campus.

Federal Energy Program Requirements

The base year for the current energy program in the federal government is Fiscal Year (FY) 1985. There are several goals to be met in the coming years. Public Law 102-486, the Energy Policy Act (EPAct) of 1992, specifies that energy consumption should be reduced by 20% on a Btu/square foot basis by FY 2000. Further, it requires that all energy and water conservation measures with life-cycle cost (LCC) paybacks of less than 10 years be installed in all US-owned Federal buildings by January 1, 2005. EPAct also amended the National Energy Conservation Policy Act on shared energy savings, giving agencies new authority to enter into energy performance contracts and describes a methodology for contract implementation.

Executive Order (EO) 13123, Greening the Government through Efficient Energy Management, supercedes parts of EPAct and requires energy reductions of 30% by FY 2005 and 35% by 2010. Therefore, installations should be on a 30% glide path over 20 years, or decreasing energy at about 1.5% per year since FY 1985. A reduction glide path of 1% per year is required from FY 2005 to 2010. The Executive Order also requires agencies to utilize innovative financing and contracting mechanisms, including Utility Energy Service Contracts (UESC) and Energy Saving Performance Contracting (ESPC) to meet the goals.

Due to a decreasing budget for public investment on military installations, reliance on the private sector is becoming the primary mode for investment in energy efficiency. However, ensuring that actual savings are being achieved falls upon the installation staff. The buildings are not individually metered and analysis techniques need to be developed to measure progress.

Measuring Progress

In order to gauge actual progress toward energy goals and determine the impact of large-scale energy efficiency projects, a common methodology is required. Accordingly, there are defined steps to the process of evaluating past and future energy progress at an installation. Relevant utility consumption and weather data must be gathered. The DoD Utility Energy Reporting System (DUERS) provides the utility data. Weather data is obtained from either local sources or the National Weather Service or the National Climatic Data Center.

The FEMP Guidelines and the IPMVP provide several approaches to assessing progress or energy savings based a spectrum of project complexities. Factors that determine the choice and, therefore, cost of M&V are the magnitude of savings, the complexity of energy conservation meaures, the interaction between the measures, and the allocation of risk. For this application, a whole-facility or main meter measurement approach is suggested. This process involves a continuous measurement of installation-wide energy use both before and after projects have been executed. This is the normal process for a military installation and the data is already compiled on a monthly basis for DUERS. Progress is normally measured by calculating the total energy consumption on a Btu per square foot basis and seeing whether it increases or decreases. One problem that arises in assessing progress is that weather is not factored into this calculation. A mild winter or hot summer can easily distort measurement of progress and obscure the effects of large projects. Therefore, energy consumption should be gauged by using statistically representative models of the installation's electrical and thermal consumption (or demand) as related to square footage and weather. Looking at the installation as a whole allows for the interaction between various projects to be taken into account.

Developing an Inverse (Regression) Model

The application of regression modeling is focused on the empirical behavior of installation energy use as it relates to driving forces or parameters. Inverse modeling is based on the empirical behavior of a system as it relates to one or more driving forces. The simplest form of an inverse model is the steady-state regression model. Steady-state models ignore dynamic effects such as thermal mass, variables other than temperature, and their inappropriateness for some buildings. Since a large installation with many buildings and systems is being modeled, these effects can be ignored provided accuracy is satisfactory. Performing a regression analysis of monthly energy consumption versus one or more important parameters develops the equations that form the baseline model. Key parameters are generally square footage and average billing period temperatures. Installation population may also be a parameter, but it usually is not informative to track it and apply it in a model unless there is something unique about the installation in question. The most accurate methods use sophisticated change-point regression procedures that simultaneously solve for several parameters including a weather independent base-level parameter, one or more weather dependent parameters, and the point or points at which the model switches from weather-dependent to weather-independent behavior (ASHRAE 1997).

At installations where there are both large air conditioning loads and large heating loads, it is best to look at each type of load separately. Accurate depiction of energy use requires a four-parameter model for both fossil (heating) and electrical (cooling) energy. The choice of model should be guided by an understanding of the physical system and its expected response. The four-parameter, change-point model with a change point and two slopes, is a good generic fit for military installations. This is especially true since we are now seeing a crossing over between the types of energy used for heating and cooling. For instance, ground source heat pumps use a typical cooling energy source (electricity) for heating and gas-fired chillers use a typical heating fuel for cooling. **Figure 1** shows the typical four-parameter models for heating and cooling. We are now starting to see a V-shaped curve rather than two lines with the same type of slope. Also, an increasing amount of air conditioning is being used due to the requirements of information age technologies and some relaxation of restrictions to its use. **Table 1** shows how the energy mix at Army installations has changed over the past fourteen years. The intensification of electrical and gas usage is readily apparent.

There are also several other issues that must be addressed to enable application of these methods at large installations. These issues are multiple heating fuels (oil, gas, coal, heat pumps), dual fuel heating plants (gas/oil, gas/propane, etc), billing month data skewing, and proper building selection. Failure to address these issues can cause confusion and lead to erroneous conclusions.

Regarding multiple fuels, it is best to sum up all sources of heating fuels on an installation. The sources may change over time, but it is the total demand for them that we are seeking. The same logic is applied to dual fuel plants. Each type of building may have a different heating or cooling demand associated with it, but the sum of all the square footage is the best parameter to use. Some have tried using a subset of the square footage, but the results do not justify this (Reddy et al. 1996). Installations may vary significantly in the distribution of building types and uses. Also, growth of the different types of buildings is related to mission. Some installations have had large changes in facility mix over the last decade due to Base Realignment and Closure (BRAC) initiatives. Ignoring a theoretically low energy demand category of buildings that is experiencing significant growth in square footage can result in overall energy intensity factors that are too high.

Table 1. Change in Army Energy Mix

Fiscal Year	85	98
Energy Type	%	%
Electricity	22	33
Natural Gas	29	36
Propane Gas	1	1
Oil	33	13
Coal	14	9
District Heat	1	8
Total Consumption	132.0 TBtu	91.4 TBtu

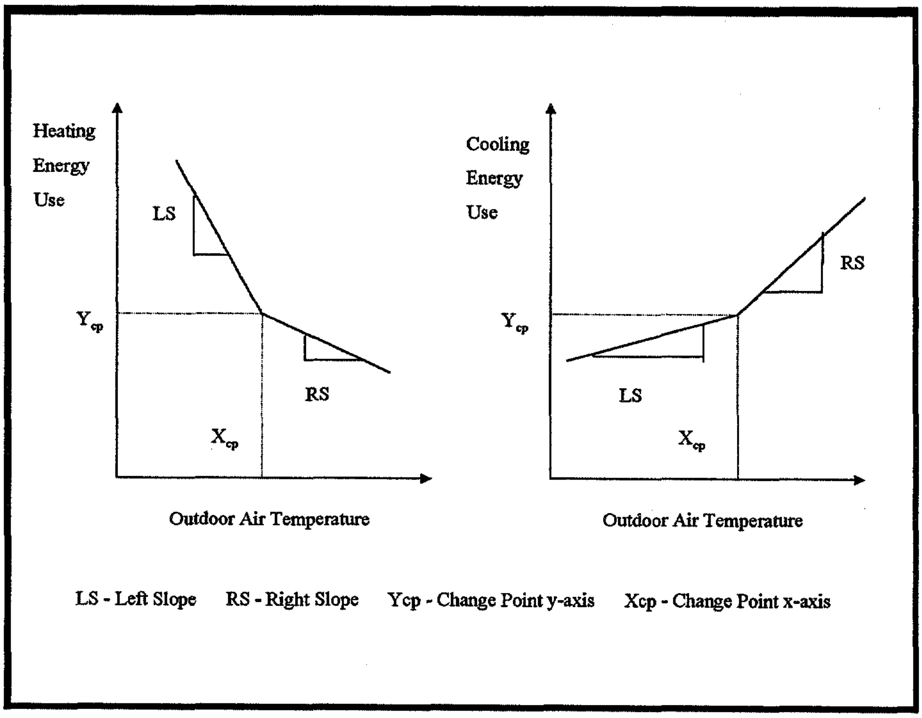

Figure 1. Typical Four-Parameter Heating and Cooling Models (Reddy et al. 1996)

Skewing of the billing data can be another problem. **Figure 2** shows how the billing data should be synchronized with the weather data. Sometimes, it can go out of synchronization. To avoid this problem, the weather and energy data should be plotted over a time period of several years and checked for synchronicity. If the data is not synchronous, then a running average of two months energy consumption is used to develop a new consumption variable that is in sync with the weather. Note how the electrical base load is increases over time.

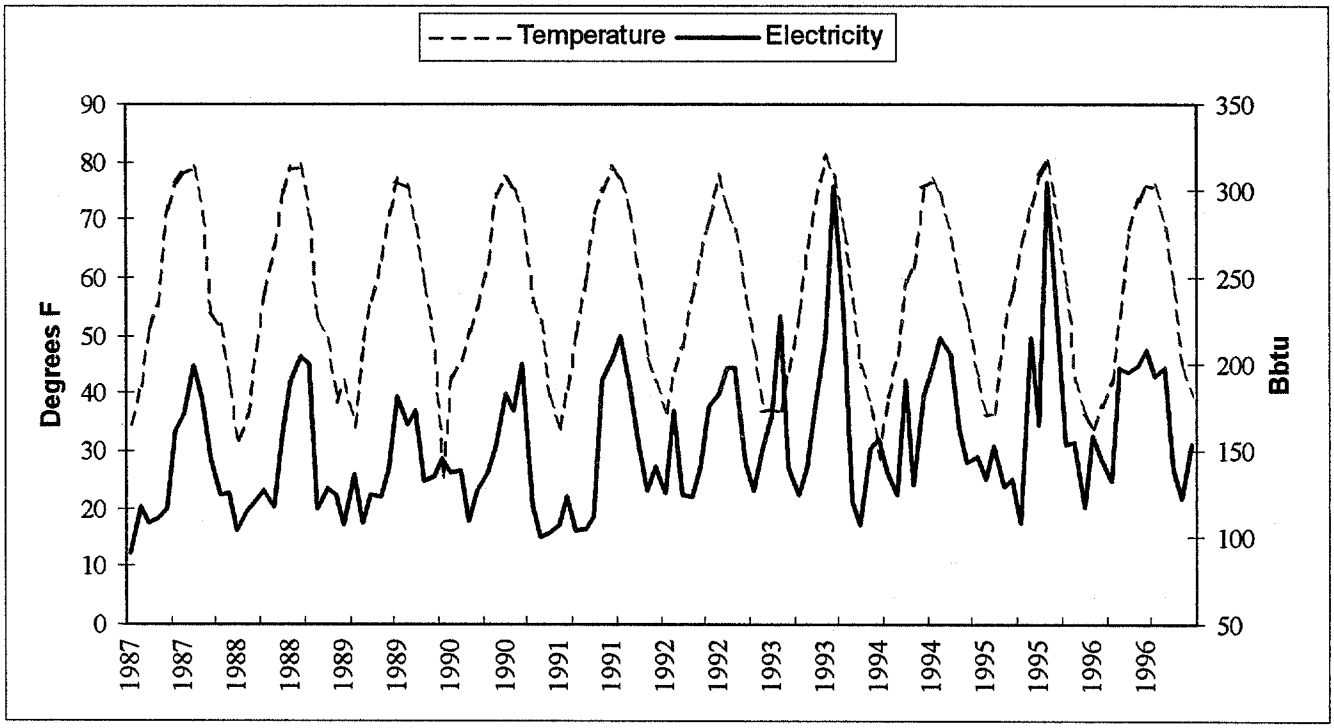

Figure 2. Annual Electrical Energy Cycles for Fort Campbell

It is important to have a good model for the baseline model year. One must evaluate the data and results for several years to determine a year with a good fit that can be used as the baseline model. The baseline can now be used to evaluate monthly energy consumption. The four-parameter model does not have a constant base-level energy use like a three-parameter model. However, a four-parameter model can be simplified to describe the three-parameter situation. The equation for predicting energy consumption becomes:

$$\text{Monthly Mean Daily Energy Use} = Y_{cp} + LS^*(T-X_{cp})^- + RS^*(T-X_{cp})^+$$

where $( )^+$ is a mathematical symbolism which denotes that the term within the brackets should be set to zero if it is negative. Y_{cp} is the consumption at the change point. X_{cp} is the change point temperature. The baseline models developed for one year can now be used to predict weather-adjusted monthly energy use into the future or to evaluate the past. Comparison of the projected consumption with actual monthly use will reveal any change in energy intensity for the installation. There is a certain amount of uncertainty in this method. It is recommended that 95% confidence level be applied (Reddy 1996). The prediction interval (PI) or confidence level for the model should be calculated using a simplified equation based on twelve monthly points for annual consumption. The mean daily energy use (Y_{calc}) is the value predicted by the model. The measured value of Y should be within the confidence level of the prediction (Y_{calc} + PI) and (Y_{calc} – PI). The formula for PI is as follows:

$$PI = (t(1-\alpha/2, n-p) / 12) \times RMSE \times (13)^{0.5}$$

where t – the Student t-statistic evaluated at (1-α/2, n-p)
α – significance or confidence level (for 95% equals 0.05)
n – number of observations, in this case 12
p – number of parameters in the model, in this case 4
RMSE – root mean square error for the model

The monthly values of Y based on Y_{calc} and the PI are used to estimate the levels of energy savings. The slopes are also used to indicate the change in energy intensity. Thus, we now have a method to evaluate actual savings.

Evaluating an Installation

The EModel Program developed at Texas A&M University is used to evaluate installation energy progress. As noted in **Figure 1**, on a previous page, the slopes of the four-parameter models can indicate how the installation's energy intensity varies with weather. A change in the slope of the model (LS or RS) is an indication of a change in the installation's response to weather for either heating or cooling. The model can be developed for successive years and the trend established that is normalized to both weather and square footage.

Fort Campbell is a large installation located on the Kentucky-Tennessee border. The installation uses about 260 thousand megawatt-hours of electricity, 1.4 million cubic feet of natural gas, and 35 hundred barrels of oil each year. The annual energy bill is about $18 million. There is an effective population of about 41 thousand people and approximately 18 million square feet of various types of buildings including a hospital, family housing, barracks, and maintenance facilities. Fort Campbell experiences about 4920 heating degree days (HDD) and 1472 cooling degree-days (CDD) each year based on 65F. This represents both a large heating load and a moderate cooling load. **Figure 3** shows the heating model for Fort Campbell for 1992. **Figure 4** shows the same installation in 1996. Note how the slopes have changed.

The left slope (LS) indicates that fossil energy demand, in kBtu/sf per degree F, has changed from negative 0.0244 to negative 0.0176. This indicates that the installation now uses much less heat per change in temperature. At the same time, the right slope (RS) did not significantly change. The positive slope indicates that the installation now actually increases its fossil energy consumption in the summer months. In 1990, there was just the hot water load and a slight decrease in consumption with increasing temperature. Reviewing the types of projects that were installed at Fort Campbell in the intervening years can give insight into these changes that are reflected in the model. During the early 1990's several projects were installed to save heating energy and there were nine projects to replace electric-driven chillers with natural gas chillers. These gas-fired chillers would demand fossil energy I the cooling season showing that there is a physical reason why the profile has a positive right slope. Reviewing the slopes can tell us that the installation is now more energy efficient for the heating season and will use more thermal energy in the cooling season.

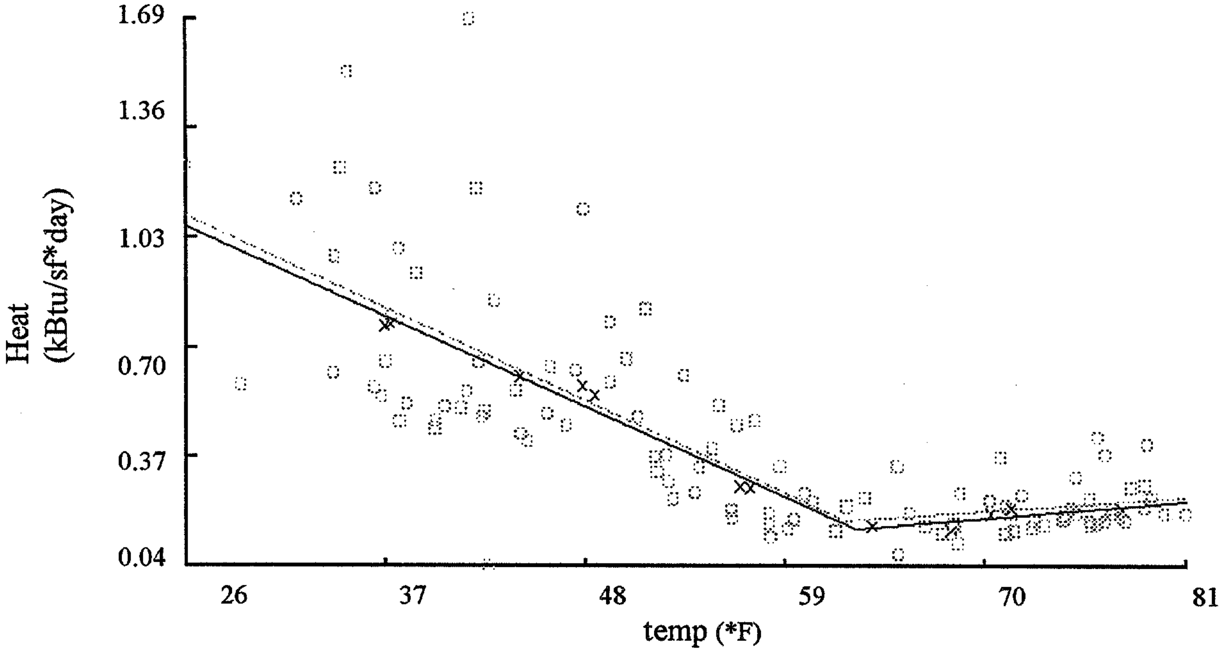

Figure 3. Fort Campbell Heating Model for 1992. Ycp = 0.1542 (0.0613) LS = -0.0244 (0.0012) RS = 0.0044 (0.0037) Xcp = 62.8436 N = 12 N1 = 7 N2 = 5 R2 = 0.99 RMSE = 0.0324 CV-RMSE = 8.2% p = -0.38 DW = 2.63 (i%)

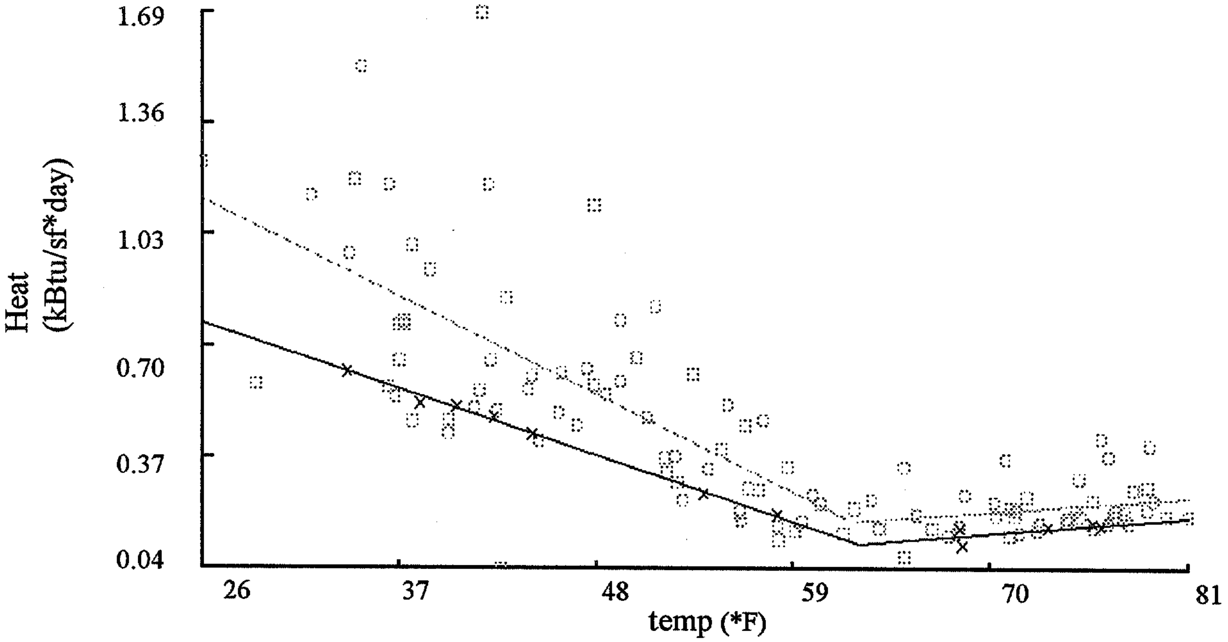

Figure 4. Fort Campbell Heating Model for 1996. Ycp = 0.1152 (0.0282) LS = -0.0176 (0.0006) RS = 0.0043 (0.0019) Xcp = 62.6200 N = 12 N1 = 7 N2 = 5 R2 = 0.99 RMSE = 0.0152 CV-RMSE = 4.7% p = -0.04 DW = 2.04 (i%)

Reviewing the electrical consumption model can give insight into the cooling season and the electrical efficiency of the installation. **Figure 5** shows the four-parameter model for Fort Campbell electrical consumption in 1992. **Figure 6** shows the same model for 1996. A review of the two figures shows how the slopes changed over the 6-year period. The left slope (LS) indicates how electricity use varies in the winter in kBtu/sf per degree F. The slope has changed from negative 0.0009 to negative 0.0075. This indicates that the installation now uses more electricity in the winter than previously due to a change in outdoor temperature. This would indicate an increase in electrical heating. At the same time, the right slope (RS) changed from plus 0.0088 to plus 0.0056. This indicates that the installation now uses less electricity per degree F change in temperature during the cooling season. Reviewing the types of projects that were installed at Fort Campbell in the intervening years can give insight into these changes. During the early 1990's several projects were executed to convert to infrared heating and there were nine projects to replace electric-driven chillers with natural gas chillers. This explains why the profile is changing. Again, reviewing the slopes can tell us that the installation is now less electrically intensive during the cooling season and is more electrically intensive in the heating season.

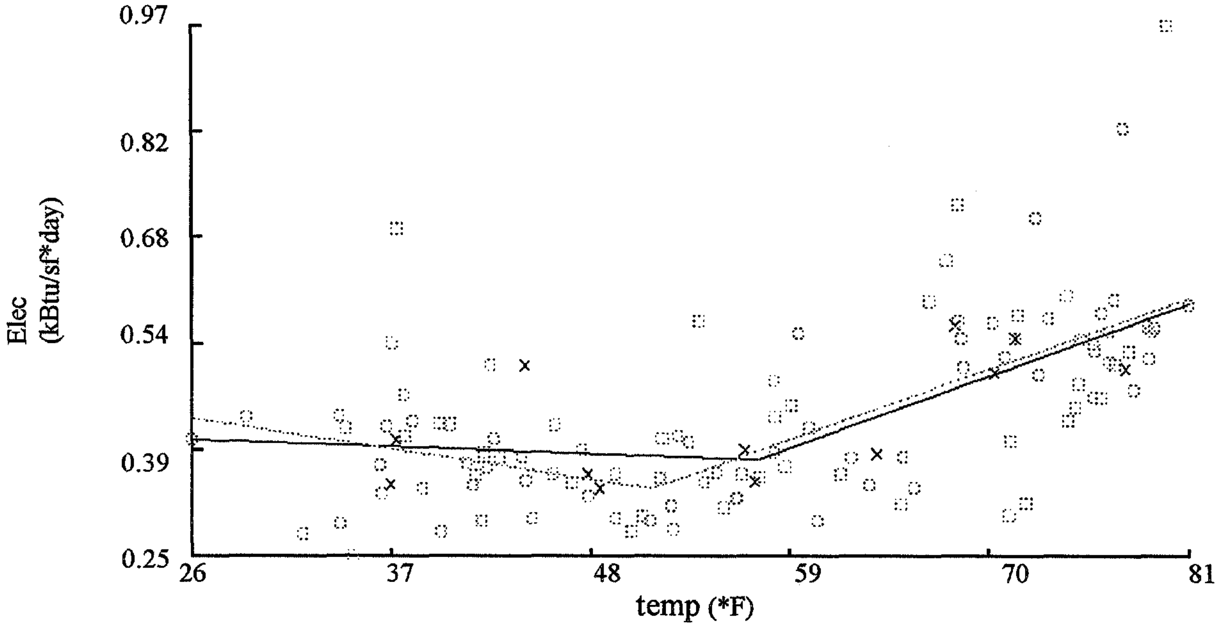

Figure 5. Fort Campbell Electrical Model for 1992. Ycp = 0.3811 (0.1390) LS = -0.0009 (0.0029) RS = 0.0088 (0.0061) Xcp = 57.1050 N = 12 N1 = 7 N2 = 5 R2 = 0.54 RMSE = 0.0620 CV-RMSE = 14.3% p = -0.21 DW = 2.33 (i%)

Finally, it is instructive to review the total energy consumption at the installation and observe the energy effectiveness of the combined heating and cooling sources. **Figure 7** and **Figure 8** show the total energy model for 1990 and 1996, respectively. It is interesting to note that in the heating season, the total energy intensity went down, even though the electrical intensity went up. The LS changed from negative 0.66 to negative 0.40, a significant drop. At the same time, the RS changed from plus 0.15 to plus 0.33, a significant increase. Again, this can be explained. The large switch from electrical chillers to natural gas chillers caused site energy to increase. Although this is cost effective and energy effective on a primary energy basis, site energy generally increases when natural

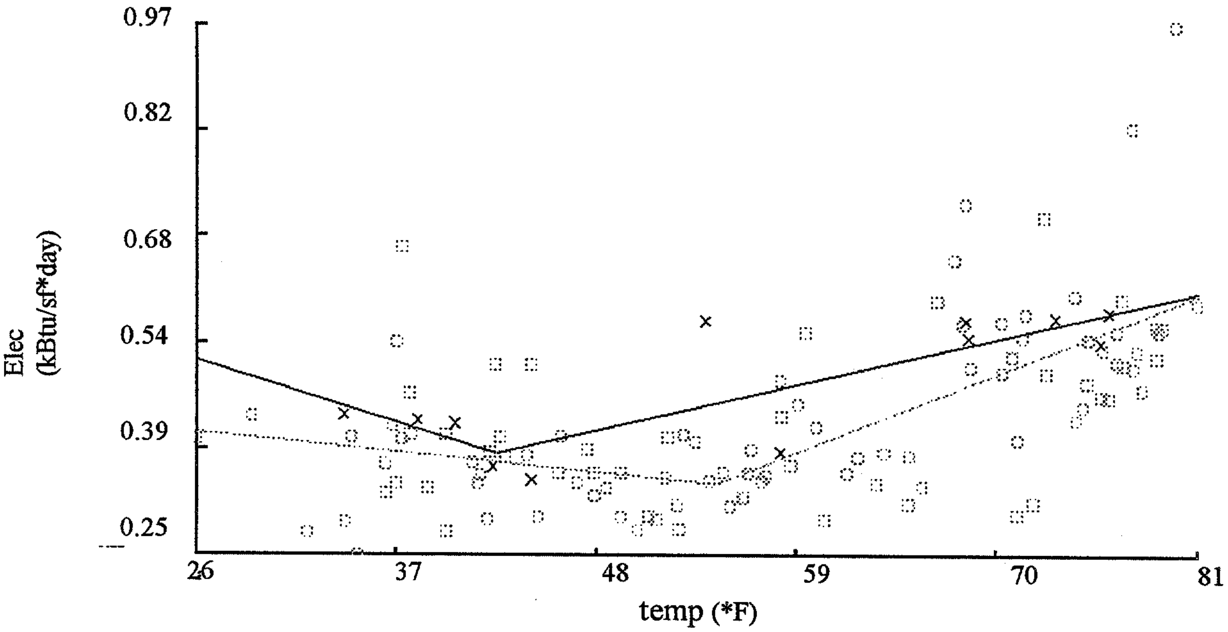

Figure 6. Fort Campbell Electrical Model for 1996. Ycp = 0.3884 (0.2946) LS = -0.0075 (0.0074) RS = 0.0056 (0.0111) Xcp = 42.2200 N = 12 N1 = 4 N2 = 8 R2 = 0.68 RMSE = 0.0547 CV-RMSE = 11.3% p = -0.11 DW = 2.19 (i%)

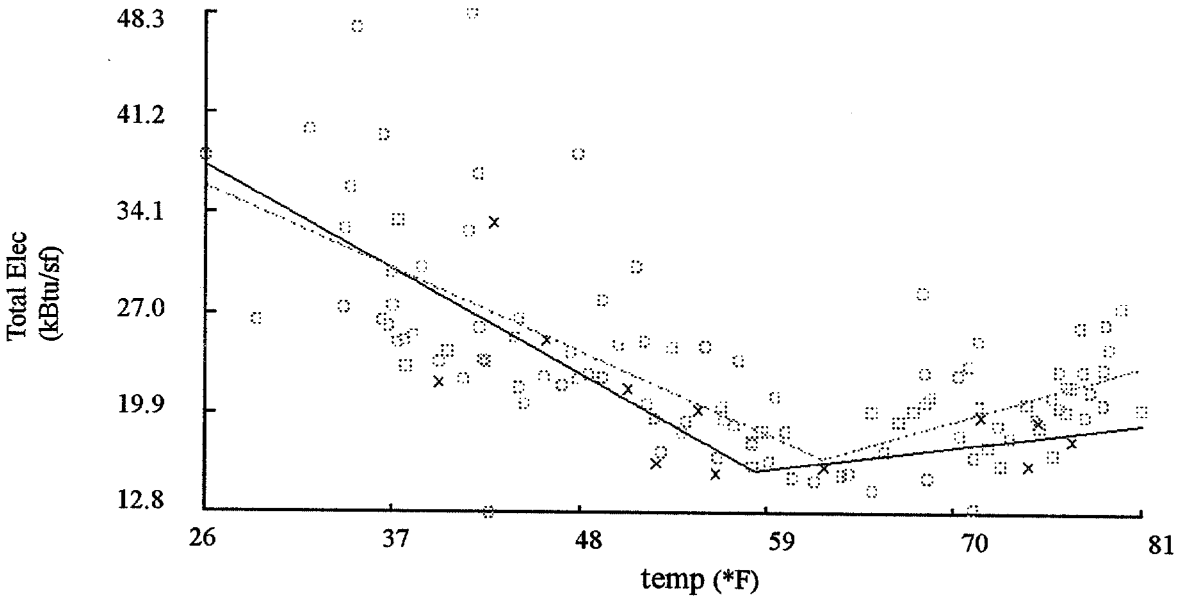

Figure 7. Fort Campbell Total Energy 1990. Ycp = 15.8103 (10.7928) LS = -0.6635 (0.2161) RS = 0.1464 (0.4219) Xcp = 58.2100 N = 12 N1 = 7 N2 = 5 R2 = 0.57 RMSE = 3.6607 CV-RMSE = 18.0% p = 0.43 DW = 0.65 (p>0)

gas is substituted for electricity. Care should be taken to know what this effect is and to understand the corresponding changes in energy intensities. Observing the data for the change point in the two different years provides information about how the installation's energy demands are changing. The Xcp value lowered from 1990 to 1996. This indicates that there are more internal heat gains in the buildings. The Ycp value lowered slightly indicating a lower base load in the buildings. The model does seem to be intuitive and provide insight into the energy effectiveness of the projects installed at Fort Campbell. We would expect the changes resulting from large projects to be visible.

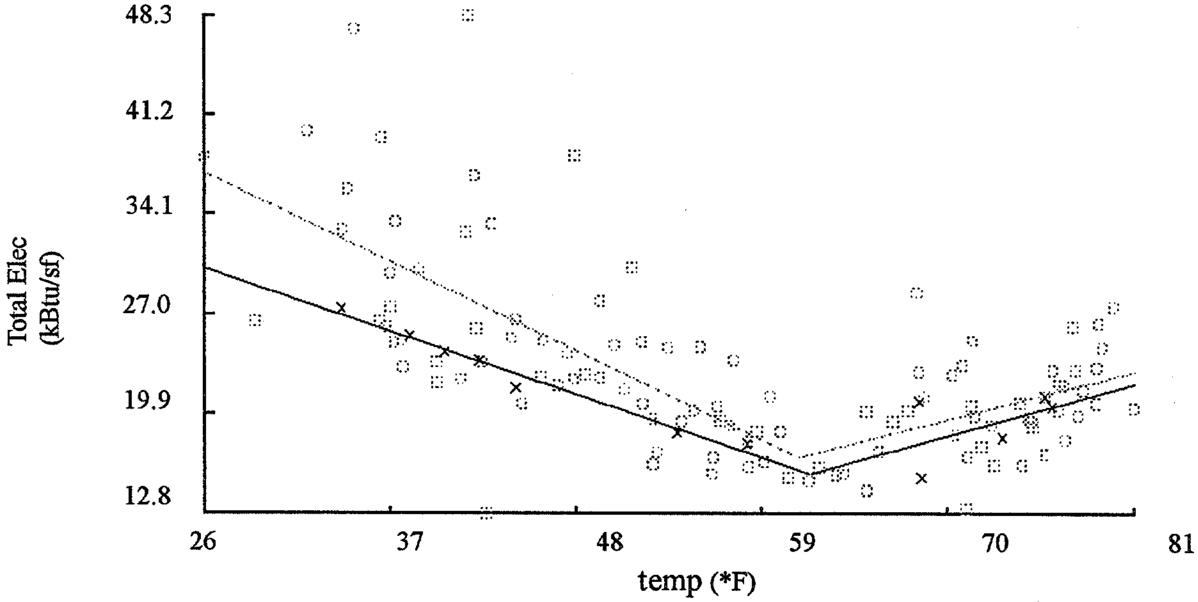

Figure 8. Fort Campbell Total Energy 1996. Ycp = 15.5962 (2.7473) LS = -0.4036 (0.0595) RS = 0.3318 (0.1712) Xcp = 61.7700 N = 12 N1 = 7 N2 = 5 R2 = 0.86 RMSE = 1.4496 CV-RMSE = 6.8% p = 0.42 DW = 1.16 (i%)

As mentioned earlier, the steady state inverse model is the simplest form of an inverse model. It represents heating loads well, but not always cooling loads. For example, the coefficient of variation-root mean square error (CV-RMSE) for the heating load was 8% for 1992 and 5% for 1996. These are quite low and indicate a good fit for the heating model. The CV-RMSE for the electrical load was 14% for 1992 and 11% for 1996. This indicates that the model is marginal, although empirical data with CV-RMSE if less than 15% is generally considered acceptable. The inverse model does not account for humidity affects on electrical loads for air conditioning. The general outdoor climate at an installation should remain relatively stable and be somewhat repeatable. The large collection of buildings may also tend to even things out. One option would be to use multiple variables when evaluating cooling, but this would increase the requirements for data and make the analysis too complex. Historically a three-parameter model was used for both heating and cooling estimates. Since loads have become more complex and interactive, the four-parameter model is now a better fit. This is because both sides of the change point may now be weather dependent.

Conclusion

When these methods were applied to actual installation data, several aspects became apparent. The fossil fuel model was more accurate than the electrical model. The installation's energy response to large projects is visible in the model. The accuracy of the billing data is extremely important in obtaining an accurate model – a good fit. Therefore, billing data should be reviewed to ensure that it is synchronous with the weather data and billing anomalies are understood and removed.

The methods described in this paper can be used to evaluate large-scale energy projects on military installations where metered data is at a premium. It is too costly to continually meter individual buildings. The EModel program is easy to use and the data required is readily available to the installation staff. It provides a simple methodology that can independently verify saving indicated by contractors. It can also be used to validate savings from the government's own investments on installations.

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