LOANSTAR DATA HANDLING AND ANALYSIS SOFTWARE FOR MEASURING BUILDING ENERGY DATA

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ABSTRACT

This paper discusses the data handling and analysis software that has been produced as part of the Texas LoanSTAR program, a $98.6 million revolving loan program for funding energy conservation projects in state agencies. In this paper an overview of the different facets of data management for monitoring building energy data is presented. LoanSTAR software that is now available for others to use is also discussed, including: PC-based MS Windows 3.1 software for analyzing before-after energy use data (EModel), software for viewing time-sequenced, temperature dependent trends (Animate), software for viewing 3-D images (Look3D), software for viewing solar data (Solrpath), and software for viewing real-time logger data (Monitor). The Energy Systems Laboratory (ESL) has also developed a combined, general purpose software package for polling, archiving, analyzing and reporting building energy data from multiple sites (MAP).

INTRODUCTION

The Texas LoanSTAR (Loans to Save Taxes And Resources) Program was established in 1988 by the Texas Governor's Energy Office as a revolving loan program for funding energy conserving retrofits in state and local government buildings. The program has been very successful. As of September 1996 the program has measured hourly savings from energy conservation retrofits of $26.0 million as shown in Figure 1 which are composed of 41.3% electricity savings, 41.6% chilled water savings and 36.7% heating savings. These savings are 117% of the audit estimated savings of $22.2 million as shown in Table 1. Total program savings are $35.9 million which also include $6.8 million in savings from Operation and Maintenance measures, $2.4 million in savings from street lighting retrofits, $551,000 in savings from schools in the Ft. Worth area and $201,000 in savings from smaller sites utilizing a monthly utility billing analysis.

LoanSTAR has been recognized by the USDOE and USEPA as a model program for its effectiveness and ground-breaking work. The data analysis methods developed in the program have also been adopted as the basis for the before-after monitoring procedures (Option C) in the North American Energy Measurement and Verification Protocols (NEMVP 1996).

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One of the important features of the LoanSTAR program is the Monitoring and Analysis Program that measures and reports energy savings from the retrofits using hourly before-after measurements in sites where the cost of the retrofit exceeds $100,000. At such sites data acquisition systems are ideally installed six to twelve months prior to the retrofit to monitor energy consumption so that an hourly whole-building, before-after analysis can be used as the basis for calculating savings.

DATA MANAGEMENT AND ANALYSIS

Currently, the LoanSTAR program is measuring hourly energy use in over 350 buildings at 127 sites which includes 1,729 channels of data or about 1.3 million readings per month. Weather data are also recorded from 61 National Weather Service (NWS) sites which add an additional 183 channels or 132,200 readings per month[4]. LoanSTAR data management includes several major functions, including: retrieving data from the data acquisition systems via modem[5], processing the data from all sites into a common format, checking the data quality, archiving the data in a relational database, analyzing the data for savings and reporting of results. Software for performing these functions has been written almost exclusively in-house or assembled from available software routines. Numerous references that document the analysis methods are reported in Haberl et al. (1995; 1992).

The flowchart for the information and data flow in the LoanSTAR program is provided in Figure 2. Each week the data acquisition systems are polled and the data downloaded into the central facility via modem[6]. These data are then loaded into the relational database that resides on a central UNIX computer. The relational database serves as the central repository for all time series data and is called upon for the analysis of savings, the production of the weekly inspection plots (IPN), Monthly Energy Consumption Report (MECR), Annual Energy Consumption Reports (AECR), and Data Summary Notebooks (DSN). All data collected since the program started in 1989 are on-line in the database which amounts to 82.2 million readings or about 2.7 gigabytes of on-line storage.

Weekly Inspection Plots

Although all channels can be processed with simple high-low limits and relational checks, the primary data quality checks continues to rely on visual inspection of every incoming channel using weekly inspection plots. Each week 1,800 plots are produced amounting to about 150 pages that are circulated to the Energy Systems Laboratory (ESL) staff and PIs in a bundle known as the Inspection Plot Notebook (IPN). Production of a single plot can involve gathering data from several sites[7], knitting the data into one

[4] Other non-LoanSTAR work at 75 sites adds 700 channels or 505,680 million readings which brings the total from all sites to 2,429 channels or 1.8 million readings per month. 15-minute data are collected at sites where peak electric demand analysis is needed to evaluate thermal storage.

[5] Recently, at one prototype site data are now being retrieved directly via the internet without the need for phone lines.

[6] The initial polling of the loggers and analysis of problematic sites takes place on a UNIX machine. Additional polling of problematic machines is performed on a DOS machine.

[7] For example, weather data and energy use data to produce an x-y scatter plot.

graph per channel[8], assembling and positioning the graphs onto a page, and printing the page. This process normally takes place on the UNIX machine as part of the polling, initial data checking and archiving that begins Monday night shortly after midnight and is completed Tuesday morning. Visual inspection of the plots takes an additional 10 to 20 man-hours per week and is completed and comments distributed to the field engineers and data analysts prior the polling process on the following week.

An example weekly inspection plot is provided in Figure 3 for a state agency in Austin, Texas. In the upper left corner one week (168 records) of whole-building electricity is plotted beginning on November 5, 1996, (Tuesday, midnight). Following across the top row is the ambient dry bulb temperature, relative humidity, and global solar radiation. In the second row, beginning on the left, is the chilled water thermal energy use, motor control center (MCC) and air handler electricity use (AHU), chiller electricity use followed by an x-y scatter plot of the chiller kW/ton versus maximum chiller load. In the bottom row, on the left, the chilled water is plotted against the corresponding hourly ambient temperature, followed by a similar plot of MCC and AHU electricity use, and chiller electricity use. Lastly, a histogram of the hours of usage is juxtaposed directly below the corresponding chiller kW/ton plot to indicate the number of hours in the week that the chiller was run at the different chiller loads -- a useful graphical figure of merit to assess chiller performance.

LoanSTAR Data Analysis

In the LoanSTAR program savings calculations utilize one of several methods, including regression models, and calibrated simulation models as shown in Figure 4. When adequate pre-retrofit data are available[9] a regression model can be fit to the baseline data that captures the weather dependent or schedule dependent energy consumption characteristics. The dependent regression parameters of the baseline model are then driven by the post-retrofit independent data (i.e., weather or schedule) to predict what the building would have consumed if the energy conservation retrofit had not taken place. This is then compared to the measured post-retrofit data to calculate the savings.

The general procedure for calculating daily[10] savings from energy conservation retrofits when adequate before-after data are available can be summarized by:

$$\sum_{j=1}^{m} E_{save,j} = \sum_{j=1}^{m} E_{baseline,j} - \sum_{j=1}^{m} E_{measured,j} \qquad (1)$$

where

j = subscript representing a particular day in the post-retrofit period,

[8] In some cases this can involve summarizing several channels, for example in 3-phase electric loads.
[9] Usually, 9 to 12 months of data are recommended to make sure that all seasonal effects are adequately represented.
[10] This type of analysis applies to sites where daily models are appropriate. Additional procedures have been developed as sites where hourly models are in use. Information about hourly modeling procedures can be obtained by visiting the ESL home page on the internet at http://www-esl.tamu.edu/.

m = number of days in the post-retrofit period,
$E_{save,j}$ = energy savings attributable to the energy conservation retrofit,
$E_{baseline,j}$ = energy use predicted by the baseline regression model for the post retrofit period,
$E_{measured,j}$ = measured energy use in the post retrofit period.

Figure 5 shows several types of steady-state, single variable regression (or inverse) models that are the most appropriate for modeling building environmental systems with thermostatic behaviors. Figure 5a shows a simple one-parameter, or constant model, and equation (2) gives the equivalent notation for calculating the constant energy use using this model. Figure 5b shows a steady-state, two- parameter model where B_0 is the y-axis intercept and B_1 is the slope of the regression line for positive values of x, where x represents the ambient air temperature. Figure 5c shows a three- parameter, change point model. This is typical of heating energy use in a single family residence that utilizes gas for space heating and domestic water heating. In equation (4), which is given for the three-parameter heating model, B_0 represents the baseline energy use, B_1 is the slope of the regression line for values of ambient temperature less than the change point B_2. In this type of notation, the exponent (+) indicates that only positive values of the parenthetical expression are considered. Figure 5d shows a three-parameter model for cooling energy use, and equation (5) gives the appropriate expression for analyzing cooling energy use with a three-parameter model.

Figures 5e and 5f illustrate four parameters for heating and cooling, respectively. Equations (6) and (7) indicate the respective expressions for calculating heating (Figure 5e) and cooling (Figure 5f) energy use using a four-parameter model. In a four-parameter model, B_0 represents the baseline energy exactly at the change point B_3. B_1 and B_2 are the lower and upper region regression slopes for ambient air temperature below and above the change point B_3.

Equation (8) gives the expression for calculating a five-parameter model where there are separate change points for heating and cooling energy use as might be expected in a facility that is heated and cooled with an electric heat pump for cases where the change point $B_3 < B_4$. For cases where there is simultaneous heating and cooling, i.e., $B_3 > B_4$, the base-level B_0 will be artificially high, and sub-metering is recommended to differentiate between heating and cooling.

$$E_{period} = B_o \quad (2)$$

$$E_{period} = B_o + B_1 (T) \quad (3)$$

$$E_{period} = B_o + B_1 (B_2 - T)+ \quad (4)$$

$$E_{period} = B_o + B_1 (T - B_2)+ \quad (5)$$

$$E_{period} = B_o + B_1 (B_3 - T)+ - B_2 (T - B_3)+ \quad (6)$$

$$E_{period} = B_o - B_1 (B_3 - T)+ \; + \; B_2 (T - B_3)+ \qquad (7)$$

$$E_{period} = B_o + B_1 (B_3 - T)+ \; + \; B_2 (T - B_4)+ \qquad (8)$$

In cases where regression models are not appropriate other analysis methods are used such as calibrated simulations. In Figure 4, on the right-hand side, an example is shown where a dual-duct constant volume air handling unit (DDCV) is retrofitted with a variable air volume (VAV) system in the case where no preretrofit data are available[11]. In such a case a simulation model is calibrated to the post-retrofit data and the effects of the retrofit analyzed with the simulation program by comparing the energy use of the measured VAV system to the simulated energy use of the DDCV system (Katipamula and Claridge 1993).

Monthly Energy Consumption Reports

The weekly generation of inspection plots allows for the primary verification of the data from the monitoring systems. However, one of the primary goals of the project as a whole is the creation of Monthly Energy Consumption Reports (MECR) which are sent back to the participating facilities. This is the major feedback route from LoanSTAR to the participating agencies. Figure 6a-d illustrate several pages of the MECR. The content and value of the MECR is discussed in additional detail in Claridge et al. (1991), and Lopez and Haberl (1992). Briefly, each building receives a six page report that consists of:

1) A title page giving the mail/phone contacts both at the agency and at the ESL (Figure 6a). This page also includes a monthly total of chilled water, hot water (or steam use), and electricity use, and the peak 60 minute electric demand (if available). In buildings where the retrofits have been completed the page also lists estimated and measured monthly retrofit savings. A comment section is also included to bring important points to the attention of the agency.

2) Scatter plots of daily chilled water use and hot water (or steam) energy use versus average daily ambient temperature (Figure 6b).

3) An hourly time series trace for the chilled water and hot water channels for the month.

4) An hourly time series of the electricity channels and ambient conditions (i.e., temperature and humidity) (Figure 6c).

5) Two three-dimensional plots that show whole-building 24-hour electricity profiles in daily slices for a two month period (Figure 6d).

6) A summary page with information about the building (e.g., square footage, occupancy schedules, retrofit dates, etc.).

[11] This has happened when construction begins immediately after a site is approved for a loan and monitoring equipment cannot be installed until the post-retrofit period.

Available Software

One of the objectives of the LoanSTAR program was to develop software that building professionals in Texas could use to perform building energy analysis. This objective has been met with the creation and distribution of several packages, including the EModel program for energy analysis, Animate, Look3D, and Solrpath programs for advanced data viewing, and the Monitor for continuously viewing data from a data logger. The ESL has also developed the energy Metering Analysis Program (MAP)[12] that allows for polling, data verification, archiving and analysis of time series data[13] from multiple sites within one package.

The EModel software (Figure 7) is a tool for the analysis of building energy use data. It integrates the previously laborious tasks of data processing, graphing, and modeling into an easy to use windows environment. EModel allows for regressions that utilize one-parameter, two-parameter and four-parameter change-point models. Multiple regressions and bin models can also be performed.

Animate allows the user to plot columnar data in multiple relational graphs. A variable-length line can also be created which sequences through the data to allow one to detect time and (in some cases) temperature dependent trends. Figure 8 illustrates a single view of the Animate software.

Look3D is the ESL's general purpose, x-y-z surface plotting routine. Look3D is used most often for plotting schedule dependent data against the day of the year and hour of the day as shown in Figure 9. Colored contours can be added to Look3D to help emphasize the surface plot. Look3D also allows for viewing from any angle.

Solrpath has been created for viewing solar data by projecting the data upon the sunpath diagram as shown in Figure 10. The impact of different shading devices can then be analyzed using the shading mask protractor that is provided for any latitude.

Monitor is the ESL's software for continuously viewing multiple channels of data from a data logger in real time. Several different graphical metaphors have been created for the monitor including: a pen-and-ink chart, a speedometer and a VU-type meter that allows for multiple (i.e., high, medium and low) bands to be preprogrammed into the background of the graph to aid in assessing data as it is plotted[14].

MAP is the ESL's software that combines all the steps of energy consumption analysis from data collection to analysis to reporting in one PC-based software package. MAP can

[12] Under a separately funded program.

[13] MAP is capable of analyzing any kind of time series data with uniform time intervals (i.e., 1-minute data, 15-minute data, hourly data, etc.).

[14] The ESL has also developed a modem-switch that allows for two modems to be connected to a data logger. At such sites the building operators can continuously view the building's energy use using one modem and the ESL can poll and retrieve the time series records for verifying the LoanSTAR savings. Additional information about the modem-switch can be obtained by contacting the authors.

collect data from several different data loggers and can automatically download data that has been reported by the National Weather Service[15]. MAP has its own internal database that allows for seamless access to data across sites. MAP contains graphical capabilities, including: time series, x-y plots, and histograms, as well as advanced features that allow for data channel creation and advanced grouping features.

SUMMARY

The Texas LoanSTAR program has demonstrated that savings from energy conservation retrofits can be accurately measured to assure that the intended retrofits are working. An important feature of the program has been the development of procedures for collecting and analyzing hourly data from multiple sites. These procedures have been documented in numerous publications that can be accessed via the internet at http://www-esl.tamu.edu/. One of the objectives of the LoanSTAR program has been the development of software for helping others setup and develop their own monitoring and analysis programs. This has been accomplished through the programs that are described in this paper.

ACKNOWLEDGMENTS

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REFERENCES

Claridge, D.E., Haberl, J.S., Sparks, R., Lopez, R., Kissock, K. 1992. "Monitored Commercial Building Energy Data: Reporting the Results." *1992 ASHRAE Transactions Symposium Paper*,Vol.98, Part 1, pp. 636-652, (January).

Haberl, J., Reddy, A., Claridge, D., Turner, D., O'Neal, D., Heffington, W. 1995. "Measuring Energy-savings Retrofits: Experiences from the Texas LoanSTAR Program", *Oak Ridge National Laboratory Report No. ORNL/SUb/93-SP090/1.*

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[15] This feature currently requires that an appropriate account be initiated with the AccuWeather weather service company in State College, PA.

Haberl, J., Lopez, R. 1992. "LoanSTAR Monitoring Workbook", Workbook and software for monitoring energy in buildings, Texas LoanSTAR Program, Energy Systems Laboratory, Texas A&M University, sponsored by the Texas Governor's Energy Office, (August).

Katipamula, S., and Claridge, D. 1993. “Use of Simplified System Models to Measure Retrofit Savings, *Journal of Solar Energy Engineering, ASME Transactions*, Vol. 115, pp. 57-68.

Lopez, R., Haberl, J. 1992. “Data Processing Routines for Monitored Building Energy Data”, *Proceedings of the ASME Solar Engineering Conference*, Vol. 1, p. 329 - 336.

NEMVP 1996. North American Energy Measurement and Verification Protocols, United States Department of Energy, Document No. DOE/EE-081, Washington, D.C., also available on the internet at /www.eren.doe.gov/.

Table 1: Total Measured Cumulative Program Savings October 1990 to September 1996.

	Electricity	Chilled Water	Hot Water/ Steam/N.Gas	Total
Baseline Use	$69,426,000	$28,724,000	$12,095,000	$108,908,000
Post-Retrofit Use	$58,665,000	$17,895,000	$7,656,000	$82,879,000
Measured Savings	$10,761,000	$10,829,000	$4,439,000	$26,029,000
% of Baseline Use	15.5%	37.7%	36.7%	23.9%
% of Tot. Meas. Use	41.3%	41.6%	17.1%	100 %
Audit Estimated Savings	$10,573,100	$7,488,800	$4,123,200	$22,185,100

Figure 1: Total Measured Cumulative Program Savings as of September 1996. Total savings include $10.7 million in electricity savings, $10.8 million in chilled water savings and $4.4 million in heating savings.

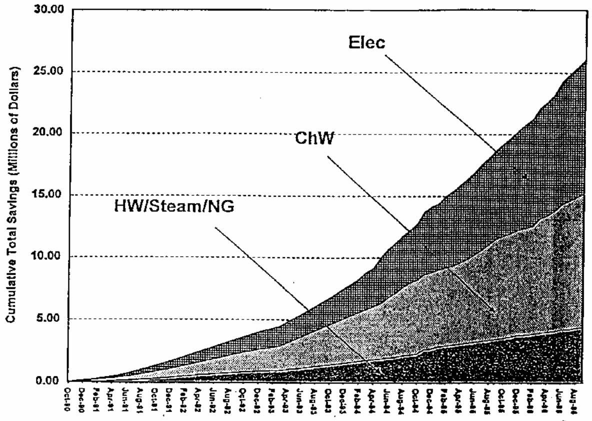

Figure 2: Information and Data Flow Diagram for the LoanSTAR Program.

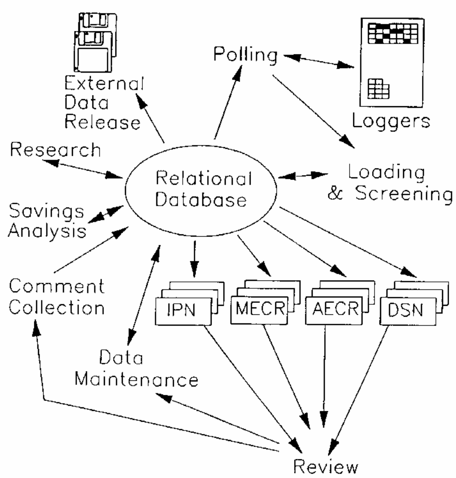

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Figure 3: Typical Inspection Plot for a State Agency in Austin, Texas.

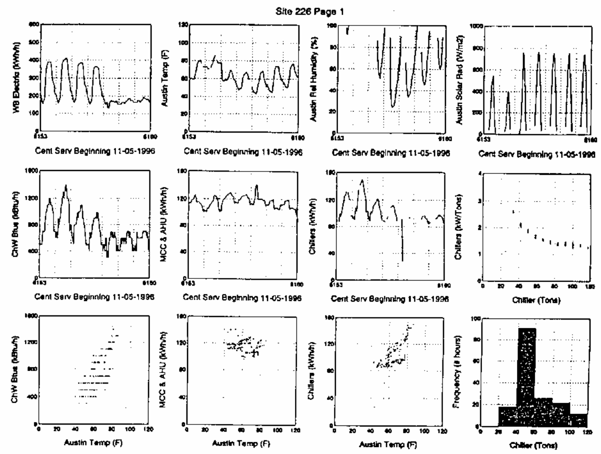

Figure 4: Basic Types of Analysis used in the LoanSTAR Program.

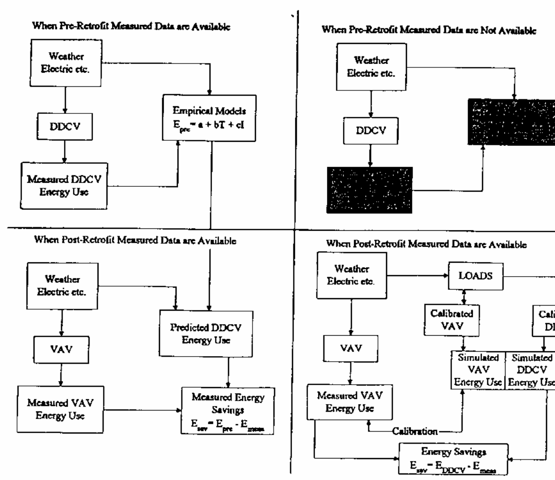

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Figure 3: Typical Inspection Plot for a State Agency in Austin, Texas.
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Figure 5: Steady-state, single variable models appropriate for commercial building energy use: (a) one-parameter model, (b) two-parameter model shown for cooling energy use, (c) three-parameter heating energy use model, (d) three-parameter cooling energy use model, (e) four-parameter heating energy use model, and (f) four-parameter cooling energy use model, (g) five-parameter heating and cooling energy use model (with distinct heating and cooling modes).

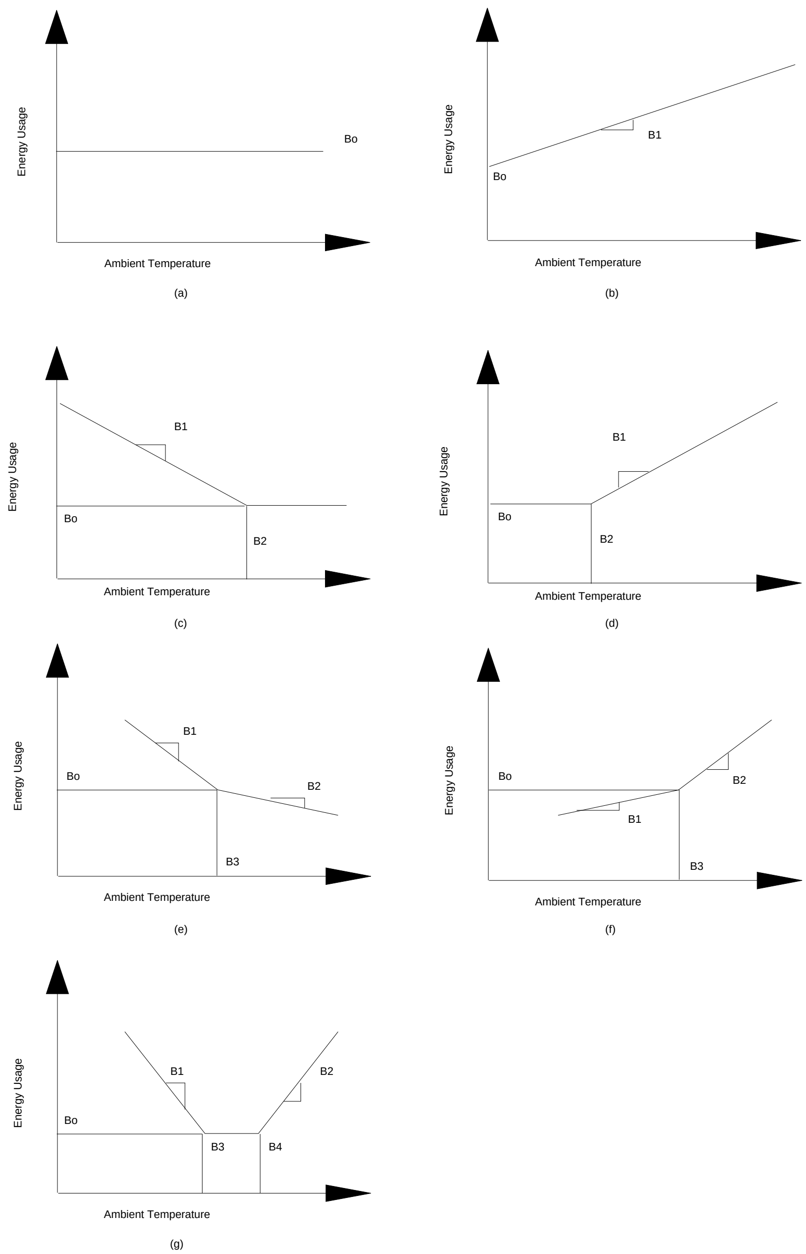

Figure 6a-d: Typical Monthly Energy Consumption Report.

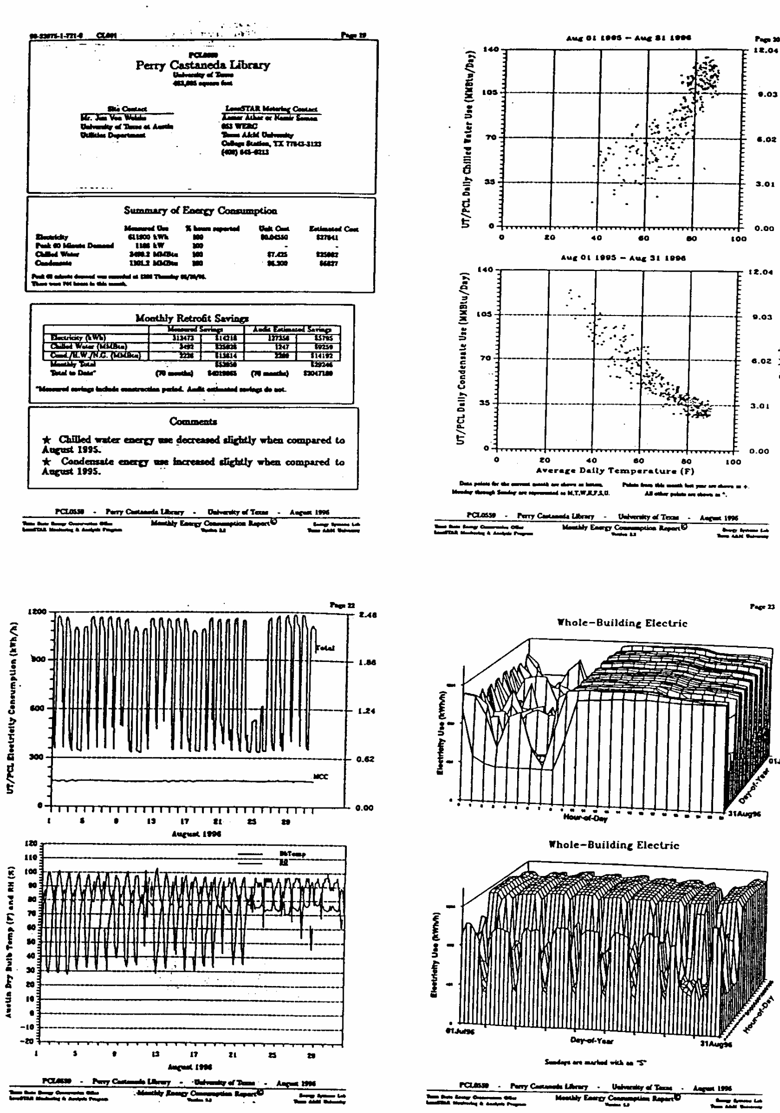

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Figure 6a-d: Typical Monthly Energy Consumption Report.

Figure 7: EModel Software for Analyzing Energy Savings From Conservation Retrofits.

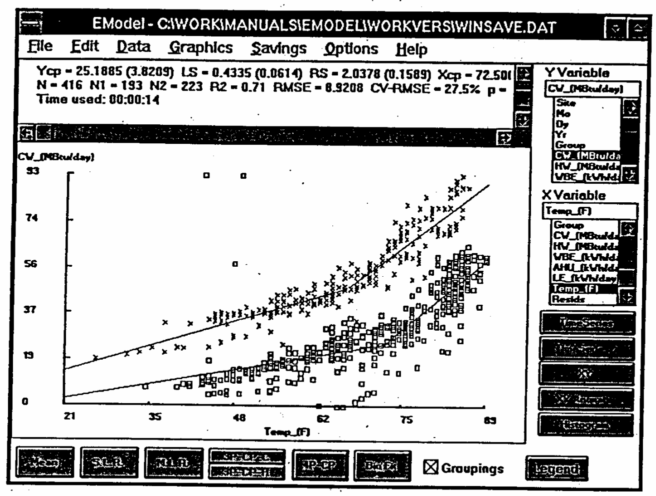

Figure 8: Animate Software for Viewing Time-sequenced Temperature-dependent Trends.

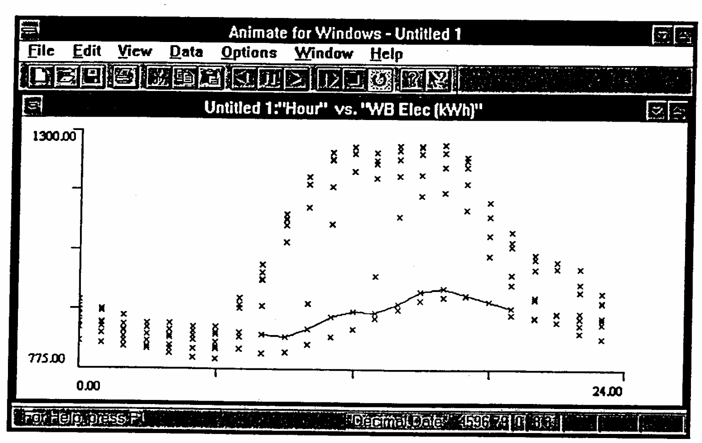

Figure 7: EModel Software for Analyzing Energy Savings From Conservation Retrofits.
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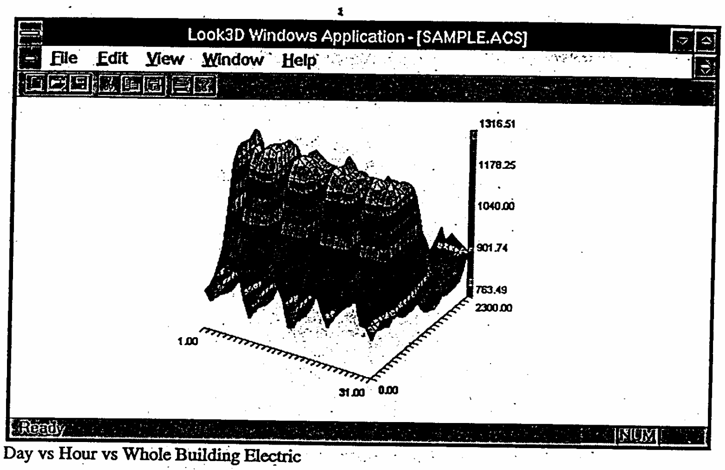
Figure 9: Look3D Software for Viewing Schedule-dependent Trends.



Day vs Hour vs Whole Building Electric

Figure 10: SOLRPATH Software for Viewing Measured Solar Data.

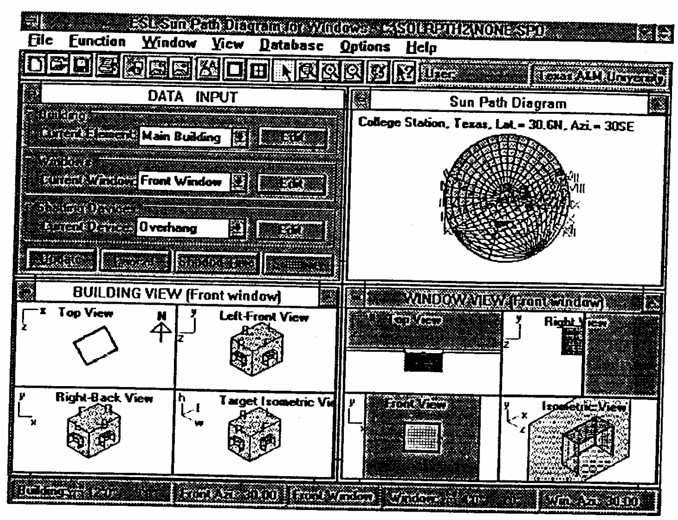


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Figure 11: Monitor Software for Viewing Real Time Data from Data Loggers.

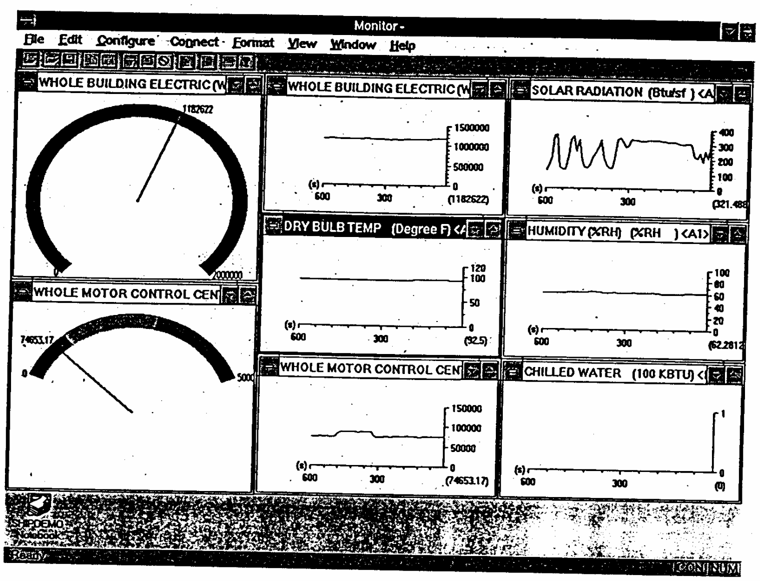

Figure 12: MAP General Purpose Software for Polling, Archiving and Analyzing Energy Use Data From Multiple Loggers.

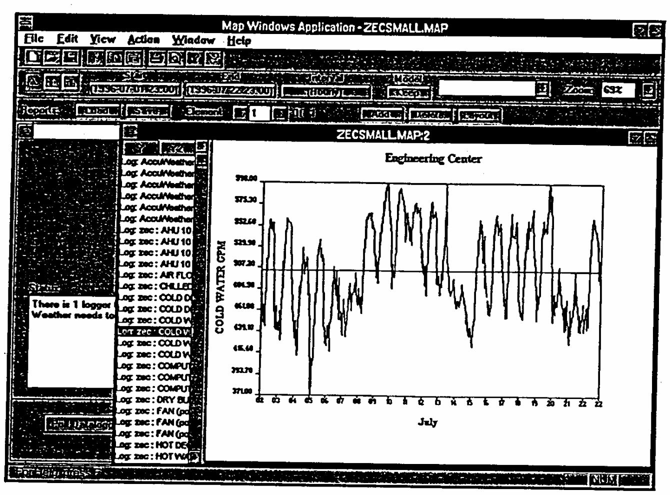

Figure 11: Monitor Software for Viewing Real Time Data from Data Loggers.

Figure 12: MAP General Purpose Software for Polling, Archiving and Analyzing Energy Use Data From Multiple Loggers.