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MONITORED COMMERCIAL BUILDING ENERGY DATA: REPORTING THE RESULTS

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INTRODUCTION

Traditionally, the only monitored whole-building energy data available have been monthly utility bills. In many instances, the bills were sent to the accounting department and ignored by everyone except the accountants. In recent years, as energy management has become a visible activity, these billing data are sometimes examined by the energy manager and in special cases may be normalized for weather, building area, etc. However, many large organizations, such as government agencies, universities, etc., often have an entire complex of buildings on a single meter, significantly complicating use of billing data for energy management. A variety of techniques have been applied to the use of utility billing data for energy accounting purposes, but these will not be discussed in this paper.

During the last 10 years, with the growth of demand-side management programs and the declining cost of data acquisition equipment and computers, there has been an increasing number of programs where a non-utility third party monitors a number of channels of energy and related data and archives the information for later analysis. The data may be recorded in monthly increments but generally are recorded more frequently, typically daily or hourly.

The general pattern for collecting and reporting these data has been to poll the data acquisition equipment at the building site by phone modem and archive the data on magnetic medium at a regular interval (e.g. daily, weekly, monthly). Data quality checks (e.g., sum checks, high-low limit checks, etc.) are sometimes applied when the data are collected or within a few days of collection. However, plotting, analysis, and reporting of the data collected have generally followed at an interval of months to years following collection. Many investigators have discussed data collected by monitoring projects, such as the ELCAP project (Pratt et al. 1989), Energy Edge (Diamond et al. 1990), and monitoring conducted by utilities around the country, while others, such as MacDonald and Wasserman (1988), Fels (1986), Hadley and Tomich (1986), Ruch et al. (1991), Claridge et al. (1990), etc., have emphasized the techniques used to analyze the data collected.

Significantly less attention has been devoted to the format and timing of reports on the monitored data. Lutz (1990) emphasized approaches that can be used to get important results published in media with a broader audience than technical reports and academic journals, while Kempton and Komor (1990) examined formats for presenting feedback, units used to present this information, and the time intervals at which feedback is presented. The relative lack of attention to this area is probably due to the typical users of the data in the past. Researchers, utility planners, government planners, etc., would all like to have the data immediately, but the information loses little currency if delivered a year or two after collection and may increase in value if it has benefited from insightful analysis. Energy managers who wish to determine the success or failure of an energy-saving retrofit project can still use the information a year later as a success story to help sell the next project, though it would be more valuable if current.

However, the use of consumption data to provide near-term feedback to owners and operators to increase operating efficiency has emerged in the last few years. Methods that provided real-time feedback on energy cost to homeowners were investigated in the 1970s (Seligman et al. 1978) but failed to catch on as concerns about energy cost waned. However, the benefits of regular feedback have been shown in several case studies (Haberl and Claridge 1987; Haberl and Vajda 1988; Haberl and Komor 1990; Kempton and Komor 1990; Katzev and Johnson 1987; Kinney and Romano 1990). Different forms of feedback, including weekly time series plots of consumption, three-dimensional time series plots, three-dimensional residuals of measured less modeled consumption, plots of savings resulting from specific operational improvements implemented, etc., have been found to be useful.

The Texas LoanSTAR program is a $98.6 million revolving loan program funding energy-conserving retrofits in Texas state, local government, and school buildings. Public sector institutions participating in the program must repay the loans according to estimated energy savings in four years or less.

This program has established an energy monitoring and analysis program (MAP), which is installing data ac-

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quisition equipment to monitor the energy use of each large building at the whole-building level, with consumption often submetered for a short period of time before the retrofits are installed and monitoring continued subsequent to the retrofits. The major objectives of the LoanSTAR MAP are to (1) verify energy and dollar savings of the retrofits, (2) reduce energy costs by identifying operational and maintenance improvements, (3) improve retrofit selection in future rounds of the LoanSTAR program, and (4) initiate a data base of energy use in institutional and commercial buildings in Texas. More than 2.4 megabytes of data are currently being acquired from more than three dozen buildings every week. Installation of the first retrofits was completed in January 1991. The program is described in more detail in Verdict et al. (1990) and Turner (1990).

As noted, the monitoring determines the retrofit savings in the program, but the second major objective of the monitoring program is to use the monitored data to identify additional measures that can be implemented to make the buildings operate more efficiently. There are several facets to this question.

- Is the retrofit working properly?
- Are the building systems working properly?
- Can changes in operation or maintenance lower operating cost?

Determining the answers to these questions requires a thorough understanding of the data collected and of the building and systems from which the data are collected. The audit reports and site description information are very useful in developing an understanding of the building, but a crucial part of the process is meetings and discussions with the facility engineer and building operators.

Furthermore, if operation and maintenance measures are identified, the cooperation of the facility engineer and building operator is essential before any operational savings can be realized. Part of the communications process is transmittal of the data collected from the building to the operators in a format that they can easily understand. Traditional engineering reports and papers are not current enough to be useful, and the format and language would typically obscure key information from most operators. Hence, we have developed several forms of largely graphical reporting that are used with the facility engineers and operators in the buildings monitored. The three forms described in this paper are monthly energy consumption reports, computer files of the data with browsing software, and weekly inspection plots. All three of these reporting forms are also used by program staff, building operators, facility engineers, and program managers for a variety of purposes.

MONTHLY ENERGY CONSUMPTION REPORTS

A six-page energy consumption report is sent monthly to each facility monitored. This report contains two pages of tables and text and four pages with graphs of consumption data for the previous month.

The first page of the report provides a concise summary of current energy consumption retrofit savings and a comments section. Figure 1 shows the first page of the April 1991 report for a 324,000-ft^2 (30,100-m^2) engineering center with a dual-duct VAV retrofit that became operational during March. The report shows that the building uses electricity, chilled water, and hot water. All three are supplied from a central plant and were not metered at the building until data acquisition equipment was installed to acquire pre-retrofit data. Peak 60-minute electricity demand is reported instead of the standard 15-minute demand, since 60 minutes is the integration period for the data collected. Though names have been removed from the figure, the original report contains the names, addresses, and phone numbers of individuals at the facility who can be contacted regarding unusual data, building schedules, etc., and the name of a person with the monitoring project to whom questions about this report can be directed. The retrofit seems to be working well—the savings are slightly higher than projected by the audit report. The comments section provides individualized feedback to the agency and building operators on items noted by the project staff, for example, that savings were also observed during the construction period and total savings of $83,694 have accrued.

Engineering Center

324,400 square feet

Site Contact	LoanSTAR Contact
Name	Name
Address	Address
Telephone	Telephone

Summary of Energy Consumption

	Measured Use	% hours reported	Unit Cost	Estimated Cost
Electricity	702476 kWh	99.9	-	-
Peak 60 Minute Demand	1312 kW	99.9	-	-
Chilled Water	1590.7 MMBtu	99.9	-	-
Hot Water	439.4 MMBtu	99.9	-	-

Peak 60 minute demand was recorded at 1500 Wednesday 4/3/91
There were 720 hours in this month

Measured Monthly Savings

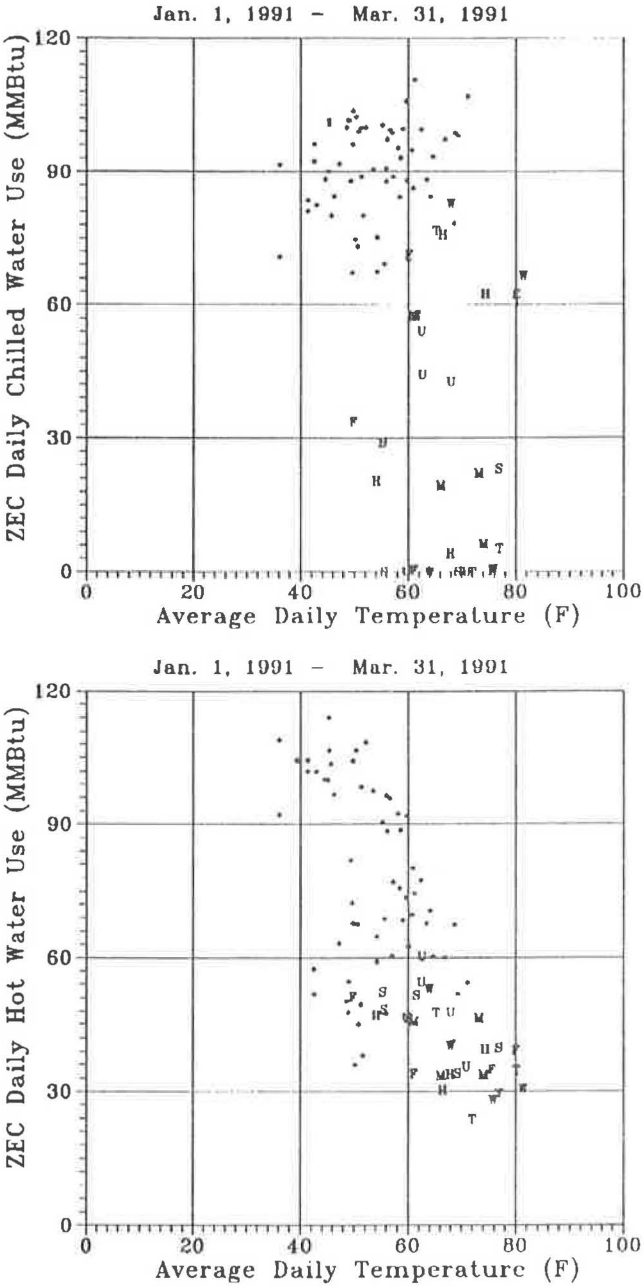
Actual	Predicted
$26,968	$24,915

Comments

★ Total savings to date including those measured during construction are $83,694. Savings are calculated with the 1988 costs used for loan payback estimates. Savings estimates are preliminary and subject to adjustment.
★ There appears to be a change in system operation near the middle of the month.

Figure 1 *Summary page (p. 1) from the April 1991 energy consumption report for an engineering center at a large university with site-specific names removed.*

The second page of the report plots daily chilled-water (or other cooling energy) consumption as a function of daily average dry-bulb temperature and hot water (or other heating energy) as a function of average dry-bulb temperature. Figure 2 shows an example taken from the March report for the engineering center shown in Figure 1. Note that the March consumption is plotted using M,T,W,H,F,S,U to indicate days of the week for the current month, with the January-February consumption plotted using dots. This helps identify changes in consumption patterns—the data of Figure 2 show sharp drops after the VAV system became operational on March 4, when compared with the January-February consumption. The use of letters also helps identify outliers and determine whether specific events occurred on weekdays, weekends, holidays, etc.



Data points for the current month are shown as letters.
Monday through Sunday are represented as M,T,W,H,F,S,U.

Figure 2 *Plots of daily chilled-water and hot water consumption for January 1, 1991-March 31, 1991 for an engineering center as given on the second page of the March energy consumption report. Letters denote March consumption and dots denote January-February consumption.*

The third page of the report gives time series plots of the hourly chilled-water and hot water consumption for the month. Figure 3 is an example taken from the March report when the VAV retrofit became operational. There is no obvious change in the consumption patterns after March 4, but the chilled-water data show gaps and sporadic consumption that is characteristic of continued construction activity to replace several chilled-water coils after initial system startup.

The top half of the fourth page of the report shows a time series plot of the hourly electricity consumption for the building and also shows submetered electricity consumption (Figure 4). The whole-building consumption (top line) shows well-defined weekday/weekend differences. Submetered data are shown for the air handlers, super-computer room, and a derived channel for the lights and receptacle loads. The air-handler channel clearly shows the VAV startup, as the air-handler consumption dropped abruptly from about 380 kW to about 130 kW. The air-handler consumption continues to show evidence of construction/commissioning activity until March 18 and shows daily variation typical of a VAV system thereafter.

The bottom half of page four shows the local ambient dry-bulb temperature and relative humidity.

Page 5 (Figure 5) gives two views of a three-dimensional surface plot of the whole-building electricity consumption taken from the May consumption report for a 251,000-ft^2 classroom/office building at another university. This figure shows the April and May consumption and provides more detail on daily patterns and day-to-day variation than is readily apparent in the two-dimensional plots given on page 4 of the reports. In the bottom part of this figure, the decrease of about 200 kW in whole-building electricity use due to the startup of the VAV air-handler drives in this building is apparent. The "canyons" show the typical weekend drop in consumption. The view in the top part of this figure tends to make unusually high consumption during any part of the period evident. It is clear that during the early morning hours of one day (which can be identified as May 10 in other plots), about 200 kW of loads normally turned off at night were left on. The last page of the report provides a written summary of the building envelope construction characteristics, HVAC system(s), building use and HVAC schedules, lighting, and planned or installed retrofits and

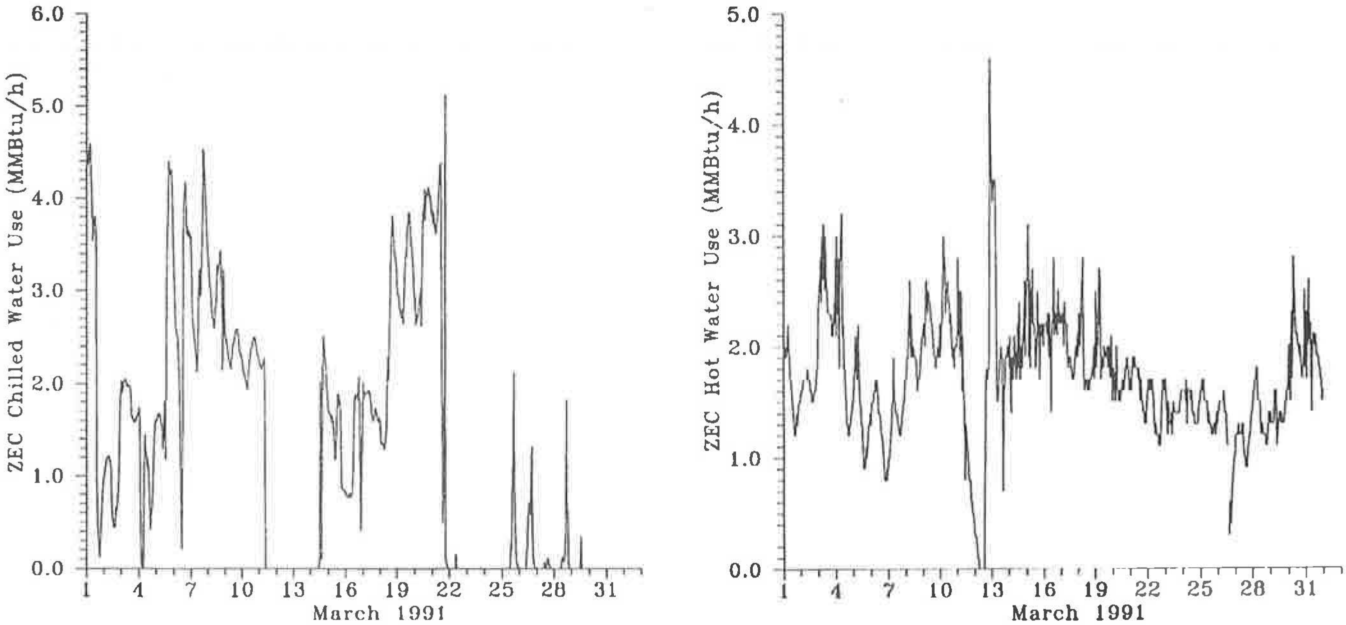


Figure 3 *Time series plots of hourly chilled-water and hot water consumption for the engineering center as shown in the March energy consumption report.*

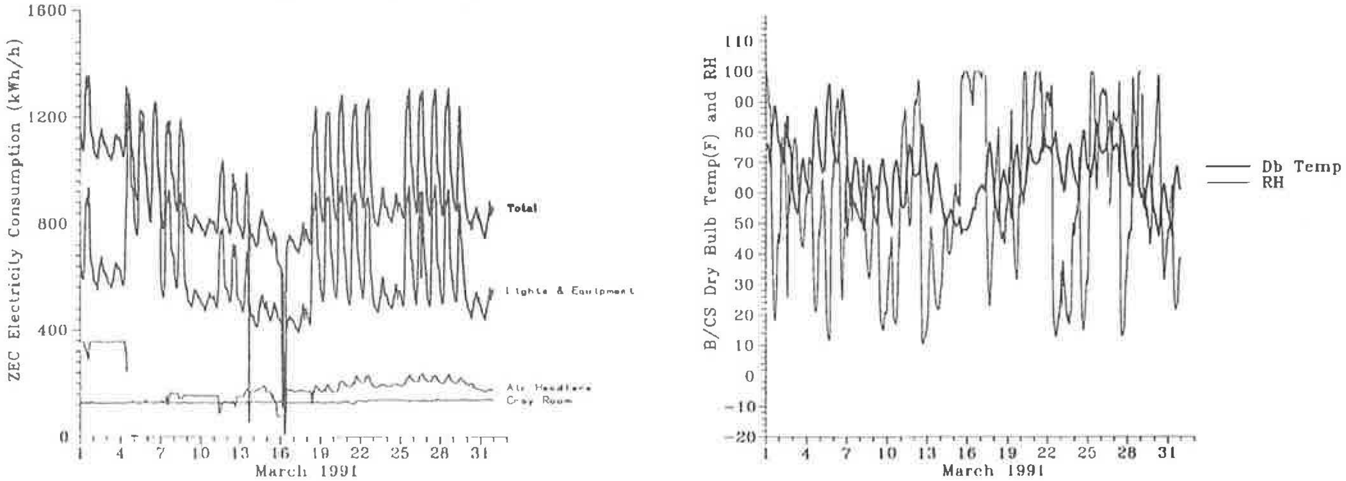


Figure 4 ***Hourly whole-building and submetered electricity consumption, ambient dry-bulb temperature, and relative humidity at the engineering center for March 1991.***

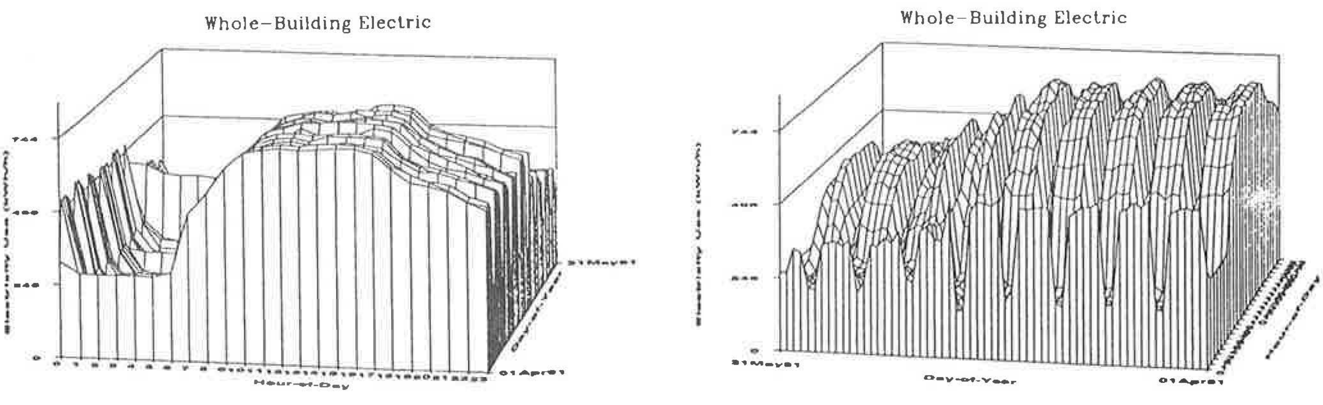


Figure 5 *Two views of a three-dimensional plot of April-May 1991 whole-building electricity consumption for a university classroom/office building as shown on page 5 of the May monthly energy consumption report.*

status. This page normally changes only when retrofits or schedules change.

DATA EXPLORATION SOFTWARE

After the first consumption report is sent to the agency and operators, the agency contact person is called and a session is scheduled where personnel from the monitoring program meet with facility engineers and operating personnel to discuss the report format, answer questions, and get feedback on the report format, suggestions for improvements, etc. There are inevitably requests for different graphs that are not included in the report.

A computer loaded with data exploration software (LC 1990) is taken to this meeting. This software was originally developed to help organize and examine meteorological data but is capable of handling most kinds of time series and geographically distributed data. It provides multiple window viewing and zoom-in capabilities by utilizing a cross-indexed, compiled data base structure. All data collected from each building monitored at the site are loaded in compiled form for browsing with the software.

Table 1 shows data available from the classroom/office building whose whole-building electricity consumption is shown in Figure 5.

Typical use of the software involves examination of time series data for, say, air-handler electricity use for periods ranging from a few days to a year or more to determine when construction activity began on a VAV retrofit. Any variable shown in the table can be plotted as a function of any other variable in the file in a matter of seconds. For the classroom/office building noted above, a plot of CHW vs. dry-bulb temperature (Figure 6) does not show any obvious temperature dependence, except possibly for temperatures above about 75°F. However, a plot of CHW vs. air-handler electricity consumption (Figure 7) shows a strong correlation.

The software package cost is comparable to popular word processors, and facilities personnel are encouraged to purchase a copy if they are interested in exploring the data in greater detail than presented in the monthly reports. Subsequently, an updated, compiled file of the

TABLE 1
Data Types Compiled for a Typical Classroom/Office Building

Summary Channels:
1. Whole-building electricity (kWh/h)
2. Chilled water (kBtu/h)
3. Condensate return (MMBtu/h)
4. Total AHU and chilled-water pump electricity (kWh/h)
5. Ambient dry-bulb temperature (°F)
6. Ambient humidity
7. Solar radiation on horizontal surface (W/m^2)
Individual Channels:
1. Return fans 2-4A (kWh/h)
2. Supply fans 2-5B (kWh/h)
3. Return fans 2-5B (kWh/h)
4. Supply fans 1A,B,C and return fans 1B,C (kWh/h)
5. Supply and return fans 5A (kWh/h)
6. Supply fans 2-4A (kWh/h)
7. Building meter B (kWh/h)
8. Building meter A (kWh/h)
9. Chilled-water pumps 1-3 (kWh/h)
10. Chilled-water flow (gal/h)
11. Chilled-water Btu (kBtu/h)
12. Condensate return (gal/h)
13. Ambient dry-bulb temperature (°F)
14. Ambient humidity
15. Solar radiation on horizontal surface (W/m^2)

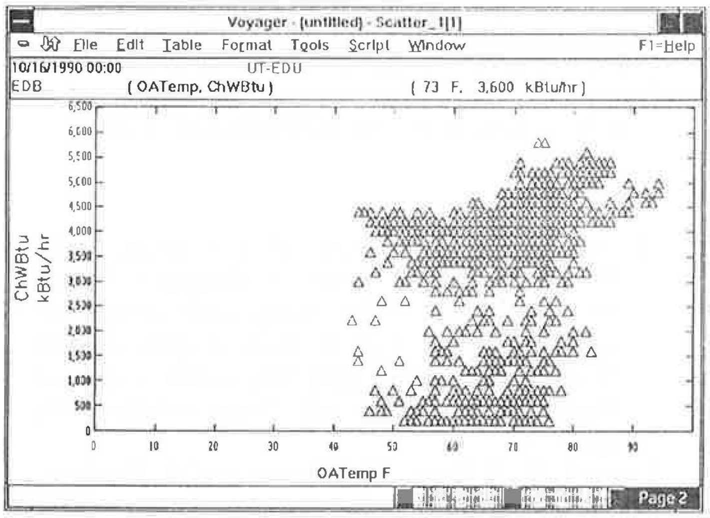


Figure 6 *March-April 1991 chilled-water consumption for a classroom/office building plotted as a function of ambient dry-bulb temperature using data exploration software.*

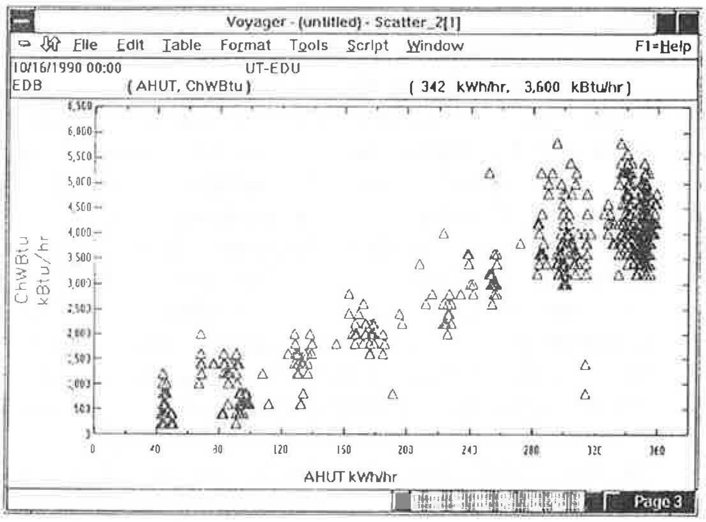


Figure 7 *March-April chilled-water consumption for the classroom/office building plotted as a function of air-handler electricity use by the data exploration software.*

building data is sent with the consumption report each month.

INSPECTION PLOTS

Data quality control is essential if the measured savings are to be meaningful. The monitoring equipment is installed by a subcontractor who checks initial readings from the system against hand measurements. High-low limits for each channel are checked with the ARCHIVE program. In addition, hard-copy time series plots of all data collected are generated each week, with a total of more than 700 plots produced each week. The number of plots is somewhat smaller than the total number of channels collected, since most electricity consumption is measured using two or three channels for three-phase service. A summary page of, typically, 10 plots is produced for each building (Figure 8). The summary page shows whole-building electricity use, ambient dry-bulb temperature, relative humidity, and global horizontal solar radiation. It includes time series plots of hourly chilled-water Btu (or chiller electricity), condensate Btu (or other heating quantity) as well as air-handler/pump electricity whenever these are available. Cross-plots of the last three as functions of ambient dry-bulb temperature are also included. Additional plots may be included in the remaining two slots if needed.

These plots are used for data quality control and as a diagnostic tool for examining unusual consumption. The inspection plots are first used by the installation subcontractors immediately following installation for range checking. They are scanned on a weekly basis by project personnel using a checklist to detect problems with the data acquisition system and changes in the building system. For example, at one site that was being retrofit, most channels suddenly went to zero. A visit to the site revealed that the retrofit contractor had cut all leads to the data acquisition system—in spite of large labels requesting a collect phone call before disturbing the equipment.

As an example, the whole-building electricity plot in Figure 8 shows that early morning loads on May 10 were about 200 kW higher than normal. They dropped on subsequent nights but were still about 50 kW higher than previously. Examination of the air-handler/pump consumption in the figure shows that essentially none of the air handlers and pumps was turned off on the night of the 10th, and not many were turned off on subsequent nights. Examination of the individual channel inspection plots shown in Figure 9 shows that none of the chilled-water pumps was turned off after May 9, none of the supply and return fans was turned off on the early morning of May 10, and a smaller portion of the fans was turned off on subsequent nights.

We have had numerous requests from facilities personnel who do not have the data exploration software for the more detailed information contained in the inspection plots, and they are released upon specific request, though they are primarily intended for internal data quality checks and diagnostic purposes.

CONCLUSIONS

This paper describes three forms for reporting monitored building energy consumption data that have proved highly useful for building operators, facility engineers, design engineers, monitoring project research personnel, and project managers. These reports are

1. Hard-copy time series inspection plots produced weekly for every channel of data collected along with summary time series plots and cross-plots as functions of ambient temperature are used for data quality control and diagnosis of operating changes and problems.
2. Data exploration software is used by building operators and analysis personnel to examine system performance and analyze consumption data to determine retrofit savings.
3. Monthly energy consumption reports provide hard-copy tabular and graphical feedback to building operators, facility engineers, and project managers on the monthly, daily, and hourly performance of building systems and are also invaluable to analysis personnel in spotting opportunities for improving the performance of building systems and retrofits.

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REFERENCES

Claridge, D.E., J.S. Haberl, S. Katipamula, D.L. O'Neal, D. Ruch, L. Chen, T. Heneghan, S. Hinchey, K. Kissock, and J. Wang. 1990. Analysis of Texas LoanSTAR data. *Proceedings of the Seventh Symposium on Improving Building Systems in Hot and Humid Climates*, Ft. Worth, Texas, October 9-10, pp. 53-60.

Diamond, R., J. Harris, O. de Buen, and B. Nordman. 1990. Evaluating actual performance of new commercial buildings: The Energy Edge demonstration program. *Proc. of ACEEE 1990 Summer Study on Energy Efficiency in Buildings*: 3.77-3.90. Wash-

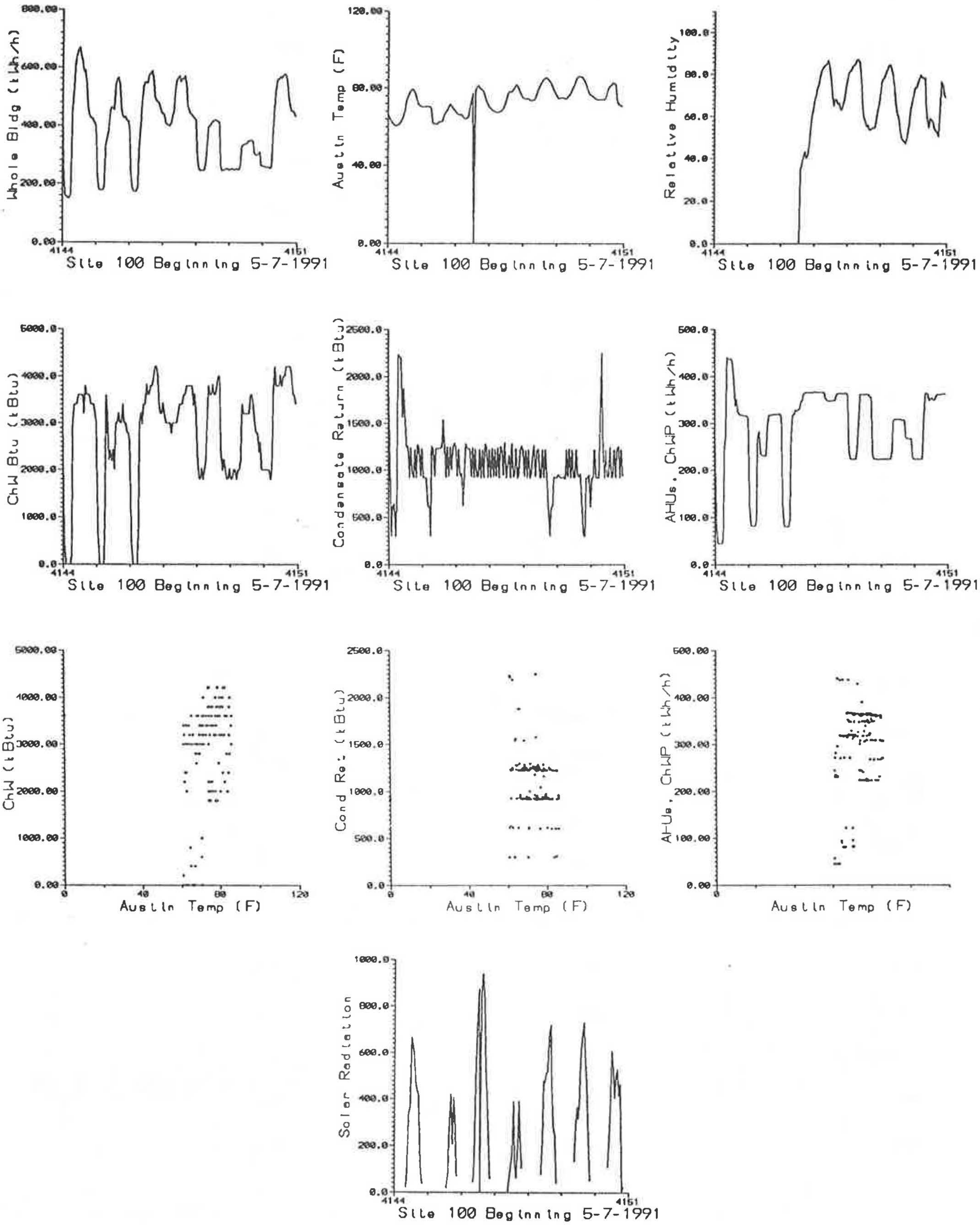

Figure 8 *Inspection plot summary sheet showing data for the classroom/office building for the week May 7-13, 1991.*

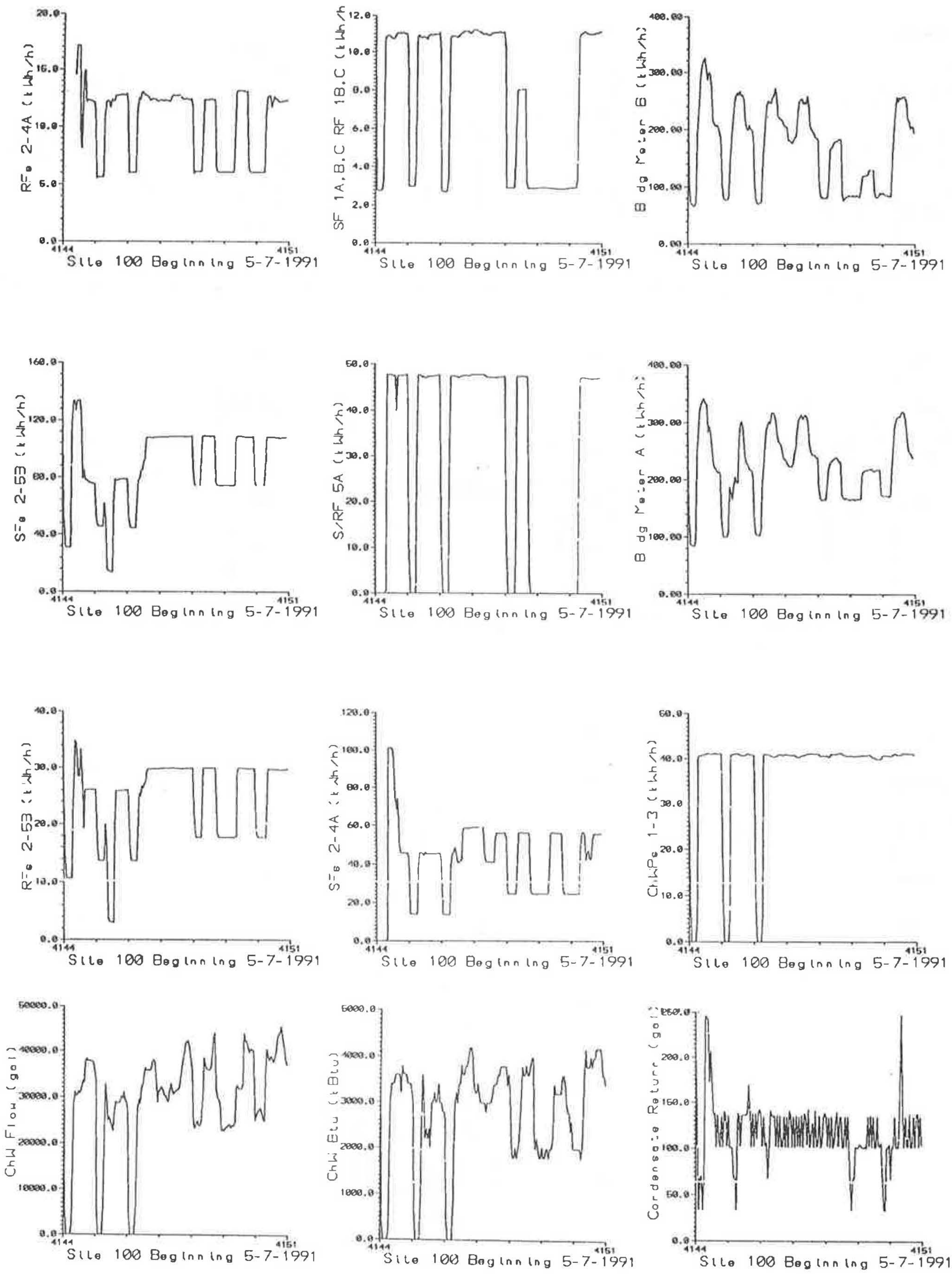

Figure 9 *Inspection plots showing individual channels for the classroom/office building for the week May 7-13, 1991.*

ington, DC: American Council for an Energy Efficient Economy.

Fels, M. 1986. Special issue devoted to measuring energy savings, The scorekeeping approach. *Energy and Buildings* 9(1, 2).

Haberl, J., and D. Claridge. 1987. An expert system for building energy consumption analysis: Prototype results. *ASHRAE Transactions* 93.

Haberl, J., and P. Komor. 1990. Investigating an analytical basis for improving commercial building energy audits: Early results from a New Jersey mall. *Thermal Performance of the Exterior Envelopes of Buildings IV.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Haberl, J., and J. Vajda. 1988. Use of metered data analysis to improve building operation and maintenance: Early results from two federal complexes. *Proceedings of the ACEEE 1988 Summer Study* 3. Washington, DC: American Council for an Energy Efficient Economy.

Hadley, D., and S. Tomich. 1986. Multivariate statistical assessment of meteorological influences on residential space heating. *Proc. of the ACEEE 1986 Summer Study on Energy Efficiency in Buildings* 9. Washington, DC: American Council for an Energy Efficient Economy.

Katzev, R., and T. Johnson. 1987. *Promoting energy conservation: An analysis of behavioral research.* Boulder, CO: Westview Press.

Kempton, W., and P. Komor. 1990. Maybe somebody forgot to turn the chiller on: Graphical feedback for small businesses. *Proc. of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*: 2.75. Washington, DC: American Council for an Energy Efficient Economy.

Kinney, L.F., and J.P. Romano. 1990. Feedback mechanism to promote weatherization client conservation. *Proc. of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*: 2.77-2.79. Washington, DC: American Council for an Energy Efficient Economy.

LC. 1990. Voyager: Data exploration. Clayton, MO: Lantern Corporation.

Lutz, K. 1990. Information transfer of energy conservation research results: Writing for a broad audience. *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*: 7.101-7.102. Washington, DC: American Council for an Energy Efficient Economy.

MacDonald, M., and D. Wasserman. 1988. Investigation of metered data analysis methods for commercial and related buildings. Oak Ridge National Laboratory Report ORNL/CON-279 (May).

Pratt, R.G., C.C. Conner, E.E. Richman, K.G. Ritland, W.F. Sandusky, and M.E. Taylor. 1989. Description of electric energy use in single-family residences in the Pacific Northwest—End-use load and consumer assessment program (ELCAP). DOE/BP-13795-21, prepared by Pacific Northwest Laboratory for the U.S. Department of Energy.

Ruch, D., L. Chen, J.S. Haberl, and D.E. Claridge. 1991. A change-point principal component analysis (CP/PCA) method for predicting energy usage in commercial buildings: The PCA model. *Solar Engineering 1991—Proceedings of the Second ASME-JSES-JSME International Solar Energy Conference*: 441-448. Reno, Nevada, March 17-22.

Seligman, C., J.M. Darley, and L.J. Becker. 1978. Behavioral approaches to residential energy conservation. In *Saving Energy in the Home*: 231-254, R.H. Socolow, ed. Cambridge, MA: Ballinger Publishing Co.

Turner, W.D. 1990. Overview of the Texas LoanSTAR monitoring program. *Proc. of the Seventh Symposium on Improving Building Systems in Hot and Humid Climates*: 28-34. Oct. 9-10.

Verdict, M., J.S. Haberl, D.E. Claridge, D.L. O'Neal, W.M. Heffington, and W.D. Turner. 1990. Monitoring $98 million in energy efficiency retrofits: The Texas LoanSTAR program. *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*: 7.261-7.271. Washington, DC: American Council for an Energy Efficient Economy.