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ABSTRACT

The Lawrence Berkeley Laboratory, DOE, has developed the Energy Signature Monitor (ESM), an innovative data acquisition system which addresses the data acquisition and analysis requirements of test programs which involve monitoring of large samples of buildings. Information about typical number of sensors and accuracy requirements for such large monitoring projects was incorporated into the development of the ESM in order to meet the needs of most researchers without adding unnecessary, and expensive, features. The ESM hardware includes a microprocessor controlled data acquisition program, sixteen analog channels, two pulse count channels, an RS232 computer interface, and a removable EPROM-based data storage module. In conjunction with the hardware a complete data management software package, written to operate on a microcomputer, was developed to facilitate analysis of the recorded data. A total of 23 ESMs have been built to date, all of which are being used in a field monitoring study currently being conducted by Lawrence Berkeley Laboratory. Lessons learned during development, field use, and ESM design technology transfer to the private sector are reported.

INTRODUCTION

The Energy Performance of Buildings Group (EPB) at Lawrence Berkeley Laboratory (LBL) has conducted building energy research which involves both laboratory instrumentation and field monitoring for the past 8 years. During that period there have been numerous proposals for research studies which required the monitoring of a relatively large number of field sites in order to accurately determine typical, as well as extreme, building operating characteristics. None of these large monitoring projects were conducted because of the high cost of field monitoring.

Across the country there have been many other research projects in which the long-term monitoring of a large sample of buildings was required in order to accurately determine a particular building characteristic (e.g. energy use patterns, indoor air quality, occupant behavior, etc.). Most of these projects were unable to proceed because of prohibitively high monitoring costs. Often overlooked is the fact that the monitoring costs incurred during a field study include much more than just the data acquisition system hardware cost. Major costs include the technical manpower required to install and maintain the equipment, retrieve the recorded data, and manage the recorded data at a central analysis station. A significant, and costly, time investment by technical personnel is required to both install and maintain most commercially available data acquisition equipment. Since very few hardware manufacturers provide any integrated software, the user must develop the software to both operate the data acquisition and manage the large quantity of data collected from a large monitoring project. The bottom line is that experience has repeatedly shown field monitoring projects to be very expensive to conduct.

There has been at least one major attempt at controlling the overall cost of a major large-scale long-term monitoring project. In 1979 the Solar Energy Research Institute (SERI) initiated the Class B Passive Solar Data Acquisition System, the goal of which was a low-cost method for evaluating the thermal performance of a large number of passive solar buildings through the country. A summary of the Class B program is given by Frey.[1] SERI solicited a number of commercial data acquisition manufacturers to submit prototype data acquisition systems from which SERI selected one system, the Aeolian Kinetics PDL-24.[2] The data acquisition equipment for this SERI project was limited to that available commercially available. I addition to the hardware, SERI assembled a set of operating procedures and data acquisition and analysis software that were to be used at each monitored site to assure compatibility of collected data. After purchasing and using approximately 71 PDL-24 systems, SERI found a variety of hardware problems which, although eventually corrected, required considerable effort. The original Aoelian Kinetic company no longer produces the PDL-24 system, although new PDL-24 systems, and maintenance and parts for existing systems are available through Datak Systems. The PDL-24 systems cost $4000-$5000 per unit.

An informal 1981 EPB review of the available commercial data acquisition products which filled the requirements of large-scale low-level field monitoring revealed that the need for an innovative data acquisition system design which cost less than $1000 had not been meet. The Aeolian Kinetics system selected by SERI for the Class B monitoring program, while providing significant versatility, was still too expensive for many research project budgets. Advances in the electronics industry suggested that, with data acquisition system simplifications, a less expensive design was possible.

ESM DEVELOPMENT BACKGROUND

The Energy Signature Monitor (ESM) was developed as a data acquisition system that integrates measurement, data collection, and compilation and is designed to provide low-cost sophisticated data in a standardized format. The 1981 target per unit cost was $500, which grew to $1500 by 1984 as additional features were added. Information about typical number of sensors and accuracy requirements for large monitoring projects was incorporated into the development of the ESM in order to meet the needs of most researchers without adding unnecessary, and expensive, features. The ESM development philosophy was to minimize the need for technical personnel during normal operation by providing menu-driven software for both data acquisition and management, easy sensor connections by using standard modular telephone connectors, and integrated data storage and retrieval by using a built-in solid-state data module. The easily replaced data module can record a month's worth of data. The ESM can monitor total energy consumption (broken down by end use), as well as related variables as diverse as temperature, lighting levels, indoor pollutant concentrations, office equipment loads, thermostat settings, and door openings.

Based on our field monitoring experience, and conversations with other researchers, it is clear that large-scale monitoring projects typically require only a limited number of sensors per test site, with less stringent sensor accuracy demands than those typically required in laboratory investigations. Within the commonly used A (laboratory grade investigations), B (general real time field monitoring), and C (compilation of utility meter readings) monitoring classifications, the ESM is designed to operate as a class B data acquisition system.

The original ESM design has evolved to its present configuration based on considerable laboratory and field evaluation of a number of prototype units, all of which have been built at LBL. The original concept was for a very simple, 2-4 channel, data acquisition system that would collect only the most critical data for determining a simple energy performance analysis. It was later decided to expand the basic idea to a more versatile, and complicated, system. Six prototype units were assembled during 1983. Although the basic design philosophy worked well, evaluation of these prototypes revealed the need for some major modifications to simplify maintenance and increase system versatility. Twenty-three second generation ESMs have been assembled, all of which were used during the 1984-1985 heating season, and are being used again during the 1985-1986 heating season as part of a field monitoring study currently being conducted by Lawrence Berkeley Laboratory. A description of the ESM system and lessons learned from the ESM development project are given in this report.

DATA ACQUISITION HARDWARE DESCRIPTION

The ESM is a microprocessor-based data acquisition system designed for long-term unattended operation. Data acquisition and communication is controlled by a 6502 central processing unit (CPU) microprocessor with 10K bytes of program memory contained in erasable programmable read-only memory (EPROM) and 2K bytes of random-access memory (RAM) for intermediate data storage.

There are two pulse count input channels, which count the number of TTL level voltage pulses received, and sixteen analog input channels, which will accept a sensor output range of ±4.095 volts. A 12-bit dual-slope integrating analog-to-digital converter (ADC) processes the analog input channels, for an effective resolution of 1 millivolt. A dual-slope integrating ADC, with an integration time of two 60 Hz cycles, was selected over the more common successive approximation ADC because of the ability to automatically eliminate 60 cycle electronic noise that may be superimposed on the sensor signal. The dual-slope ADC conversion rate is limited to 7.5 reading/second, compared to much faster successive approximation ADCs, but that is not important for most long-term monitoring projects involving building energy issues.

Each of the analog channel inputs can be recorded either as an analog millivolt value or as a programmable digital ("ON/OFF") value. The "ON" digital signal is defined as a value that is greater than a user-defined threshold. This allows the use of standard analog sensors, such as a temperature sensor, to also be used as status sensors. An example is the use of a photo cell pointed at the burner of a gas furnace to measure the "ON" time of the burner based flame light intensity. No external hardware comparator circuits are needed, and the threshold value can be easily set in software by the user during equipment setup.

Data acquisition is controlled by an assembly language program which resides in 10K byte of EPROM. During equipment setup the data acquisition program communicates to standard ASCII terminals through a built-in RS-232 interface using menu-driven software. Because the communication program has extensive input prompting and error checking the operator does not need extensive knowledge of the program options and input requirements. Although a computer terminal is used to communicate with the ESM during setup at a test site, it is not required during operation of the experiment. An external telephone modem, connected via the RS-232 interface, can be used to remotely check on the test site during the study.

During data collection the data acquisition program monitors the pulse count channels as interrupts and scans all the analog and digital channels every fifteen seconds. Pulse count channels can record a maximum of 65,535 counts. The total number of pulses for the pulse count channel, the total number of "ON" scans for each digital channel, and the millivolt value for each analog channel are recorded on the data module at the end of each record interval. The record intervals are user seletable to between 1 and 8191 minutes. The analog channel value is recorded either as the average for all the 15-second readings taken during the record interval, or as a single reading based on the last scan of the record interval, depending on a user selectable option.

No software signal conditioning is built into the ESM data acquisition program. The analog sensor outputs are recorded and displayed to a terminal as millivolt values. For ease of use the standard temperature sensors designed for use with the ESM (which are described later in this report) are calibrated to output 1mV/°C, which makes the millivolt display easily readable in engineering units. Signal conditioning and linearization for special sensors must be conducted by external circuits.

Data is stored in 24K bytes of EPROM memory, which is contained on a removable plug-in 3.5 X 5 inch data module for convenient physical transfer to a central data analysis station. The data module can store up to twenty-nine days of hourly averages from a typical full compliment of 18 sensors, which consists of two pulse count sensor, eight analog, and eight digital channels. The use of fewer channels for a monitoring project would mean a proportionally longer recording time per data module. A commercial high-intensity ultraviolet light EPROM eraser can erase a data module in approximately 15 minutes. It is unlikely that a data module would be accidentally erased in the field.

The data module contains not only the time sequential data for each of the input channels used, but also critical information about the experiment which is required to manage and analyze the data. When the ESM is first setup at a test site the user must input information about the test name, location of the monitored site, type of sensors used, codes for what is actually being monitored, etc. All of this information is automatically recorded on each erased data module before any data is recorded. The field technicians do not have to write any of this information in a log book, and since the information is always available with the data there is little chance of missinterpretation the data. If a new data module is inserted in an ESM, the data acquisition program automatically checks to make sure that it is either fully erased, or that any existing information in the data module is compatible with the test configuration currently entered in the ESM memory. If there is a incompatibility problem when a user inserts a new data module (e.g. a test configuration recorded from another test site, or not fully erased) the ESM will indicate that it has not accepted the data module, and user is prompted to use another data module. This procedure is designed to prevent operator errors which result in lost data.

During normal operation the ESM is line powered, but battery backup power is supplied for RAM memory, clock, and short-term data acquisition. The ESM will continue normal data acquisition operation during a line power failure until the end of the next record interval, at which time the ESM will go into a "sleep" mode. The "sleep" mode, which conserves battery power, can be continued for more than 6 days. The clock remains operational during the power failure, and the ESM will automatically continue normal operation when line power is restored.

Transfer of data from the data module to a microcomputer-based data management and analysis program is accomplished by using an ESM identical to the field units. The standard ESM data acquisition program includes the software needed to read a data module and transfer the data through its RS-232 port to a computer or terminal. When used with the microcomputer-based data management software, the data transfer procedure includes routines to assure error-free data transmission. One of the spare ESMs that would be required for a large monitoring project could be used at the central data processing station to transfer data to a computer.

The original ESM design, which was developed in 1982, has evolved to its present configuration based on two years of laboratory and field evaluation of a number of prototype units, all of which have been built at Lawrence Berkeley Laboratory. The current ESM design, along with a standard computer terminal, is shown in Fig. 1. The computer terminal, which could be replaced by a much smaller portable terminal (e.g. Texas Instruments Silent 700 or Radio Shack TRS- 80 Model 100) is used to communicate with the ESM during setup at a test site and is not required during operation of the test, thus reducing site equipment requirements. Since the ESM was designed for long-term unattended operation, there is no need for a built-in display (except for the front panel's four status indicator lights), a printer, or a keyboard. A removable data module and three ESM operation control switches are located behind the front panel access door. The rear panel has connectors for the sensors, power supplies, and a standard RS-232 connector for communication with a terminal, another computer, or a telephone modem.

DATA MANAGEMENT SOFTWARE

The ESM data management software, designed to be used on a microcomputer at the central data processing station, in conjunction with the data acquisition hardware forms an integrated system which will allow a user to monitor a large number of sites, perform automatic data management on the recorded values, and process the aggregate data into a usable form with a minimum of time and expense. The data management software was written to operate with both CP/M and MS-DOS computer operating systems, which covers most of the commonly used microcomputers. The data recorded on the ESM data module and transferred with each data set includes information which identifies the test site and sensor configuration, which avoids much of the time-consuming cross-referencing with logbooks and installation reports. Transformation of the raw data recorded by the ESM to physical units and management of the data from multiple sites is handled automatically by the data management software. Both the data acquisition and data management software are menu-driven to facilitate their ease-of-use with non-technical personnel. The recorded data can be displayed as individual readings or averages, transferred to other computer programs, or plotted to analyze trends.

It is important to realize that the availability of data management software compatible with the data acquisition hardware is a major cost savings for the monitoring project. The general data management software developed for the ESM required more than two man-years of effort. Such software development is too expensive for a single project, but when supplied as an integral part of the hardware, which was the ESM design intent, the software provides a significant cost savings to a research project.

Although not available when the ESM data management software development was initiated, there are now commercial software packages available which may be useful as the bases of data management systems for future monitoring projects. The use of commercial speedsheet and data base programs, customized for a specific application, or the use of commercial data acquisition/data analysis programs, may be a more productive use of manpower than writing a data management program from scratch.

SENSOR CONNECTIONS

Standard 6-wire modular telephone connectors were built into the ESM for all the sensor connections. This allowed for convenient connection of ESM supplied +5 and +15 volt sensor power, automatic connection of the electric power signal conditioning circuit to the appropriate clamp-on ammeter, and sensor output. Standard 6-wire telephone extension cables, with modular connectors, were used as extension wires to the sensors. The objective was to simplify the field installation of sensors, and make it fool-proof. The modular telephone connectors can be inserted in only one orientation, with the total connection procedure requiring only a couple seconds. This compares to spending a minute or more to strip wires and assure that the correct wire was attached to the appropriate terminal lug, with a good chance of some improper connections. Everyone that has used the ESM has liked this connection concept.

Although the telephone extension cables are not twisted pairs or shielded, no electrical noise problems have been experienced with up to 100 feet long extensions. The integrating ADC is the major reason that electrical noise has not been a problem. Shielded cable and good grounding practices will become a more important consideration in environments which produce large static charges and have lightning induced electrical noise.

The main problem experienced with the modular telephone extension cables was attachment of the sensors to the telephone wires. The wires are fragile, with nylon threads for reinforcement, which makes for difficult soldering. Although it is not obvious, in order for the modular connectors to work the electrical signal may go from one color wire to another, and back. This can be very confusing, and has resulted in a number of incorrectly wired sensors. The 6-wire extension cable is non-standard, and can be difficult to purchase. A new design, which could be incorporated in future ESM designs, would allow the use of readily available 4-wire telephone extension cable.

SENSOR DESCRIPTIONS

To accommodate the two most common sensor types used by building energy researchers, air temperature and electrical power, two specific sensors were incorporated into the ESM design. The Analog Devices AD590 temperature transducer was used because of its good accuracy and linearity, insensitivity to supply voltage (4 to 30 volts), high output sensitivity (2.732 volt at 0 °C, with 10 mV/ °C sensitivity), and low cost ($5-$15). The ESM supplied +15 volts at the sensor's modular telephone connector powers the temperature transducer. Field comparisons of ESM recorded average air temperatures have shown the ESM to be within 0.5 °C of air temperatures recorded at the same locations by a class A data acquisition system (see Fig. 2). The disadvantages of the AD590 temperature transducers are that temperature values are limited to 150 °C, and the sensors must be protected from direct contact with moisture by sealing them in an epoxy or silicone glue.

Commercial electrical power sensors that fully account for power factor effects cost $200-600, which was deemed excessive for the ESM. A simple, inexpensive ($50) clamp-on wattmeter was developed as part of the ESM, with electrical signal conditioning for eight sensors built in to the ESM in order to reduce the cost of multiple electrical power sensors at one site. Unfortunately, field experience has shown that the accuracy is not adequate for most applications and the sensor is too fragile. An improved version of the clamp-on wattmeter has been designed but has not been adequately tested at this time.

Monitoring of gas fired water heater and furnace operation has been successfully accomplished by using either temperature sensors or miniature photocells. Burner operation is detected with a temperature sensor by monitoring the flue pipe temperature, or with a photocell by monitoring the the light intensity in the burner compartment. For both of these applications the user selects a digital recording option for an analog input channel. The ESM interprets the sensor value to be either above a user set threshold value, "ON", or below the threshold value, "OFF", and records the total number of "ON" scans during a recording interval.

The AD590 temperature sensors are limited to 150°C, which will not allow them to be placed directly into the burner or the flue. But they can be attached to the outside of the flue pipe. The problem with this configuration is that the appropriate threshold value for the temperature sensors is very dependent on ambient temperature, which can vary for water heaters located in garages during large changes is ambient temperature. The photocell works well as long as it doesn't get over 100°C, which means that it can not be located in a gas domestic water heat burner chamber. The photocell does work in gas furnace combustion chambers, where incoming combustion air can keep the sensor cool.

It was not practical to develop specific ESM interfaces for all of the many sensors that are used by researchers. But, the ESM will accept any sensor that outputs a signal of ±4.095 volts, which means that most sensors need minimal signal conditioning in order to be compatible with the ESM. In addition, +5 and +15 volts are available from the ESM to power the active sensors. The pulse count channels accept standard TTL level voltages (0 - 5 volts).

In order to simplify the field hardware of the ESM, a design compromise was to include all software sensor signal conditioning in the microcomputer based data management program instead of the ESM. All sensor outputs are recorded by the ESM as millivolt levels; there is no built in linearization for non-linear sensor outputs. This means that if time-average values are to be recorded non-linear sensor outputs must be linearized before being connected to the ESM.

FIELD EQUIPMENT INSTALLATION EXPERIENCE

One of the major non-hardware costs incurred in a monitoring project is installation and maintenance costs. By providing simple menu-driven software and very easy-to-use and foolproof standard telephone connectors for all sensor connections the ESM design attempts to minimize the actual time required to install the hardware. But, depending on the monitoring project complexity, installation may still be a major expense. And, it should be evident that even though the installation personnel may be non-technical with regard to the ESM, they must be fully qualified with regard to sensor installation or the results of the monitoring project may be compromised. Three case studies of field equipment installation experiences with the ESM are discussed below, but they are typical of most field monitoring projects. The first case study was a very simple monitoring project close to LBL that was conducted by LBL personnel very familiar with the ESM. The second and third case studies were conducted 700 miles from LBL by field personnel who were under contract to LBL, and had received a one week training session at LBL before beginning the field study. These two cases are typical of experiences with large remote monitoring projects.

The first case study was part of a LBL conducted ESM field evaluation in an unoccupied housing unit that was part of a public housing research project. The housing unit was concurrently monitored with a second, class A, microprocessor based data acquisition system to provide a baseline for comparison. The ESM installation had a total of 16 sensors, which included inside, outside, and attic dry- bulb and dew-point temperatures, weather conditions, and electric power use. Hardware installation and setup required approximately five manhours, although had the housing unit been occupied the installation time would have been a couple hours longer because of the need to assure that all sensor wiring was neatly secured where it would not be accidentally disturbed by the occupants. This housing unit was a one bedroom single-story configuration, which greatly simplified wiring runs.

Installation of ESMs in three additional occupied housing units in the same housing project required only three manhours each due to fewer and simpler sensor wiring configurations (five sensors per site, all inside). In all cases the ESMs were simply located on a closet shelf, which hid the wiring from the occupants while allowing convenient access for the LBL researchers. Removal of the ESMs from the four housing units required only one manhour each. There was a minimum of interference with the occupants during the field evaluation since LBL researchers were in the units only three times during the study; once during installation, once for data module retrieval, and once for removal of the equipment. There were no occupant complaints about the equipment or sensor wiring.

The second case study involved the monitoring of eight occupied homes in the Portland, Oregon area. This project required the installation of of approximately fourteen ESM monitored sensors per site, which included air temperature, dew point temperature, clamp-on wattmeters, photocells for monitoring furnace operation, a real-time radon monitor, and a weather tower. In addition there were stand-alone particulate samplers and a number of passive air quality samplers. Since the study was to be conducted over a five month period the hardware had to be secured from accidental occupant disturbances. Installation and maintenance was conducted by a LBL trained field contractor in conjunction with a LBL staff member. Installation required approximately 25 manhours per site. Because of some problems with both the ESM and other equipment some of the sites required over 40 manhours.

In addition, there were weekly visits to each site to recover the passive air samplers and ESM data modules and perform regular maintenance. The ESM data modules could have recorded data for up to a month, but weekly checks assured that there would not be excessive data gaps due to equipment failures that were not noticed. The weekly visits required two to three hours per site, mainly for the non-ESM sensor maintenance. By the end of the study some of the occupants resented the investigators' weekly intrusions. An average of five manhours was required for equipment removal.

The third case study involved short-term (two weeks) monitoring of fifty occupied homes at two sites in Washington. This project required installation of sensors very similar to case two described above. A log was maintained by one of the field contractors to give an accurate appraisal of installation time requirements. For these sites, which includes both simple and complex installations, the installation times varied from a low of 14 manhours to a high of 48 manhours, with an average of 29 manhours. Most of the low installation time sites were due to unusually easy access and no weather tower installation. Removal times averaged five manhours.

Problems incountered during the short-term testing program, where the loss of significant data is unacceptable, made it evident that the ESM needed a watchdog timer. A watchdog timer would automatically restart the ESM if any problem prevented continued data collection operation. All the ESMs are now being retrofited with watchdog timers.

The reason for discussing these three case studies is to emphasize the fact that field monitoring scheduling and cost estimates must include appropriate field installation and maintenance estimates. Historically researchers have greatly underestimated the non-hardware cost of field monitoring projects.

ESM TECHNOLOGY TRANSFER

The goal of the ESM development was to provide the design specifications to private industry in order to stimulate the production of a commercial product in an area where there was a need, but no product. LBL staff has built 23 ESMs as part of the design evaluation and for use in two research projects, but there are no plans for LBL to provide ESMs to outside researchers. The process of technology transfer of the ESM design to a private sector company willing to market a commercial version of the ESM was initiated during 1984. Based on an information package mailing by the LBL Office of Research and Technology Applications Office there were two private sector companies which were interested in working toward development of a commercial version of the ESM. The companies were willing to learn from the field experience of the LBL prototypes and design advanced features into the production units before they went to market.

Both companies greatly underestimated the development effort required to transform the LBL prototype design into a viable commercial product. There is a very large gap between a laboratory prototype that works under the guidance of familiar technical personnel and a commercial product that must survive the real world. Both private companies have discontinued development of a commercial ESM due to the higher than expected development costs, and because the excessive delays have reduced the opportunity in the market place. During the last year a few independent commercial products have appeared on the market which fill most of the ESM hardware specifications for unit costs of $2000-$3000. Unfortunately, the commercial products do not address the issue of integrated micro-computer data management at this time.

Since the total market may not be large enough to justify development of another such data acquisition system LBL has discontinued efforts at ESM design technology transfer to a private sector company.

MONITORING INSTRUMENTATION SURVEY

Because of our experience in field monitoring and the ESM development program we regularly receive numerous requests for assistance in locating the right data acquisition system for a particular project. Many researchers are not aware of the data acquisition equipment on the market, with their widely varying characteristics and prices.

LBL has begun begun a project to survey the existing commercial monitoring instrumentation and categorize the equipment by its capabilities, usefulness, and cost. During the next six months LBL will be compiling a list of information for numerous commercial data acquisition systems; to be published next year. This report will also give criteria for deciding which equipment package, from the many different options currently available, is suitable for which user needs.

CONCLUSIONS

LBL has developed the Energy Signature Monitor in response to a demand for a low-cost data acquisition system capable of class B monitoring of large-scale long-term sites. The ESM design attempts to reduce the cost of monitoring by using state of the art electronics, sophisticated menu-driven data acquisition software, foolproof easy-to-use sensor connections using modular telephone connectors, and integrated data management software designed to operate on a microcomputer. The complete ESM design, hardware and software, will fully support going from field recorded data to final data analysis. Operator training is minimized by simplifing the operating procedure, using foolproof hardware designs, and using menu-driven software. Although standard temperature and clamp-on wattmeters were developed for the ESM, any other sensor with ± 4.095 volt output can be connected. With most sensors a minimum of external signal conditioning is required.

Comparisons of ESM recorded data with a class A data acquisition system showed that the ESM, although not as versatile as the more sophisticated class A system, is sufficiently accurate when recording hourly averages of environmental parameters such as temperatures or voltage outputs from other sensors. More accurate electric power sensing from the built-in clamp-on wattmeter signal conditioning circuit must await development of an improved clamp-on wattmeter design.

Although there have been 23 ESMs built at LBL as part of the design evaluation and for use in LBL conducted research projects, there are no plans for LBL to provide ESMs to outside researchers. The two private sector companies that initiated a commercial product development based on the ESM have been unsuccessful, mainly because of undercapitalization. LBL is not actively pursuing any further ESM technology transfer.

As an extension of the ESM development effort LBL has begun a project to survey the existing commercial monitoring instrumentation and categorize the equipment by its capabilities, usefulness, and cost. During the next six months LBL will be compiling a list of commercial data acquisition system specifications to be published next year. This report will also give criteria for deciding which equipment package, from the many different options currently available, is suitable for which user needs.

ACKNOWLEDGMENT

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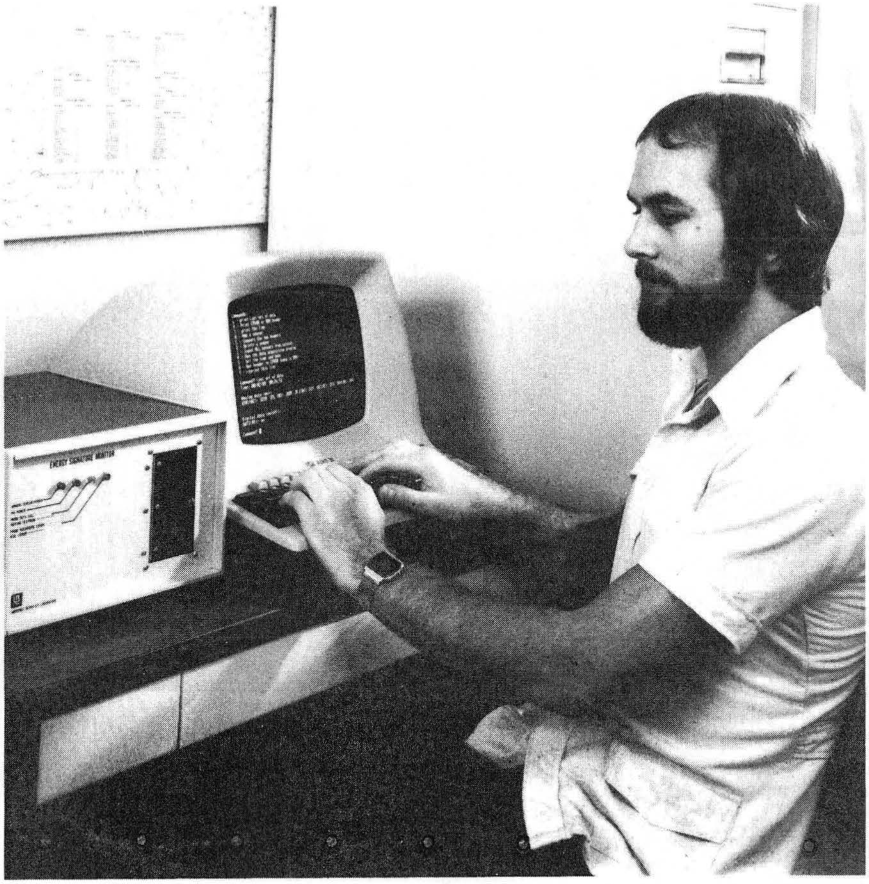
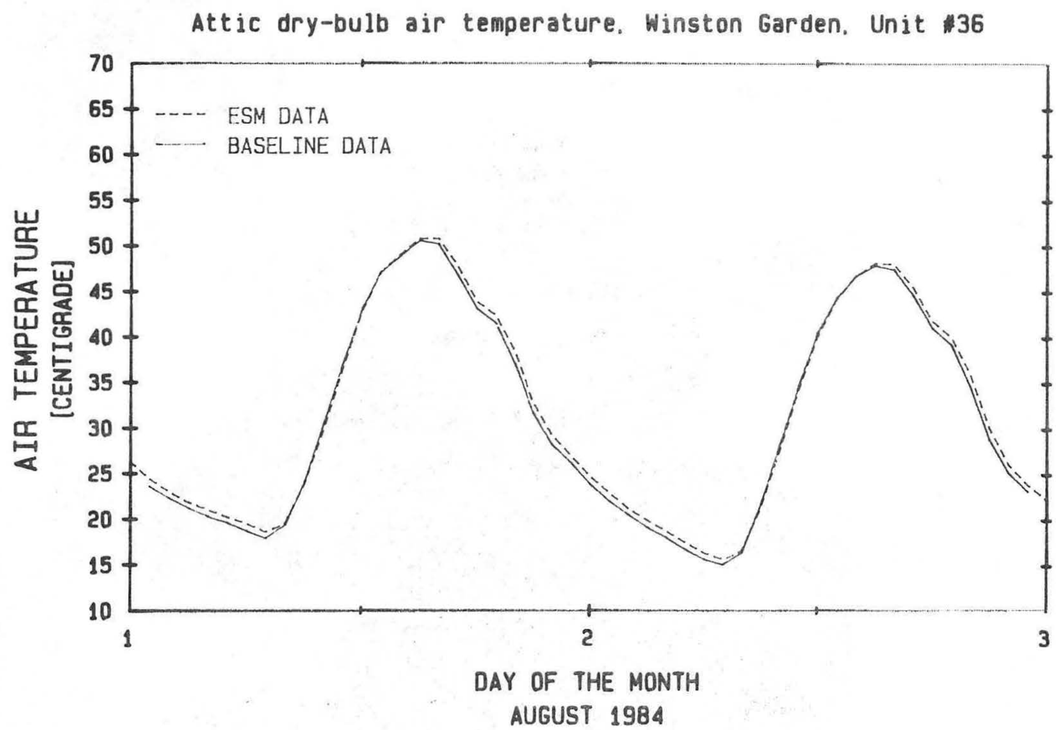
Table 1. List of Energy Signature Monitor (ESM) specifications.

Processor	Rockwell or Synertek 6502, 8 bit CPU.
Program Memory	10K bytes of EPROM, 2K bytes of RAM, data acquisition program written in assembly language.
Communications	Built in RS232 interface, switch selectable to 300, 1200, or 9600 baud.
Analog to Digital Converter	Intersil 7109, 12 bit, dual slope integrating, $\pm$4.095 volt input range, with a 1 millivolt resolution.
Sensor Channels	16 analog channels, all of which can be recorded as millivolt values or digital "ON"/"OFF" values based on a user set threshold.
	Two pulse count channels, optically isolated, TTL (0-5 volts) pulses, record a maximum 65,535 counts.
Data Storage	24K bytes of EPROM on a removable data module (3 x 5 inch PC card), stores one month's worth of data from a typical full complement of channels recorded hourly (13,800 points). Data retrieval is made with a standard ESM.
Battery Backup	One 12 volt gel-cell (lead acid) battery which provides one hour of full operation and one week operation of clock and internal RAM memory.
Power Source	One 24-volt plug-in wall transformer and one internal transformer.
Data Management Program	Written in Pascal to operate on CP/M and MS-DOS micro-computer operating systems, requires a minimum of 64K bytes RAM, data management limited by available disk memory.



CBB 830-8721

Figure 1. The Energy Signature Monitor shown connected to a video terminal.



XBL 851-1052

Figure 2. A comparison of ESM and baseline field data.