A Data Collection and Processing System for Efficiency Experiments in Commercial and Residential Buildings

Michael Baker, SBW Consulting, Inc.
Betsy Krieg, Pacific Gas & Electric Company

This paper describes the design and implementation of the data collection and processing system used by the Pacific Gas and Electric Company's Advanced Customer Technology Test for Maximum Energy Efficiency (known as ACT^2). The system supports the collection of data for a wide variety of measurements, e.g., power, temperature, micro climatic conditions, fluid flow, pressure, and humidity. These data may be collected for a variety of measurement intervals, e.g., 1-minute, 15-minute, and 1-hour, as is called for by each specific experiment. The system is designed to allow for the collection of a large number of short- and long-term measurements from each demonstration site. A data visualization environment is provided to the users of the system that allows both two-dimensional and three-dimensional interactive graphical examination of one or more of these measurements.

The system is designed to support the following research activities for each demonstration site: (1) acquisition and verification of time-series measurements, (2) development of calibrated models used in the design of energy efficiency measures (EEM), (3) analysis of the data required for EEM commissioning, and (4) evaluation of energy savings for EEMs installed at each ACT^2 demonstration site.

Introduction

Pacific Gas and Electric Company's Advanced Customer Technology Test for Maximum Energy Efficiency project (known as ACT^2), is a Research and Development (R&D) experiment designed to determine the maximum achievable energy savings for residential, commercial, industrial and agricultural customers. This R&D experiment involves the installation of maximum energy savings packages of Energy Efficiency Measures (EEMS) at a series of demonstration sites, and intensive measurement and analysis of the performance of each EEM and of the EEM packages. ACT^2 commissioned the development of a custom Data Processing and Analysis System (DPAS) to support the required measurement and analysis activities of this project.

The system is designed to support the following research activities for each demonstration site: (1) acquisition and verification of time-series measurements, (2) development of calibrated models used in the design of Energy Efficiency Measures (EEM), (3) analysis of the data required for EEM commissioning, and (4) evaluation of energy savings for EEMs installed at each ACT^2 demonstration site. DPAS has been initially implemented to satisfy these requirements for residential and commercial building demonstrations.

System Design Constraints

A detailed research plan was prepared for ACT^2. This plan specified all of the data collection and analyses that were to be performed for each of the demonstration sites. The research plan called for a highly detailed analysis of the energy performance of each demonstration site over a five year period. The research process was to start with the design of a maximum energy savings package of EEMs and end with the analysis of energy savings based on observing the performance of the EEMs for two years after the package was fully commissioned[1]. The design of DPAS was highly constrained by the specific requirements of this research process. The balance of this section describes the most important of these design constraints.

The research plan called for detailed measurements of end-use energy consumption, both electric and gas, along with a wide variety of system performance measurements, e.g., temperature, pressure, and micro climatic parameters. 100 to 200 measurements will be taken at each of the demonstration sites to collect the required information. In addition, the measurements taken at each site are expected to change as each site passes through the various stages of the demonstration process. The demonstration process involves five stages: (1) initial pre-conditions[2], (2) final pre-conditions[3], (3) commissioning, (4) ACT^2 operation, and (5) owner operation. New measurements may be introduced at each of these stages of the demonstration process and old measurements may be reconfigured. DPAS had to insure adequate documentation of the large number of measurements at each site throughout all phases of the demonstration process.

In general, the research plan specified a 60-minute measurement interval. However, the plan allowed for measurements at shorter intervals, on an as-needed basis. For example, shorter interval measurements might be required during the commissioning stage to detect whether control systems are properly responding to environmental conditions. DPAS needed to support the collection and analysis of data for measurement intervals ranging from 1 to 60 minutes.

Some of the measurements called for by the research plan are only needed for short periods, although these periods may be scattered throughout the five year history of measurements at a site. For example, it may be necessary to measure a number of individual plug loads in an office building. These loads might include copiers, printers, computers and other office equipment. Device level measurements would be required if the design for the site included the replacement of these devices with more efficient models. Continuous measurement of these devices might be unnecessary or prohibitively expensive, in which case measurements would only be taken for three short periods of time--during preconditions, ACT^2 operation and owner operation stages of the demonstration. DPAS had to be capable of acquiring and providing access to these short-term measurements in addition to the continuous measurements at each site.

The plan called for extensive verification of all measurements. All data intervals for each measurement are to be subjected to one or more standardized verification tests. These include range, repeat-value and check-sum tests, which will be described in the next section of this paper. The plan specified that these tests were to be performed on-site, as the final step in the installation of measurement equipment. The plan also specified that these tests be conducted on a routine basis throughout the measurement period. DPAS had to support the specification of the verification tests for each measurement, apply the test and report on the results.

Finally, the plan specified a complex array of analyses of the data. DPAS had to provide support for each of these data analyses. The first type of analyses were those required to complete the verification of the data. In many cases the standardized verification tests will not be adequate. Analysts will have to perform visual inspections of the data and statistical analyses in order to complete the data verification process. For example, it may be necessary to examine the relationship between measurements of temperature, pressure and power consumption to insure that a reasonable value for the efficiency of a heating or cooling plant can be derived.

The second type of analyses are those required to prepare and use calibrated simulations. These analyses are similar to those described by Ivey (1988) and Cleary (1988). The plan specified the use of DOE 2.1E as the building energy simulation language. The measurements taken at each site are to provide input values for the simulation. For example, measurements of lighting and other loads are to be used to develop schedules of internal load profiles, a critical input to the model. In addition, measurements of heating, cooling and other loads are to be compared to the model predictions and used to calibrate the model. Finally, the calibrated model is to be used to examine the impact of EEMs. These calibrated models are first used in EEM design. After EEM installation, these models are used in estimating the actual impact of the EEMs on the building's hourly end-use consumption.

The third type of analyses are those used to examine the performance of EEMs during the commissioning and ACT^2 operation stages. These analyses need to be customized to the specific EEMs and circumstances found at each demonstration site. Both statistical and graphical analyses are required. For example, it might be necessary to examine 3-dimensional surface plots of outside air temperature and heating or cooling efficiency, in order to determine whether EEMs are having the intended impact on efficiency. In some cases this analysis might involve data collected for multiple measurement intervals.

Key Design Concepts

As discussed in the previous section, the ACT^2 research plan posed a number of complex and difficult design constraints for DPAS. A complete design for the system was created which met these constraints. The key concepts of this design are discussed in the balance of this section.

Site Logger Groups

The measurement plan for each demonstration site will involve multiple data loggers. Some of these recorders will be permanently installed and will record various measurements throughout the five year experiment at each demonstration site. Other data loggers will be installed for one or more short-term measurement periods. The short-term measurements in many ways constitute separate sub-experiments within the overall experimental design for a site. It is possible that each of these sub-experiments might require dozens of measurements and that each sub-experiment might be performed during different periods. The concept of a site logger group (SLG) was created to efficiently handle multiple loggers at each site which may be used for multiple sub-experiments. The loggers which provide continuous measurements are also treated as a separate SLG.

Each SLG defines a data table in the DPAS time-series database. Thus, data from each subexperiment are maintained as independent data tables. This simplifies the database update processing and significantly reduces the overall size of the database. The measurements defined for a sub-experiment can change without causing any changes in the data tables for other sub-experiments. Within a sub-experiment, the SLG concept allows all of the measurements from each of the loggers to be consolidated into a single data table. This allows the definition of equations, which create new variables, to refer to measurements from any of the loggers in a group. The SLG concept also allows data verification tests that involve measurements from more than one logger.

Measurement Names

In this project, the logger channel assigned to a particular measurement can change. This is a common occurrence with long-term metering projects and can plague the analysts of the data. The problem is particularly intense for this project because of the planned modifications of the measurements at the beginning of of each the five demonstration stages defined in the previous section. For example, a channel on a logger might be devoted to measuring interior lighting in the perimeter zone of an office building during the final preconditions stage. Once EEMs are installed, this channel might be reassigned to measure power to the lighting circuits which are to be controlled by a photoelectric sensor. The measurement of all lighting for the zone might be moved to another logger. Other types of changes might cause certain channels to no longer be used.

From the analyst's point of view, it is irrelevant how the channels on each data logger are assigned. The analyst just needs to be able to get a complete time-series of values for each distinct measurement taken at the site. The concept of a measurement name was introduced so that the analyst does not have to worry about the physical assignment of data logger channels. For example, the measurement name "ILPZ" might be assigned to the measurement of (I)nterior (L)ighting in the (P)erimeter (Z)one. If the physical channel assigned to ILPZ is changed, the name is reassigned to the new channel. The analyst can interact with the database by specifying the name and can access any of the time-series data values, regardless of which logger channel generated the data values.

Heterogeneous Time-Series Database

Usually, metering projects only collect data for a single measurement interval, e.g., 5-minute or 30-minute intervals. The default measurement interval for this project is 60-minutes; however, it may be necessary at times to collect more detailed data. The measurement interval may be set to 1-minute for a few days, for channels that are typically recorded at 60-minute intervals. Alternatively, some data loggers may be set to a measurement interval smaller than 60-minutes for the duration of a subexperiment.

These variations in measurement intervals can create a difficult database design problem, particularly for computed variables which may require data values from measurements taken at different intervals. For example, a computed variable may be defined for total interior lighting. This might be the addition of ILPZ (Interior Lighting Perimeter Zone) and ILCZ (Interior Lighting Core Zone). In the commissioning stage, ILPZ might be set to 1-minute intervals to evaluate the effectiveness of the new photoelectric controls. The measurement of solar insolation might also be set to 1-minute to support this analysis. However, ILCZ might be left at 60-minute measurement intervals because that end use is not affected by the photoelectric controls. However, it is necessary to add ILPZ and ILCZ in order to calculate the computed variable TIL (Total Interior Lighting). A heterogeneous time-series structure was adopted in order to make this calculation possible.

The key[4] fields of a homogeneous time-series data structure might be--(1) Site ID, (2) Year, (3) Month, (4) Day, and (5) Hour--if the measurement interval were always 60 minutes. The heterogeneous design for this project adds three additional key fields--(6) Minute, (7) Measurement Interval, and (8) Least Common Denominator (LCD). Minute and Measurement Interval allow any of the following measurement intervals to coexist in the same data table--1, 5, 15, 20, 30 and 60. The last key field, LCD, is the component which allows for computed variables.

LCD is a flag, which can have the value '1' (indicating a Boolean TRUE), or '0'. The data records with LCD = '1' contain an aggregation of all measurements for a Site Logger Group (SLG) to a measurement interval which is the least common denominator of the intervals defined in the SLG. For example, if one logger in the SLG is set to 15-minute intervals and all the rest are set to 20-minute intervals, an LCD record will be created which has a

60-minute interval. All measurements will be summarized on that record. The values for computed variables will only exist on that record.

Homogeneous time-series extracts from the permanent database can be formed by sub setting an SLG data table based on the value of Measurement Interval and LCD. This will generally be required prior to graphical or statistical analysis of the data.

Automated Verification Tests

Data verification is vital to the success of all experiments on building energy performance. The need for detailed data verification increases rapidly as the number and complexity of measurements increases. This project presents an extreme requirement for data verification, which must be done in part through automated verification tests. These tests will not trap all bad data, but they will substantially reduce the amount of time that the project analysts must spend in verifying that the data collected are plausible and internally consistent.

Three automated verification tests were included as key design concepts for this system. The first is a range test. This test is used to determine whether the recorded values are reasonable for a particular measurement. For example, a channel may be measuring the power consumption of an electrical panel devoted to lighting circuits. Power measurements on this channel should not be negative and should not exceed the combined capacity of the circuit breakers in the panel. The second is a repeated values test. This test is used to identify sensors which are "stuck." Many measurements are highly variable, e.g., power consumption for devices which frequently cycle on and off. Any channel which is expected to vary, but does not, is a potential problem. The third is a check-sum test. This test applies only to electrical power measurements and is accomplished by comparing the sum of circuit level measurements to control totals measured at the panel, switch gear, or utility meter level of the electrical distribution system. When done by phase, in a polyphase electrical system, this test can provide a powerful diagnostic for locating measurement problems.

Controlled Simulation Environment

The research plan specifies a major role for the DOE 2.1E building energy performance simulation program. This computer program is to be used to develop calibrated hourly simulation models for each demonstration site. These models will be used in the design of the maximum energy savings package of EEMs and will be used to estimate the energy savings associated with each EEM. In the design process, the model allows the designers to quickly examine the likely impact of various designs for EEMs and combinations of EEMS. In the savings estimation process, the model is used to control for the effects of non-EEM changes which will occur at each demonstration site, e.g., the number of occupants in a single family home may increase between the preconditions stage and the owner operation stage.

A large number of simulation runs will be required to complete the design and savings estimation analyses for each site. These runs will be conducted over a five year period. There were a number of related design concepts which were adopted to create a controlled environment for this large body of simulation analysis. The first concept involved making modifications to DOE 2.1E to expand its ability to generate hourly end-use reports. The program is now capable of producing a standardized, binary, hourly end-use report file which can be processed by DPAS. This file contains a disaggregation of energy consumption into 17 end uses, plus user defined calibration variables. The standard end uses can be used to prepare estimates of energy savings by end use and time-of-use periods. The user defined variables can be compared with measurements as part of the model calibration process.

The second design concept is a standardized directory and file naming convention for DOE 2.1E input files. Each demonstration site is assigned its own directory. Within these directories, the DOE 2.1E input files are stored in a series of standardized sub-directories. The first sub-directory layer is organized by study phase. There are four study phases relevant to the simulation analysis: (1) PDESIGN - Preliminary Design, (2) FDESIGN - Final Design, (3) ACT2OP - ACT^2 Operation Period, and (4) OWNEROP - Owner Operation Period. The second sub-directory layer is organized by estimation type. There are three estimation types relevant to the simulation analysis: (1) CALIB Calibration, (2) INDV - Individual EEM Savings, and (3) INCR - Incremental EEM Savings. The names of individual input files, stored within the second sub-directory layer, are formed by concatenating a 1-character file type code (C - Calibration, B - Base Case, E - EEM), a 3-digit site ID, and a 3-digit EEM ID, e.g., B087001.INP.

This standardized directory and file naming convention allows the system to manage all of the input and output files and to spawn the appropriate DOE 2.1E runs. Further, this directory structure for each site can be maintained in a compressed format necessary to minimize the requirement for disk storage. This is especially true for the hourly output files, which can typically be compressed to one eighth of their original size. The compressed directory structure can be easily moved from on-line storage to archival storage and back again as each site progresses through the five year demonstration process.

Generalized Statistical and Graphical Tools

A wide variety of data analysis tasks will have to be performed on the DPAS time-series database. These tasks will include data selection, transformation, statistical modelling, summarization, tabulation and data visualization. It would be possible to develop a custom facility for such processing using a conventional programming language, e.g., C or FORTRAN. However, there are two major disadvantages of a such a custom facility. First, its development would be a complex and uncertain undertaking and most likely expensive. Second, it is inherently inflexible, as the system developers can only provide a limited set of processing functions, which may or may not satisfy all of the processing requirements.

Instead of developing a custom facility for statistical and graphical processing, a key design concept for DPAS was to integrate highly generalized, commercially available, statistical and graphical processing languages. Integration is achieved by building data links between the DPAS time-series database and these general purpose languages. These links allow the user to reference the measurement names and period of interest within the statistical or graphical processing language. Once referenced, the user can perform any operation on the data allowed by the general purpose language.

These general purpose statistical and graphic all processing languages are to be used for two purposes. First, they will be used to prepare tabulation and graphs for the data verification process. The tabulations allow the user to see the results of the verification tests, such as the check-sum results. Standardized 2- and 3-dimensional time-series plots and XY scatter plots allow for routine visual inspection of the time-series data. Second, these general purpose languages are used by project staff to perform ad hoc analyses of the data. These analyses can include interactive data visualization, such as rotating surface plots with cutting planes.

System Components and Structure

The components and structure of DPAS are illustrated in Figure 1. As shown in the figure, the system is composed of three computers plus the network of data loggers. Each of the three computers plays a unique role in processing the data. The roles of each computer are discussed in the balance of this section.

It is important to note that certain DPAS functions were not implemented in the current version of the system. The functions not implemented are: (1) portions of the DOE2.1E calibration facility, (2) data export, (3) life cycle cost calculations, and (4) interactive editing of SLG data tables.

DPAS-HOST

As shown in Figure 1, the DPAS-HOST computer supports eight functions: (1) data entry and management of parameters which define sites, loggers, measurements, computed variables, and data verification plots; (2) communication with data loggers, including time synchronization, installation of defining parameters, and data acquisition; (3) creation of SLG data tables, including aggregation to form LCD records, creation of computed variables, and conduct of automated verification tests; (4) entry and management of EEM specifications data, including components of EEM costs and service life; (5) creation of updates for the DPAS database maintained on the DPAS-SERVER computer; (6) running DOE 2.1E to support model calibration, including comparison of model outputs to measurements taken at each site; (7) running DOE 2.1E to support estimation of EEM savings; and, (8) preparation of exportable data products.[5]

The DPAS-HOST computer is connected to the DPAS-SERVER computer via a standard Ethernet network connection, such that it can share disk volumes on the DPAS-SERVER. Approximately 5 MBytes/Minute can be moved across this connection, between the two computers. The DPAS-HOST computer is connected to the DPAS-FIELD computer via either a 2400 BPS, dial-up connection, or a direct serial connection at 19.2 kBPS. Only relatively small amounts of data (less than 200 KBytes) are routinely transferred between the DPAS-HOST and DPAS-FIELD computers.

DPAS-FIELD

The DPAS-FIELD computer is a portable unit. Its primary function is to support the installation and maintenance of data loggers at each demonstration site. The system is capable of performing functions 1, 2, 3 and 5 as described for the DPAS-HOST computer. In addition, it has a facility for preparing simple time-series plots, XY scatter plots, and data tabulations, which can be used at the site to diagnose measurement problems. The DPAS-FIELD machine can also be used to collect data from loggers installed for short-term measurements.

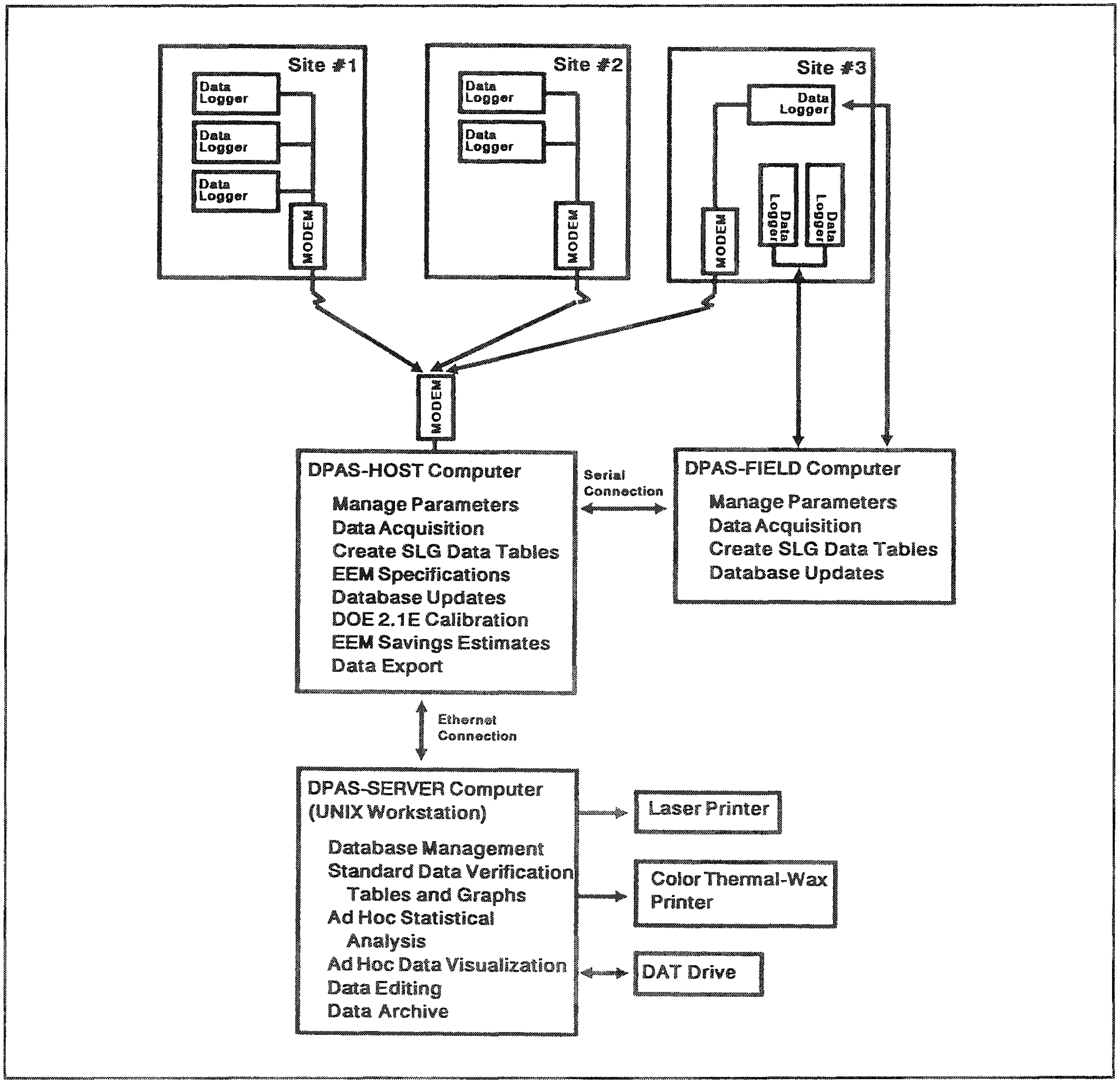

Figure 1. DPAS Components and Structure

DPAS-SERVER

The DPAS-SERVER computer is a Unix workstation, which supports the following functions: (1) central database management; (2) creation of standardized data verification data displays, including 2 and 3-dimensional time-series plots and XY scatter plots; (3) ad hoc statistical analysis; (4) ad hoc data visualization; (5) data editing; and, (6) maintenance of a data archive. An example of the data verification plots produced on this computer are shown in Figure 2.

The DPAS-SERVER is connected to a series of peripheral devices, including a 2.3 GByte DAT drive and two printers. It has approximately 1.4 GBytes of on-line storage, which can easily be expanded as the database grows. One of the printers is a thermal-wax color printer capable of preparing high quality presentation graphic displays.

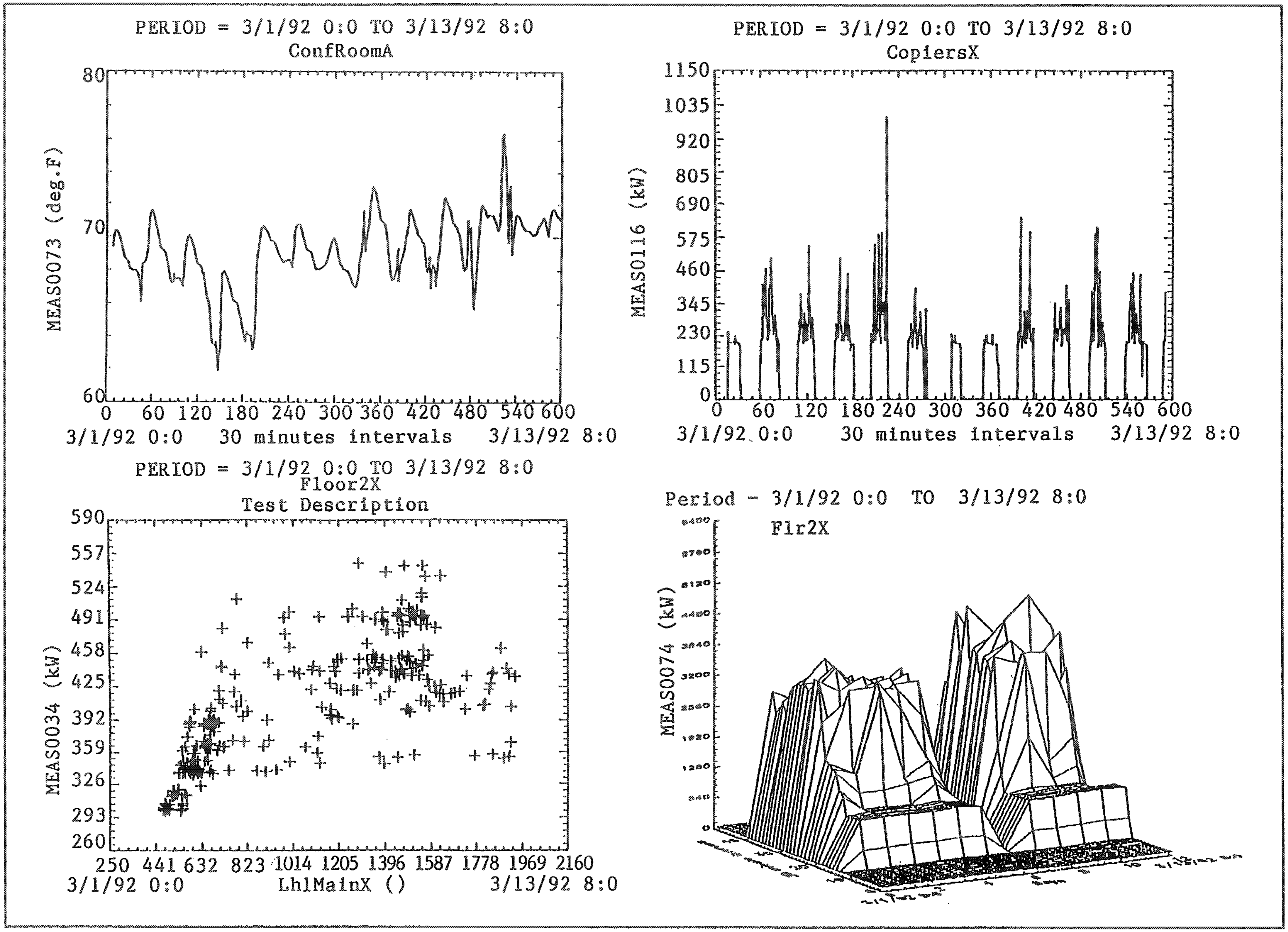

Figure 2. Examples of Standard Verification Plots

System Operation

DPAS has a number of distinct modes of operation. Some of these modes of operation are highly automated and run with little or no input from the user. Other modes of operation are highly interactive and require substantial input from the user. These various modes of operation are described in the balance of this section.

Site Installation

In this mode of operation the system is used to install loggers at a demonstration site. This mode of operation applies to both the initial installation of loggers and the re-installation of loggers throughout the various stages of the demonstration process. For a new site, the first step in operating the system is to create a site. Once the site is created, the system is used to enter the information that defines the data to be collected from each logger. This includes the definition of Site Logger Groups, assignment of measurement names, the definition of computed variables, and the assignment of data verification tests.

Once all of the defining information for the loggers is entered on the DPAS-HOST computer, the site can be "checked-out" to the DPAS-FIELD computer. Next, the DPAS-FIELD computer is transported to the site and connected to the data loggers. The information defining all measurements is downloaded to the data loggers and used to collect test data. After the period of test data collection, the system is used to acquire the data collected by each logger, create SLG data tables, and apply the data verification tests. The results of the data verification tests are reviewed to determine whether any problems exist. If any problems are identified, corrective actions can be immediately implemented, including any necessary changes to the information which defines the data to be collected from each logger. Once the installation is fully corrected the DPAS-FIELD computer is connected to the DPAS-HOST computer and all of the defining information for the site is "checked-in."

Nightly Processing

Each night the system is used to collect information from the permanently installed data loggers at various sites. As sites become operational they are entered into a data collection schedule. This schedule determines which sites will be called each night.

The nightly processing consists of the following steps. (1) The system automatically starts at a prespecified time, e.g., 1 a.m. (2) A call is placed to the US Naval Observatory to obtain the current time. This time is used to synchronize the system time for the DPAS-HOST and SERVER computers, and for each data logger which is called. (3) All of the data present in the on-board memory of the loggers is downloaded to the DPAS-HOST computer. (4) Any changes in the information which defines the measurements at a site are downloaded to the loggers. (5) Updates to all SLG data tables are prepared, including the creation of LCD records, calculation of values for computed variables, and the application of data verification tests. (6) SLG updates are transferred to the DPAS-SERVER and loaded into the on-line time-series database. (7) Data verification reports are printed for all new data. (8) New data are added to the database archive, which is maintained on magnetic tape (8 mm DAT).

Time-Series Data Editing

The automated data verification tests along with other analysis of the time-series data will identify data problems. These may either be portions of the data which are missing or portions of the data which contain erroneous values. The data must be edited to correct these problems before it can be used to evaluate the EEMs installed at each demonstration site. The commercial statistical processing language, which is integrated with DPAS, is used to perform the required data editing.

The statistical processing language is used to specify the data transformations required to correct the data problems. These data transformations may be used to interpolate values for missing measurement intervals or to modify the measured values. All of the necessary data transformations are stored in an edit history files on the DPAS-SERVER. Once the data transformations are prepared and fully tested, they can be used to supply fully edited extractions from the time-series database. When the system receives requests for edited data, each of the transformations are applied and a fully edited copy of the requested measurements is created.

Calibrated Simulation

The development of calibrated simulations for each demonstration site is a complex process which involves considerable effort by the project engineers and considerable analysis of the time-series measurements collected from a site. DPAS supports portions of this process. The first step is to conduct analyses of the measurements from the site and to use the results of these analyses in preparing a DOE 2.1E Building Description Language (BDL) input file. The measurements are most useful in developing portions of the BDL input file that specify the schedules for internal loads. The user includes in the BDL file a command to create the standardized hourly end-use report, including a specification of any desired calibration variables. The user stores the file in a directory with a name that conforms to the naming standards described in the section titled KEY DESIGN CONCEPTS. This process can be repeated for a number of sites.

Once the BDL input files have been created, DPAS is invoked and used to select the calibration runs to make with DOE 2.1E. The system performs the selected calibration runs and stores a compressed form of the standardized hourly end-use report created by DOE 2.1E. The user can then select calibration variables which are to be compared to measurements present in the time-series database. The system extracts the selected calibration variables from the compressed DOE 2.1E output report and the corresponding measurements from the time-series database.[7] After assembling the appropriate data, the system prepares a plot showing the differences between the simulation model prediction and the measured values. For example, the HVAC energy consumption for a building might be compared to the measurement of HVAC consumption.

The user examines the report which compares model predictions to measurements and makes appropriate changes to the BDL to achieve a calibrated simulation of the building. Each time the BDL input file is changed, the system can be used to re-run the comparison between the model predictions and the measured values.

EEM Data Entry and Analysis

As with calibrated simulation, DPAS automates a portion of the work associated with the analysis of EEMs. This process begins with the preparation of data describing the EEMs which are to be evaluated for a site. The EEM specification data include installation and maintenance costs along with the expected service life of the EEM and its major components. DPAS is used to enter these data into the project database and to use these data, along with DOE 2.1E input files, to conduct an analysis of the expected energy savings and life cycle costs associated with each EEM.

The user selects a site, study phase and estimation type, and then enters the data for each EEM. In addition, the user prepares two versions of the calibrated DOE 2.1E model for each EEM. One BDL describes the base case conditions of the EEM, i.e., the conditions of the building prior to installation of the EEM. The other BDL file describes the building with the EEM installed. These input files are named and stored according to the standards described in the section titled KEY DESIGN CONCEPTS.

Once the EEM specifications are entered and the BDL files prepared, the user selects the EEMs for which the analysis is to be performed. The system runs the base case and EEM simulation for each selected EEM and computes the hourly energy savings for each end use. In addition, the system uses the data on EEM cost and service life, along with the computed energy savings, to calculate various life cycle cost parameters, such as the Benefit-to-Cost ratio.[8] DPAS can then be used to view the results of the energy savings and life cycle cost calculations for each EEM.

Acknowledgments

DPAS was developed under contract to the Pacific Gas and Electric Company. The system consists of custom software developed specifically for the ACT^2 project and a variety of commercial software products. The commercial software products include the following: 1) SYNERNET, Synergistics Control Systems, data acquisition; 2) SAS, SAS Institute, general purpose statistical and database management language running under SUN OS and PC DOS; 3) PARADOX, Borland International, data entry and database management under PC DOS; 4) DBMS/COPY PLUS, SPSS, file format conversion; 5) AUTO-MIGHT, The Pendulum Group, automatic event processing; 6) PV-WAVE, Precision Visuals, general purposed graphical processing and data visualization language running under SUN OS.

Endnotes

1. Commissioning is a special analysis of building energy performance which is performed for a three to six month period following installation of EEMs at each site. The analysis is conducted to determine whether the EEMs are performing in a manner consistent with design assumptions, and, if not, to identify necessary corrective actions.

2. During the initial pre-conditions stage, the measurements of energy use are only conducted at the of "circuit" level. Approximately 1 month of these data are collected and analyzed to determine whether more detailed "device" level measurements are required.

3. The measurement plan for a site is modified for the final pre-conditions stage, if it is determined that "device" level measurements must be taken. This may be accomplished by extending the permanently installed measurements or by taking short-term measurements with another group of data loggers.

4. Each data table has a primary key in a relational database design. The value of the primary key uniquely identifies each record. The fields in the primary key, e.g., Site-Year-Month-Day-Hour, can be thought of as the table's sort order. A complete discussion of relational table design and the properties of key fields are provided by Date (1990).

5. Support for the creation of exportable data products has not be implemented in the current version of DPAS.

6. In the current version of the system this edit history consists of batch jobs written in the general purpose statistical processing language. An interactive editing facility was included in the design of DPAS which would store the edit history as part of the time-series database. This feature has not been implemented in the current version of DPAS.

7. In the current version of the system the comparison of simulation results to measurements stored in SLG data tables must be accomplished through ad hoc batch jobs using the general purpose statistical processing language. An interactive facility for selecting variables for comparison and preparing relevant graphs and tabulations was included in the design of DPAS. This feature has not been implemented in the current version of DPAS.

8. In the current version of the system these calculations must be performed by a separate spreadsheet model. A fully integrated facility for computing life cycle costs was included in the design of DPAS. This feature has not been implemented in the current version of DPAS.

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