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A BUILDING SIMULATION PALOOZA: THE CALIFORNIA CEUS PROJECT AND DRCEUS

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ABSTRACT

The California Commercial End Use Survey (CEUS) project is being conducted for the California Energy Commission (CEC) by Itron, Inc. with support from KEMA-Xenergy, ADM Associates, and James J. Hirsch & Associates. The project is a massive effort designed to gain a detailed knowledge of end-use energy in commercial buildings in California. The basic premise of the CEUS project is: Collect detailed information via an onsite survey for a sample of 2,800 commercial establishments from across the state, use that data and an automated system to create detailed end-use building simulation models, then calibrate the models using all available information including billed electric and natural gas use, time-of-use logger data for inside lighting and HVAC fans, and interval metered data. The database of commercial building characteristics and calibrated end use simulation results contained in the DrCEUS system will then be used by the CEC and others for an endless variety of applications. The purpose of this paper is to describe the DRCEUS system that was developed to facilitate and accomplish the California CEUS project.

INTRODUCTION

The Random House Dictionary of the English Language defines a "lollapalooza" as "*an extraordinary or unusual thing, person, or event; an exceptional example or instance*". More commonly, lollapalooza is just shortened to "palooza" and added to the end of an existing word or group of words, as is the case here. The California CEUS project is the epitome of a palooza in the following ways:

- Onsite surveys of <u>2,800</u> commercial premises representing about 18,500 buildings and approximately 282 million square feet of floor area. A "premise" is either part of a building, a single building, multiple buildings, or a campus.
- For every surveyed premise, a calibrated building simulation with up to <u>13 electric</u> end uses and <u>6 gas</u> end uses.
- Electric/gas consumption data from <u>five</u> utilities: 2 electric/gas (PG&E and SDG&E), 2 electric-only (SCE & SMUD), 1 gas-only (SoCalGas)
- Almost <u>500</u> premises with interval metered data converted to hourly values.
- Actual-year data for <u>20</u> weather stations.
- Time-of-use logger data for inside lighting and/or HVAC fans for <u>500</u> premises.
- Creation of a sophisticated system/tool – DrCEUS – that enables these simulations to be done in a reasonable amount of time, and to a respectable degree of accuracy.

This paper will describe the California CEUS Project and DrCEUS, and will demonstrate that a "building simulation palooza" is the only fitting description of this effort.

THE CALIFORNIA CEUS PROJECT

Background

The California Commercial End Use Survey (CEUS) project is a massive effort designed to gain a detailed knowledge of end-use energy in commercial buildings in California. Conducted under the auspices of the California Energy Commission (CEC), and in cooperation with five of the state's utilities, it is unique in that this is the first statewide CEUS effort; previous CEUS efforts were conducted by individual utilities.

The CEC and the participating utilities will rely heavily on the information collected through this survey to forecast future energy needs and to ensure that those needs are met in the most efficient manner. The results, and the system used to create the results, will also be used to evaluate energy-related legislation and to develop sound energy policy for California. The utilities will also use this information to plan for their commercial customers' energy needs, develop energy efficiency programs, and to help their customers manage load.

There are two basic components of the CEUS project; onsite surveys which are used to gather premise equipment and operation characteristics, and the building simulation tool that would be used to create calibrated end use models from the survey data.

Onsite Survey Sample Design

The California CEUS project called for the collection of detailed information via an onsite survey for a *representative* sample (i.e. building types and sizes, climate zones, utility service areas, etc.) of 2,800 commercial premises. That is, each of the surveyed premises represents similar commercial facilities located throughout the State.

A modified stratified random sample was developed; stratification variables included utility service territory, CEC forecasting climate zones, building type, and annual kWh usage (4 size categories).

The commercial building types covered by the CEUS survey include: Small Offices, Large Offices, Restaurants, Retail Stores, Food/Liquor Stores, Refrigerated & Unrefrigerated Warehouses, Colleges, Schools, Health/Hospitals, Lodging, and Miscellaneous (churches, public assembly, fitness centers, museums, theaters, prisons, amusement parks, etc.).

Utilities included in the sample were PG&E, SCE, SDG&E, SMUD, and SCG. Utility service areas were subdivided by CEC forecasting climate zones as appropriate.

Onsite Survey Data

The onsite survey form used for the CEUS project evolved over many years of CEUS surveys by Itron. The most significant evolution for the California CEUS project was integration of some key building simulation concepts from the eQUEST Design Development (DD) Wizard into the survey form structure, as is explained later in this paper.

For the California CEUS project, the end uses used and the types of equipment that each end use encompassed were strictly defined. The end uses represented on the survey form and simulated by DrCEUS are as follows

- HVAC: Space heating and space cooling (electric and gas), and ventilation
- Service water heating (electric and gas)
- Cooking (electric and gas)
- Refrigeration (self-contained as well as built-up/remote refrigeration systems)
- Inside and outside lighting
- Office equipment
- Process equipment including: NonHVAC motors, air compressors, and non-motor process equipment.
- Miscellaneous equipment, which includes any equipment type not covered by one of the previously defined end uses.

Data collected on the survey form includes the following categories of information:

General Information Actual building type and type of work done at site, business-type specific information, notes and comments about unique operation, recent energy-efficiency improvements or changes at the site. Digital photos of the exterior, key/unique equipment, and sometimes interior, are also part of the data set.

Utility Services Utility service meter and account information is verified. Meters are often changed out and the sample process is not perfect, so this information is crucial for lining up the correct utility bills corresponding to the areas that were physically surveyed, and to which the simulation should be calibrated. Propane and other fuels used on-premise are also identified. Self-generation systems – like cogen and photovoltaic systems – are also identified.

Schedules Business hours, seasonal operation, holidays, hourly end use schedules, HVAC schedules.

Building Envelope/Shell Building shell construction, windows, skylights, doors, orientation, generic footprint shapes and dimensions, multiple buildings and relative locations, etc.

HVAC Equipment Single zone and Multi-zone air handlers, chillers, boilers, heat rejection, thermal storage systems, auxiliary equipment, etc.

HVAC Zoning HVAC and nonHVAC equipment surveyed by "activity area", e.g. Dining Area, Kitchen, Office, Conference Room, Lobby, etc. Thermal zoning schemes include perimeter/core, one-per-floor, and zone-by-activity-area.

NonHVAC Equipment Inside lighting, outside lighting, office, cooking, air compressors, nonHVAC motors, process equipment, water heating, refrigeration end uses.

Time-of-Use (TOU) Loggers Information about when and where the TOU loggers were installed.

Calibration Data

Calibration data for the CEUS project includes utility-provided electric and gas bills, as well as interval metered data when available. For a subset of sites, the CEUS effort also required installation of time-of-use loggers for inside lighting and HVAC fans as an experiment, to see if this data would be useful for calibration.

Building Simulation Tool/System

A key requirement of the Project was, of course, the need for a building simulation tool/system that could be used as a) the front-end to the survey data, b) would create a detailed end-use building simulation model from the data, and c) could be used in calibrating the model to available data.

The only hope of accomplishing such a building simulation palooza, was to develop a system that utilized a standardized method for collection of data, which would allow automated generation of the building simulation models. The DrCEUS system was the tool that Itron created to perform that function.

THE DRCEUS SYSTEM

DrCEUS is a building energy use simulation tool that combines features of Itron's SitePro software, with the eQUEST/DOE-2.2 Design Development (DD) Wizard for building simulation. It incorporates error-checking procedures to debug common simulation problems, and full color graphics to facilitate calibration and reporting of results.

Input Data Input data for the DrCEUS system includes the following:

- **Onsite survey data** The onsite survey data is contained in an Access or SQL database.
- **Technology data tables** This database provides default values when data are unavailable, as well as "starter shapes" that provide realistic shape to non-HVAC end use load profiles.
- **Weather data** Actual-year weather data for 20 California cities.
- **Utility data** Electric and natural gas consumption data from the utilities.

DrCEUS Features and Functions

Key features and functions of the DrCEUS system include the following:

- The Site Selection screen shown in Figure 1 facilitates selection of premises for performing simulation, printing, copying, or deleting sites.
- Provides numerous graphical displays of simulation results.
- Provides error log and various reports used for troubleshooting building simulations.
- Creates eQUEST Design Development Wizard pd2 file, stores results, and provides interactive access to the eQUEST model from the Site Selection screen.

Use of eQUEST DD Wizard

The eQUEST Design Development (DD) Wizard is the basis for the building simulation models created by DrCEUS. The DD Wizard's template-based approach was exactly what was needed to process sites en masse. As such, DrCEUS converts the survey data into an eQUEST DD Wizard model (*.pd2 input file). Specific features of the eQUEST DD Wizard that led to adopting it as the structure of choice include:

- The wizard-based, boilerplate approach to all inputs made it perfect for mass simulations.
- A variety of predefined generic footprint shape templates, and a systematic method for specifying the dimensions of those shapes, as illustrated in Figure 2. This made it easy to not have to oversimplify building shapes, i. e. model everything as a rectangular box.

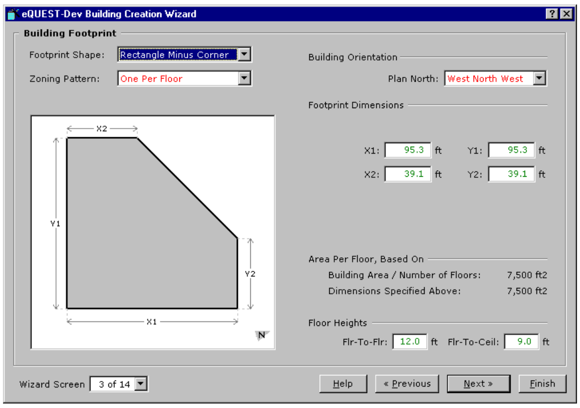

Figure 2 eQUEST Generic Footprint Example

- The "Building Shell Component" concept allows multiple footprint buildings and multiple building campuses to be simulated in a single model.
- 3-D visualization of the model, as shown in Figure 3, that can be manipulated and rotated. These can be easily compared to photos taken as part of the onsite survey.

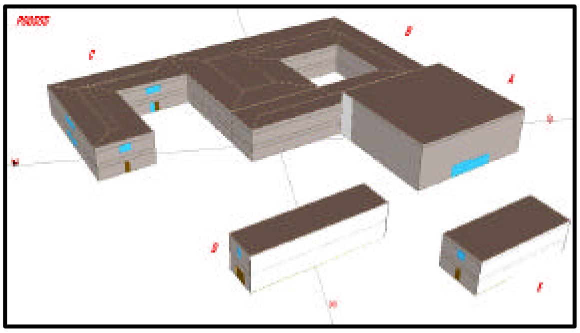

Figure 3 eQUEST 3D View

- Building-type specific defaults are provided for all wizard inputs
- 60+ HVAC system types described in real-world vernacular, not DOE2 BDL keywords.
- Wizard approach to the most common thermal zoning schemes like perimeter/core, one-per-floor, and a unique Zone-by-Activity-Area zoning scheme.
- Detailed Activity Areas, end uses, schedules, etc. were very compatible with the existing Itron onsite survey form.

Key Simulation Concepts

There are several key concepts that helped facilitate this mass modeling effort. These concepts were integrated into the onsite survey form, and surveyors were instructed in their application to real-world situations via training sessions. The key concepts are as follows:

Premise. The premise is the most basic unit of analysis for this study. The "ideal" premise is defined as a collection of buildings and/or meters serving a unique customer at a single contiguous location. A premise may be a portion of a building, such as one suite in a strip mall, or a multi-building school campus.

Building Shell Component. This is a term borrowed from the eQUEST DD Wizard. The most basic way to think about a building shell component, or simply a "component" is as a single stand-alone building. However, the concept can be used to create multiple-building sites, as well as single buildings with multiple-footprints, as is often the case for high-rise hotels. *Components are the basic building blocks of the eQUEST DD Wizard building simulation approach.* Components can be stacked and positioned relative to each other. Dividing the premise into component survey areas is a way to isolate distinct building construction types, locations, or activities and examine each area individually. Multiple components are generally only used with larger, more complex sites.

Activity Area. Activity Areas are used to identify areas of a building that have distinctly different equipment densities, occupancies, energy-use patterns, HVAC configurations, or operating characteristics. Up to eight Activity Areas may be defined for each component

Thermal Zoning Schemes. Another feature adopted from the eQUEST DD Wizard is the approach to thermal zoning schemes. The thermal zoning schemes utilized for the CEUS effort are:

- **One-per-floor** This thermal zoning scheme is the simplest in that each floor would be simulated as a single thermal zone (i.e., only one HVAC system per floor).
- **Perimeter/Core** For this zoning scheme, only two thermal zones – perimeter and core – would be indicated on the survey form, but for the building simulation eQUEST will sub-divide the perimeter into north/east/south/west thermal zones.
- **Zone-by-Activity-Area** Under this zoning scheme, each Activity Area would be defined as a separate thermal zone. Activity Areas / thermal zones are positioned within the building envelope via a coordinate system that is relative to the footprint. A primary application of this zoning type is in restaurants, where the kitchen and dining areas should be modeled as separate thermal zones because their energy intensities and HVAC systems (typically) would be significantly different.

DRCEUS GRAPHICS

A key feature of the DrCEUS system is its graphics, which allow the simulation results to be reviewed and compared visually as well as numerically to billed consumption and interval metered data. The graphics that are part of the DrCEUS system and that are used in the calibration process are described and illustrated in the following paragraphs.

Annual Energy Summary This screen, shown in Figure 4, provides basic premise characteristics such as SiteID, business name and total floor area. It also provides whole-building and end use energy intensities (kWh or mmBtu /ft^2-yr), a pie-chart of energy use by end use, peak loads, connected loads, and full load hour estimates.

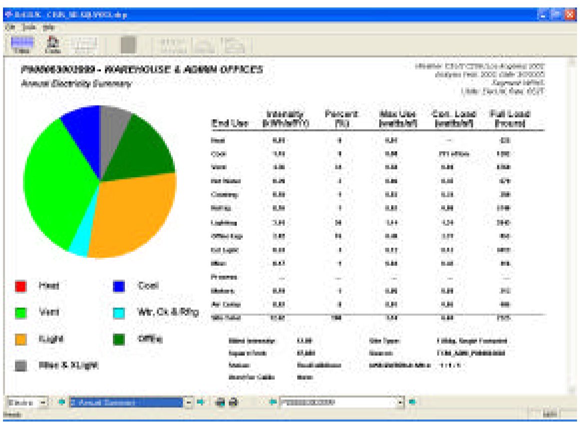

Figure 4 Annual Energy Summary

Monthly Billing/Consumption This screen, shown in Figure 5, provides a comparison of simulated versus actual monthly energy use (kWh or mmBtu) and demand (kW), whenever available.

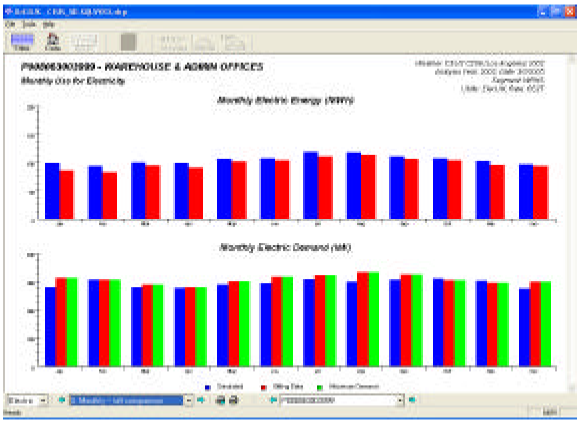

Figure 5 Monthly Billing/Consumption

16-Day Whole Building Shapes Figure 6 shows this screen, which displays simulated whole-building shapes on a 16-day type basis; four seasons and four day types (Typical/Hot/Cold/Weekend). For electric results, interval meter data when available will also be displayed. A larger version of this graphic is provided at the end of the paper in Figure 7.

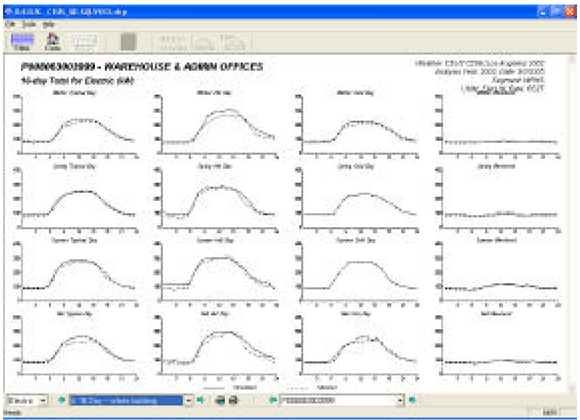

Figure 6 16-Day Whole-Building Load Shapes

16-Day Stacked End Use Load Shapes This screen, shown in Figure 8, presents simulated stacked end use shapes on a 16-day basis.

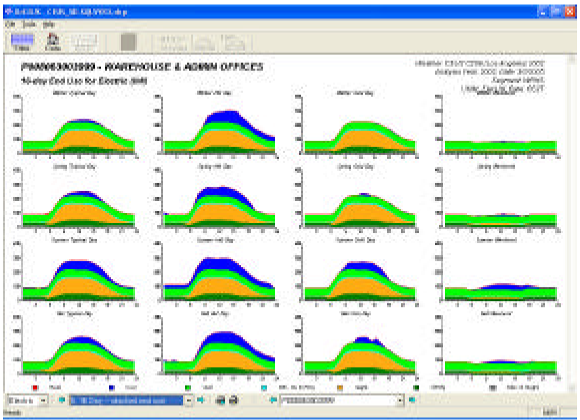

Figure 8 16-Day Stacked End Use Load Shapes

Summary Sheet The DrCEUS Summary Sheet, shown in Figure 9, displays mini-versions of the four graphics previously described in a four-panel layout. This graphic is most typically used at the beginning of the calibration process to quickly scan for major simulation problems. It is also used at the end of the process to document the final state of the simulation on a single page.

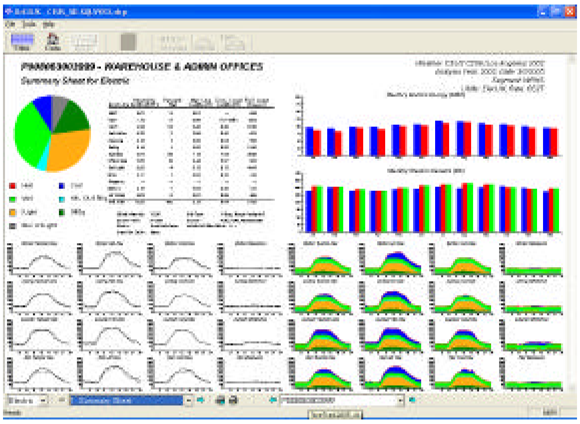

Figure 9 DrCEUS Summary Sheet

8760 (or 365 day for gas) Whole Building Profiles This graphic shown in Figure 10 presents 8760 (or 365 day for gas) whole building load shapes on a daily basis, 3 months of data per screen.

Figure 10 8760 Whole Building Graphic

Photos versus eQUEST 3-D Model Photos taken of the site can be accessed from the DrCEUS interface. The eQUEST 3-D model (example in Figure 3) can also be viewed by bringing up the model via the DrCEUS interface. This makes it very easy to quickly compare and evaluate the two if there is ever a concern about the physical model.

MODEL CALIBRATION METHODS

Calibration in the DrCEUS system is truly an art, because it is part visual, part quantitative, and every site can have its own unique eccentricities. Calibration involves not only evaluating the model, but also all the inputs to the model including the consumption data, the logger data, and the interval metered data. Simulation specialists need good detective skills, and a comprehensive understanding of the whole system's inputs and outputs.

Calibration for the CEUS project was generally accomplished via a "top-down" approach. That is, the review and evaluation started from the highest, simplest, and most concise level and proceeded down to the most-detailed level as needed, until the simulation was considered to be "calibrated". The procedure was roughly as follows:

1. Obtain the correct billing data for the premise as surveyed.
2. Check to see what other calibration information is available, i.e. interval data or logger data.
3. Select a site or sites using the DrCEUS Site Selection screen (Figure 1), and run the initial simulation and troubleshoot the data errors using DrCEUS error logs and reports and eQUEST/DOE2.2 error reports and 3-D view.
4. Check overall annual energy intensity, verify that it is sensible for this specific building type.
5. Check monthly simulated versus billed energy use and demand.
6. Check that <u>significant</u> end uses make sense for this building type, e.g. for a supermarket, refrigeration should be about 50% of annual energy use, and the next highest end uses should be lighting and HVAC.
7. Check that <u>non-significant</u> end uses are sensible, or at least not out of expected ranges.
8. Compare simulation versus interval metered data. Check operating hours and days, check seasonal weather sensitivity, etc.
9. Compare simulation versus logger data; Operating hours and fan cycling (always on or intermittent).
10. Make appropriate adjustments to the data (schedules, operating hours, etc.) as warranted to calibrate to calibration data sources.

LESSONS LEARNED

Although much knowledge was gained in processing and calibrating this many premises, the primary ideas that would be useful to anyone else contemplating such an effort, or even someone just calibrating a single premise would include:

1. "Every building is unique", that is, even though buildings of the same ilk typically operate with a given range of energy intensity (kWh/ft^2-yr), and generally with the same predominant end uses, no two businesses are ever completely identical.
2. As the result of item 1, a building simulator often needs to be a good detective in order to understand and calibrate a model. Each site is a puzzle to be solved, and the more information available to solve that puzzle, the better.
3. Unoccupied operation can significantly impact energy consumption, so don't just assume all equipment is turned off after hours. Furthermore, unoccupied operation can be very unique (see Item 1), and is often hard to characterize without an after-hours visit, TOU loggers, or whole-building interval metered data.
4. Small, low intensity sites – like churches – can often be as difficult to calibrate as the largest office building. Sporadic/irregular operation, manually controlled HVAC, etc. all contribute to this situation.
5. When calibrating a site, concentrate on the most significant end uses for each building type; the other end uses are typically just noise, but of course still need to be sensible.
6. HVAC systems are very often not operated the way they are designed and assumed supposed to be operated (e.g. HVAC fan should always be on in a commercial business).
7. If there is both gas and electric service at a premise, the gas bills should also be used for calibration even if the emphasis is only on calibrating the electric side, because the gas space heating will yield clues about how the HVAC system is operated.
8. Gas bills are more difficult to calibrate to because there are typically just one or two end uses, and hence they must be simulated more accurately.
9. Short-term logger data can be very useful for smaller sites in identifying fan operation (always on versus cycling with heat/cool) and identifying operation during unoccupied hours.

CONCLUSION

The California CEUS Project is a building simulation palooza that could have only been accomplished with a tool like the DrCEUS system. The data, results, and systematic approach to end uses in commercial buildings will be invaluable to the CEC and California utilities in evaluating energy efficiency and forecasting efforts in California.

Although the key features of the California CEUS project and the DrCEUS system have been explained herein, there is much more that could – and will – be written about this project.

ACKNOWLEDGMENT

I would like to acknowledge the onsite survey staffs of KEMA-XENERGY and ADM Associates. Special thanks to the creative and always helpful eQUEST/DOE2.2 team of JJH & Associates. Special thanks also to the Itron CEUS Team, especially the staff of simulators who worked tirelessly in calibrating each and every simulation. And finally to Itron programmer Mr. John Pritchard, for coining the DrCEUS name.

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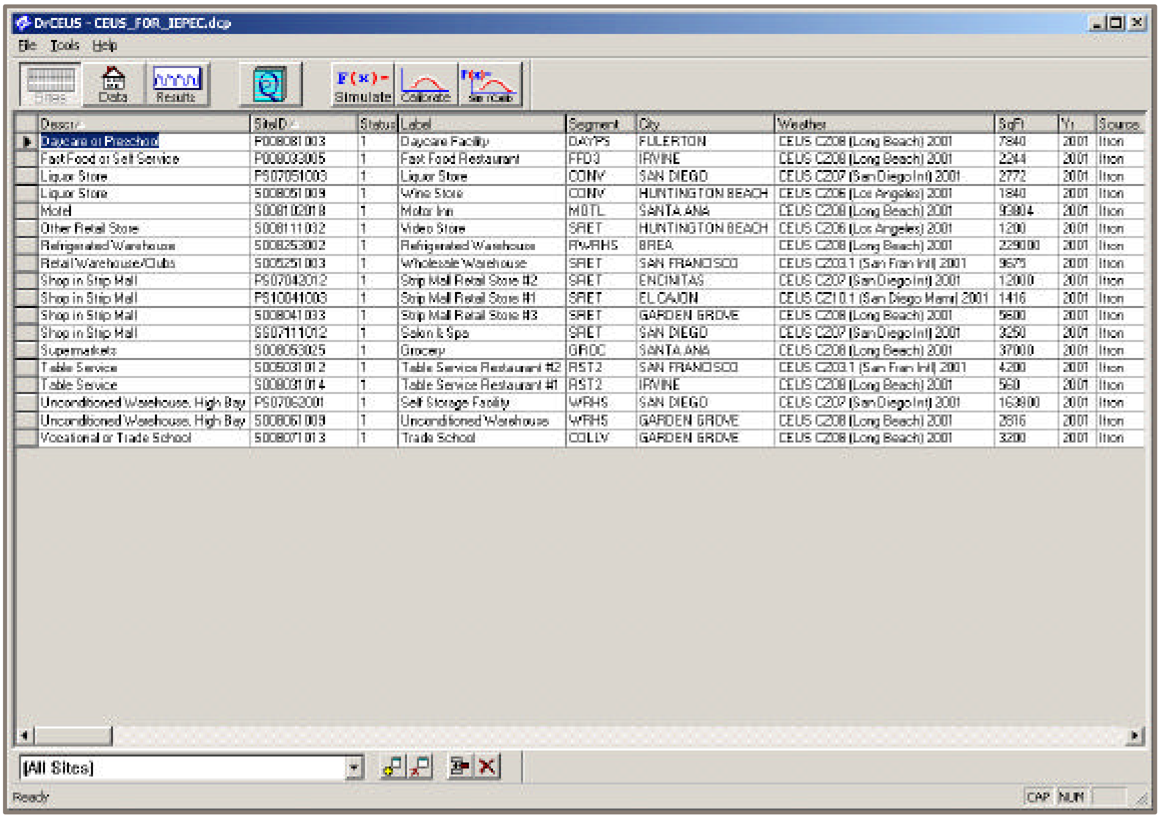

Figure 1 DrCEUS Site Selection Screen

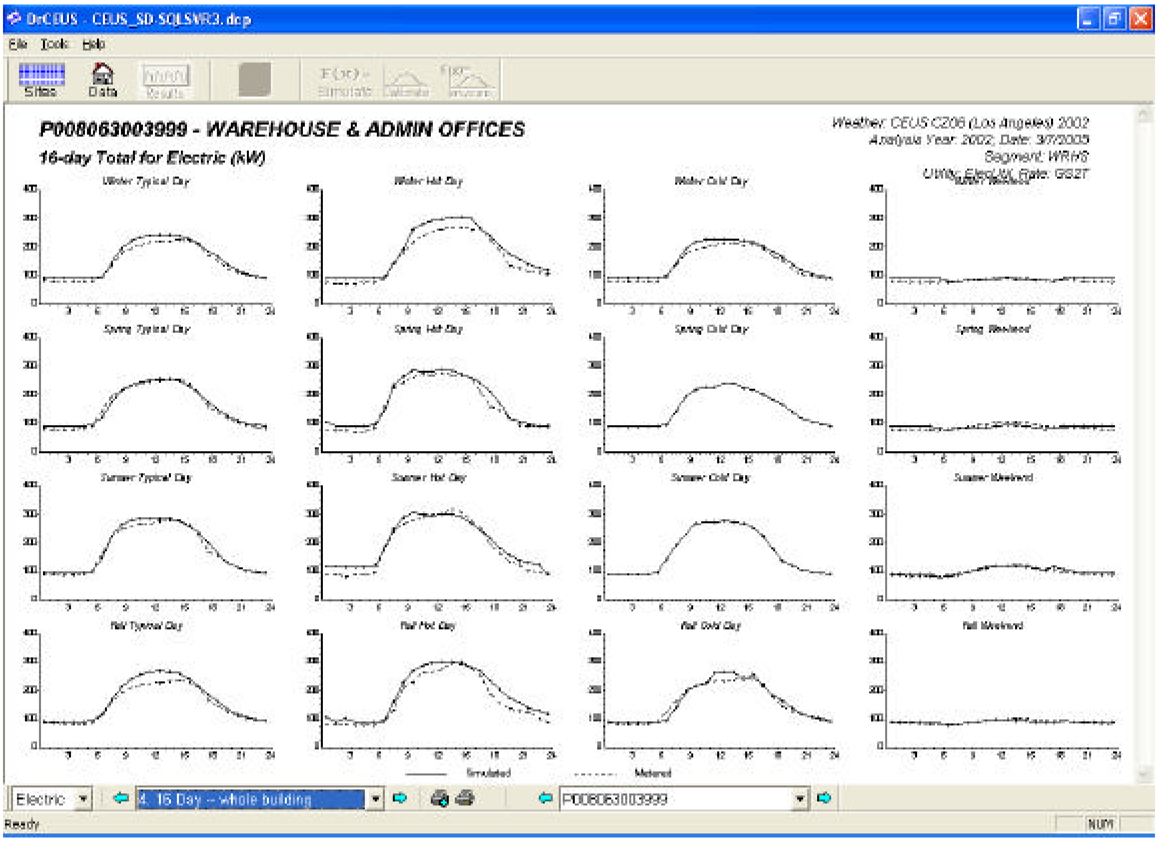

Figure 7   16-Day Whole Building Load Shape and Interval Metered Data