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# HPCBS
## High Performance Commercial Building Systems

# Development of a California Building Energy Benchmarking Database

***Element 2***
***Project 2.1***
***Task 1d2***

**Satkatar Kinney and Mary Ann Piette**
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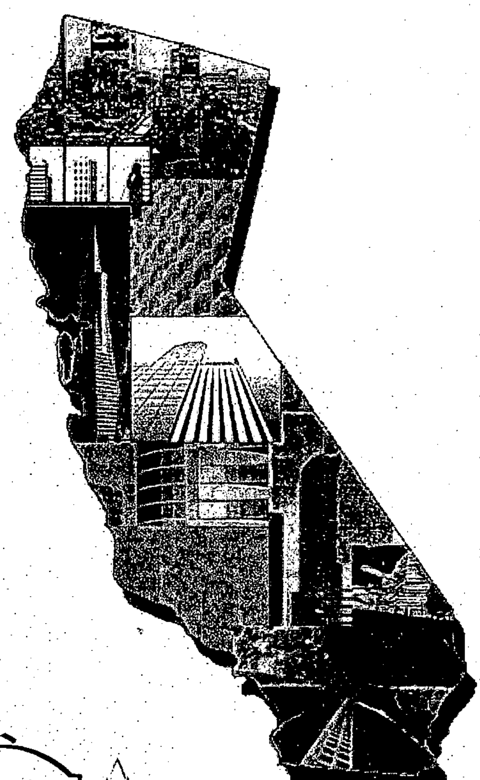

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# Development of a California Commercial Building Benchmarking Database

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# Development of a California Commercial Building Energy Benchmarking Database

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## Abstract

Building energy benchmarking is a useful starting point for commercial building owners and operators to target energy savings opportunities. There are a number of tools and methods for benchmarking energy use. Benchmarking based on regional data can provides more relevant information for California buildings than national tools such as Energy Star.

This paper discusses issues related to benchmarking commercial building energy use and the development of Cal-Arch, a building energy benchmarking database for California. Currently Cal-Arch uses existing survey data from California's Commercial End Use Survey (CEUS), a largely underutilized wealth of information collected by California's major utilities. Doe's Commercial Building Energy Consumption Survey (CBECS) is used by a similar tool, Arch, and by a number of other benchmarking tools. Future versions of Arch/Cal-Arch will utilize additional data sources including modeled data and individual buildings to expand the database.

## Background

Building energy benchmarking is the comparison of whole-building energy use relative to a set of similar buildings. It provides a useful starting point for individual energy audits and for targeting buildings for energy-saving measures in multiple-site audits. Benchmarking is of interest and practical use to a number of groups. Energy service companies and performance contractors communicate energy savings potential with "typical" and "best-practice" benchmarks while control companies and utilities can provide direct tracking of energy use and combine data from multiple buildings. Benchmarking is also useful in the design stage of a new building or retrofit to determine if a design is relatively efficient. Energy managers and building owners have an ongoing interest in comparing energy performance to others. Large corporations, schools, and government agencies with numerous facilities also use benchmarking methods to compare their buildings to each other.

Cal-Arch is based on Arch, which was built as a simple demonstration tool using CBECS for making distributional benchmarking information readily available. Cal-Arch is intended to provide information that is more appropriate for buildings in California. It does not provide a score, but gives the energy use intensity (EUI) for all similar buildings in the database along with relevant statistics.

## Existing Tools

Several benchmarking tools have emerged on the market in recent years. Some were developed as a service to utility and ESCO customers or as a component of an enterprise tools providing a broader range of functions. There are also a number of online tools, many of which are free. A list of online benchmarking tools and information relevant to benchmarking commercial building energy use can currently be found at http://poet.lbl.gov/cal-arch/links/. The benchmarking programs easily found online can be categorized into four different types of benchmarking services: simple benchmarking, load shape libraries, utility services, and enterprise tools.

Simple benchmarking refers to free tools whose primary purpose is to provide benchmarking information to the public. Except for Cal-Arch, all U.S. tools readily available on the Internet are based on CBECS. Load shape libraries use data and models to develop load profiles that can be used for benchmarking whole-building load profiles. Several utilities offer benchmarking tools as a service to their customers tailored to their service territory. Typical services available to a customer include the ability to compare energy use to past usage or to other buildings in their account, and in some cases, to regional benchmarks based on actual or modeled data. Enterprise tools are commercial products targeted at large organizations with multiple facilities that provide a range of services, including benchmarking energy use to identify and prioritize problem areas. Features range from simple benchmarking, to load shaping and forecasting, and can include direct connections to one or more utility meters.

## *Benchmarking Methods*

The most common energy use benchmarking metric in use is Energy Use Intensity (EUI), usually measured in annual kBtu or watts per square foot per year. In comparing a building's EUI to a population of similar buildings, the mean EUI can be a poor benchmark as distributions of EUIs are generally nonnormal. Distributional benchmarking is more reliable as it masks the effect of outliers (Sharp, 1998). Distributional benchmarking refers to percentile ranking, i.e., determining the percentage of buildings that are better or worse performers.

Benchmarking tools can also be categorized by the method in which benchmarking information is provided. Sartor et al. list four types of benchmarking techniques: Statistical Analysis (also known as Regression Model-Based) Benchmarking, Points-Based Rating Systems, Simulation Model-Based Benchmarking, and Hierarchal and End-Use Metrics. Points-Based Rating Systems, including the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Rating System, do not allow comparisons against other buildings, rather, they provide standards and guidelines to measure how efficient and environmentally friendly a facility is and compared it to best-practice standards. A LEED score is made up of credits assigned for satisfying different criteria including energy efficiency and other environmental factors. Hierarchal and End-Use Metrics refers to the generation of benchmarks that link energy use to climate and functional requirements. This method is useful for accounting for more of the differences in features affecting energy use; however, the type of data required is not readily available (Sartor et al., 2000). Of most interest in the development of Cal-Arch are the Statistical Analysis and Model-Based Benchmarking approaches.

In Statistical Analysis benchmarking, statistics for a population of similar buildings are used to generate a benchmark against which a building EUI is compared. This method requires large data sets to produce a reasonably sized sample of comparison buildings. Cal-Arch queries its database for similar buildings and provides a histogram and statistics for the distribution of the query results. Energy Star takes a different approach, attempting to account for more of the differences between buildings through the use of models and normalization methods that are used to generate an efficiency score.

Simulation model-based benchmarking calculates benchmarks based on an idealized model of building performance, such as DOE-2. Models have many uses in benchmarking, and they have the advantage that they can be tweaked to account for a wide range of factors that contribute to variation in energy use. They can also be used to generate targets and compare design alternatives. A disadvantage to many users is that they are in fact, simulation models, and benchmarks based on models may not be well calibrated to the actual buildings stock data.

The use of models in conjunction with actual data is being explored in the development of Cal-Arch. While the building characteristic information in CEUS is very detailed, some sections of the database do not contain complete energy use information. While the surveys were conducted in on-site interviews and include fuels used by end use, the energy use was reported by the utility conducting the survey, and thus only the energy use provided by that utility is reported. Thus for most buildings in CEUS only electric use can be benchmarked without the aid of modeled data.

## *Energy Star Benchmarking*

Perhaps the best-known and most technically robust building energy benchmarking tool is the EPA/DOE Energy Star Benchmarking Tool. We have reviewed the office and school benchmarking tools in detail. These tools are unique and the most valuable initial screening tool available for national building energy use analysis. The office and school tools account for numerous factors that can confound comparisons of building energy use across the nation. These include climate, building schedules, and occupancy, as well as personal computers, ventilated garages, air-conditioning, computer centers and kitchen equipment.

It is important to be clear about the pros and cons of a regression model-based benchmarking tool compares to raw data visualization provide by Arch and Cal-Arch. A major strength of Energy Star is that it goes much further in providing a "ranking" of efficiency–the score. A building receives a score between 1-100; a score of at least 75 is required for an Energy Star Buildings Label, which is intended to recognize buildings among the top 25 % nationwide in energy performance. This assessment provides a user with a clear evaluation methodology, hopefully encouraging building owners to perform retrofits or improve operation to ensure that a building reaches an efficient target (Hicks and Clough, 1998; Hicks and von Neida, 2000).

In the development of Cal-Arch we have been examining how California buildings compare with the national stock. This research has included both school and office building data. The basic question is, "Are California building more efficient?" within the Energy Star benchmarking framework. Or, put another way, do they receive higher Energy Star scores? Recent work by LBNL and EPA suggests they do. EPA has identified 128 California office buildings in CBECS. While the office buildings (a sample of 776) in CBECS receive an average score of 50, the California office buildings in CBECS receive an average of 60, or 10 points higher, which turns out to be statistically significant.

CEUS currently includes 218 office buildings with floor area and energy data. We found 153 of the buildings had sufficient data to enter into the Energy Star benchmarking tool. EPA screened out buildings with anomalous occupant densities, PC densities, parking structures, and EUIs and calculated Energy Star scores for 117 office buildings. These buildings achieved a mean score of 63.

We also provided similar data for about 40 K-12 schools, of which 30 had adequate data for the Energy Star Schools benchmarking tool. Similar to the office buildings analysis, California schools appeared to perform better compared to the national average; however, data quality and definition conflict issues are still being resolved. Most striking is that the occupant densities recorded for the schools in CEUS were significantly higher than the nationwide average. The Energy Star model is highly sensitive to occupant densities; when the occupant densities are reduced to national averages, the scores are greatly reduced.

LBNL, EPA, and the California Energy Commission are all interested in the question of why California buildings receive higher scores. There are numerous possible explanations. One explanation may be that California buildings are more efficient from years of Demand-Side Management and stricter building energy codes. Another possibility is that higher energy prices cause owners and others to design and operate buildings with greater attention toward efficiency and energy conserving practices. Another explanation may be that there are biases within the model. One possible source of bias may come from the climate variables in the Energy Star models. The climate variable in the office model is cooling degree days (CDD), and the climate variable in the school model is heating degree days (HDD). **Figure 1** shows the relation between HDD and CDD for each census division in the U.S. Notice that for the majority of the U.S. HDD and CDD are correlated; however, in Division 9, which includes California, Oregon, Washington, Alaska, and Hawaii, this is not the case. Thus, one possibility is that for a given office in California, the Energy Star model expects a higher HDD than there actually is based on what the CDD for that office is. That is, the model predicts a higher EUI, and the building performance appears "better" than the comparison data.

We have not demonstrated the magnitude of the affect of using only one weather term, but this example is included to illustrate some of the technical challenges in developing robust models. EPA is aware of this finding and plans to make a series of revisions to the regression models; future versions of the models will include both HDD and CDD terms.

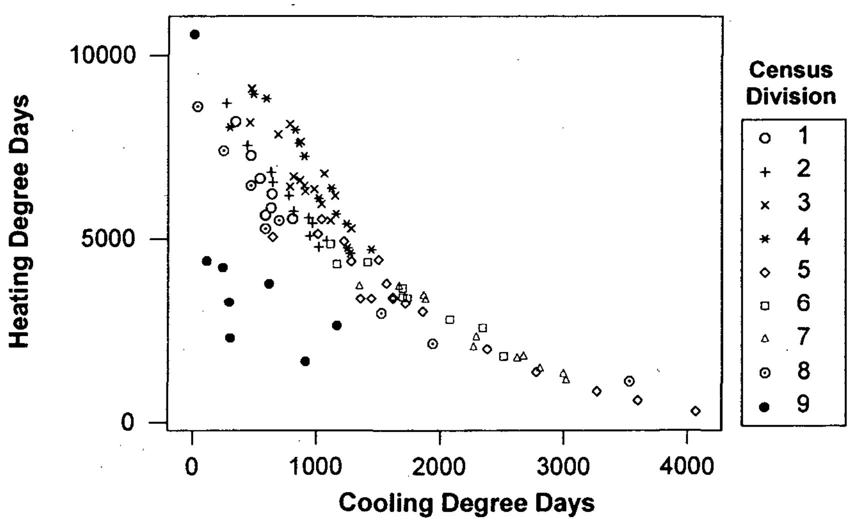



**Figure 1.** Heating degree days vs. cooling degree days for CBECS offices.

An additional issue with benchmarking models is they need to account for the miscellaneous loads found in buildings such as computer centers and garage fans. The Energy Star models have done this well for office buildings. LBNL found that a similar miscellaneous end-use can greatly influence school EUIs–swimming pools. LBNL developed a simplified "pool correction" method to account for pool energy use which will be incorporated into future Energy Star models. **Figure 2** shows the site EUI for 30 California schools in CEUS. These data are still being refined; however, it four of the seven highest EUIs correspond to schools that have pools.

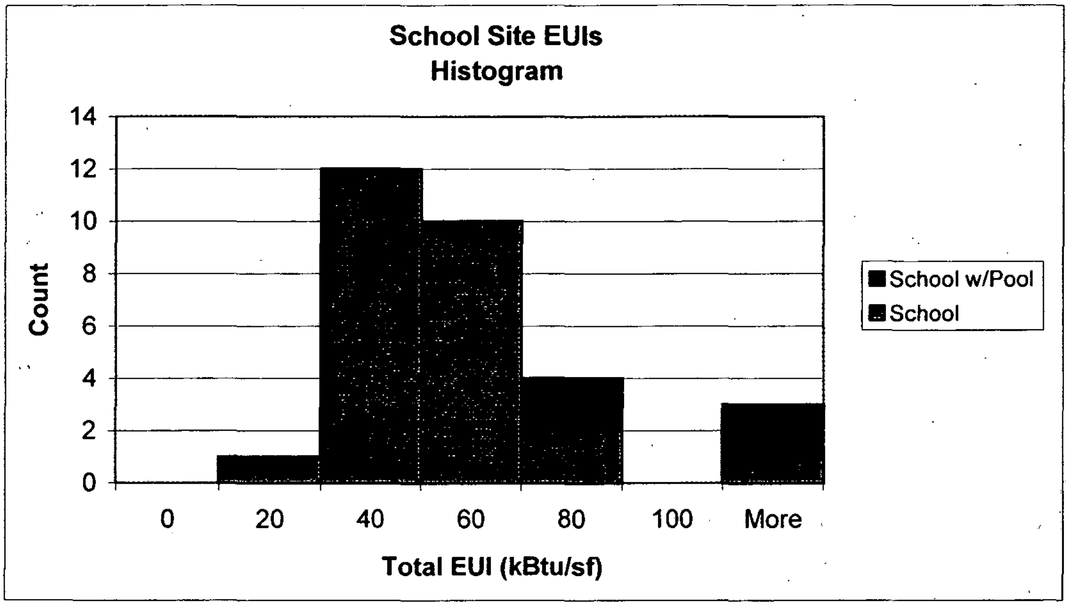



**Figure 2.** Total EUI for 30 California schools.

A philosophical question about benchmarking is, "Can there be an efficient school with a pool?". Where does one stop in developing "correction" factors? Does one develop a correction factor for a ceramics kiln? The answer is probably that one develops correction factors when the correction is applicable to a large percentage of the building stock. In general, the concept of an efficient building should be linked to some "level of service" provided within a building. Hinge, et al. examined several Northeastern schools in detail and tracked their performance using the Energy Star benchmarking tool known as Portfolio Manager. They found the results can be counterintuitive, i.e., an older school with less services and amenities could achieve a higher score than a modern school with more efficient technologies (2002).

Since we have found that Californian office buildings and schools tend to score well within the Energy Star benchmarking model, the California Energy Commission (CEC) has been exploring the question of how to use the EPA/DOE framework to promote efficiency within California and reduce the labeling of buildings as "efficient" when significant opportunities for improvements exist. One possible approach is to require a higher score, perhaps an 85 (ten points higher) to be considered a high-performing building in California. Another possible approach for California is to develop a separate set of regression models for the California commercial sector based on California data. Unfortunately, the current CEUS database is inadequate for developing such a model; however, the CEC is currently developing a much more robust statewide CEUS that will provide a much better benchmarking dataset than currently available. These data will be available in a few years. Furthermore, EPA plans to revise the current office and schools models in early 2003, which may turn out to provide scores for California consistent with the national distribution. This discussion of the Energy Star model helps demonstrate the technical challenges in benchmarking. By contrast, Cal-Arch is only a raw EUI data visualization and does not provide the more sophisticated underlying model to help explain variations in EUIs.

## Data Sources

A significant part of the effort to build Cal-Arch has been the statistical analysis of the 1992—95 CEUS data provided by the California Energy Commission in SAS datasets. This is a rich database of building characteristics based on on-site surveys, which has seen limited use since it is unavailable to the general public. Several hundred fields are available in the CEUS datasets; however, only a few are required for Cal-Arch: gas and electric billing data, floor area, building type, zip code, and statistical weights. Other data have been examined closely in preparing the data for Cal-Arch, in particular, fields relating to fuels and energy use.

The CEUS survey provides detailed audit data for commercial buildings. The data include a list of which energy sources are provided to a premise. LBNL has obtained the Pacific Gas and Electric (PG&E) and Southern California Edison (SCE) CEUS data sets. The PG&E dataset includes both electricity and gas use because they sell both types of energy. The SCE dataset includes the electricity use only.

### *CBECS*

CBECS is a national sample survey of energy-related building characteristics and consumption for the United States commercial sector. It is currently the only publicly available national database containing commercial building characteristics and end use information and thus it is widely used for benchmarking and other applications. Use of CBECS data is not planned for Cal-Arch; however, a link will be provided to Arch 2.0 so that both regional and national comparisons may be performed. Cal-Arch will initially rely solely on the CEUS data, in particular the 1995 PG&E survey. Future versions of Cal-Arch may implement the use of models and other statistical methods, as well as additional data sources, which will greatly expand the information that Cal-Arch is able to provide.

### *Other Data Sources*

Additional regional and specialized databases exist which are less readily available. There are a number of large corporations that collect data on their own facilities, and utilities and energy service companies that collect data on their customers" facilities. For Cal-Arch we are also considering the use of public building data provided by the U.S. General Services Administration as well as a California new construction survey (RLW, 1999). In addition, the incorporation of data from Cal-Arch users is being considered. Although this method does not constitute accepted survey methods and the statistical inferences that can be made will be limited, there is an overriding interest in being able to have links to real buildings.

**Combining Data Sources.** Combining data from different data sources presents a challenge as survey methodologies differ. Even within the most recent CEUS database, three separate surveys were conducted by three major California utilities. Although they are closely aligned, there are enough differences to complicate data processing. CBECS data are not used at all in Cal-Arch as the geographic resolution of CBECS is too broad to determine which buildings in the survey are in California. Statistical weights developed in the different surveys also become suspect and need to be re-evaluated or excluded when combined and used for different purposes than intended when the weights were designed.

## Data Requirements

A common complaint of benchmarking tools is the inability to account for all the main differences between buildings. There is a trade-off between having a significant sample size of buildings to compare against and the similarity of those buildings to each other and those being compared. The variables currently used in Cal-Arch include Principal Building Activity, Climate Zone, and Floor Area. A number of other parameters could also be used, including operational variables such as occupancy, number of computers, and hours of operation, and physical variables such as number of floors, cooling and heating system types, structure type, and shading; however, it is necessary to restrict the parameters to a few broad yet critical categories so that a sizeable sample is returned when the database is queried. Modeled data can be adjusted to account for any number of parameters.

**Principal Building Activity.** The principal building activity (PBA), or building type, is defined to be building function occupying the most floor area. The categories for PBA in Cal-Arch have been designed to correspond roughly to CBECS categories. How PBA is defined in a survey is very important when combining data from multiple surveys, as definitions do not always correspond. Thus, although CEUS has a greater number of categories, these had to be grouped and reassigned to match up as closely as possible to CBECS categories, as shown in **Table 1**. As CEUS has more narrowly defined its building type categories, assigning them to CBECS categories is relatively simple; however, also shown in **Table 1** are Title 24 building categories. In this case, some categories are more general than CBECS, and thus some buildings may fit into more than one CBECS categories.

**Table 1.** Building Type Correspondence

| CBECS Category | CEUS Category | Title 24 (RLW survey) |
|---|---|---|
| Agricultural | Agricultural | |
| Education | Daycare or Preschool<br>Elementary/Secondary<br>College or University<br>Vocational or Trade School | School |
| Enclosed Shopping/ Mall | Shop in Enclosed Mall | |
| Food Sales | Supermarket<br>Convenience Store<br>Other Food Store | Grocery Store |
| Food Services (Restaurant) | Fast Food or Self Service<br>Table Service<br>Bar/Tavern/Club/Other | Restaurant |
| Health Care (Inpatient) | Hospital | |
| Health Care (Outpatient) | Medical Office<br>Clinic/Outpatient Care | Medical Clinic |
| Industrial Processing/Mfr | Assembly/Light Manufacturing<br>Med/Heavy Equip. Mfg<br>Food/Beverage Processor | |
| Lodging<br>(Hotel/Motel/Dorm) | Hotel<br>Motel<br>Resort | Hotels/Motels |
| Nursing Home | Nursing Home | |
| Office/Professional | Administration & Management<br>Financial/Legal<br>Insurance/Real Estate<br>Other Office | Office |
| Public Assembly | Recreation or Other Public Assembly | Religious, Auditorium<br>Theater<br>Community Center<br>Gymnasium<br>Libraries |
| Public Order & Safety | | Fire/Police/Jail |
| Religious Worship | Church | Religious, Auditorium |
| Retail (except mall) | Department/Variety Store<br>Other Retail | Retail & Wholesale |
| Service (except food) | Gas Station/Auto Repair<br>Repair/Non-Auto<br>Other Service Shop | |
| Warehouse (non-refrigerated) | Warehouse (non-refrigerated) | C&I Storage |
| Warehouse (refrigerated) | Warehouse (refrigerated) | C&I Storage |

**Floor Area.** Floor area is a major source of error in EUI calculations and is frequently misreported (Sharp, 1996). There are also many different ways of defining floor area and inconsistencies in how it is calculated. For example, parking garages are sometimes included in floor area calculations and sometimes not. In CBECS, floor area is rounded off for all buildings, producing errors in EUI estimates of 5–10 %. Overall this is not seen to be a problem; however, the distribution tails are more affected, and for smaller buildings, the error can be up to 14–25 % (Sharp, 1998).

In CEUS, the survey unit is a "premise" rather than a "building." A premise may be all or part of a building, and sometimes more than one building, but is usually a single utility customer billing account. This is advantageous or disadvantageous depending on the site being benchmarked. Floor Area is also one of the variables that Cal-Arch allows you to filter the comparison buildings with.

**Climate Zone.** The California Energy Commission recognizes sixteen climate zones in California. As CEUS contains zip codes, these are easily mapped to climate zones. Depending on the sample size in each climate zone, it may be necessary to group these into four or five larger zones.

**Whole Building Energy.** Annual energy use data used to calculate EUI is usually obtained from utility billing data. Part of the analysis of CEUS has been to determine which fuels are used by buildings and to assess whether the energy use reported, which includes electric and in some cases gas, represents "whole-building" energy. Especially important in benchmarking electricity use is determining which building are all electric. The electric EUI for an all-electric building represents whole-building energy use while the electric EUI of a building with gas heat does not.

## User Interface

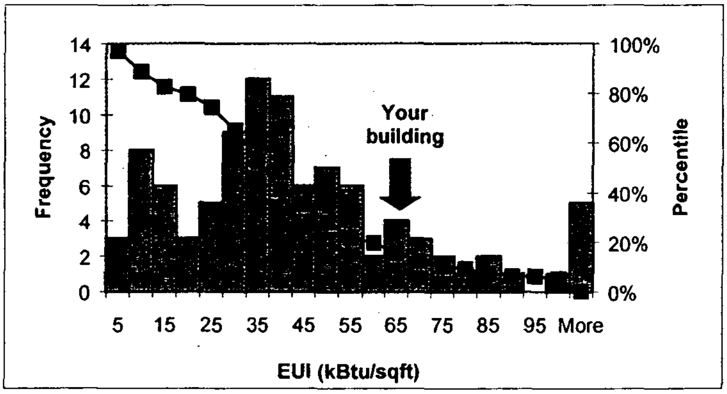
Cal-Arch is a web-enabled tool that can be used from any web browser on most operating systems. It is intended to be a simple tool that is quick and easy to use, and thus a minimum number of user inputs are requested. The information requested includes:

- **Building Type.** This is the only required input.
- **Zip Code.** Used to determine the climate zone.
- **Floor Area.** This is used to calculate the user's EUI. An option is available to filter by floor area.
- **Annual Energy Consumption.** This is used to calculate the user's EUI.
- **Site/Source Preference.** An option is provided to display results in Source energy or Site energy.
- **Archive Option.** Users may select to have their data included in a database.

### *Results*

Depending upon the inputs entered, the Cal-Arch database is queried and the results are displayed as a histogram displayed with statistics describing the comparison buildings and the user's EUI. Additional information is provided to aid in the interpretation of the results as well as link to further information about the data sources and other benchmarking tools.

**Electric Use Comparison**

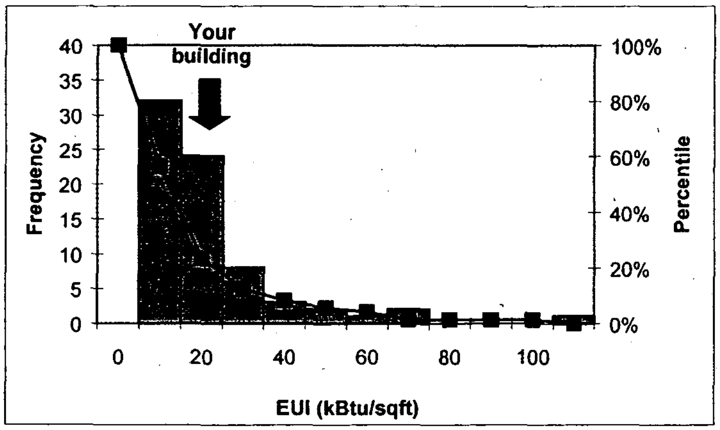



Your electric EUI is 63 kBtu/sf, or 2.2 watts/sf-yr, which is higher than 80 % of comparison buildings shown.

Comparison Buildings:

| | |
|---|---|
| 25th percentile | 24 kBtu/sf-yr |
| Median | 36 kBtu/sf-yr |
| 75th percentile | 50 kBtu/sf-yr |
| Your EUI | 63 kBtu/sf-yr |

**Gas Energy Use Comparison**




Your gas EUI is 21 kBtu/sf, which is higher than 60 % of comparison buildings shown.

Comparison Buildings

| | |
|---|---|
| 25th percentile | 9 kBtu/sf-yr |
| Median | 12 kBtu/sf-yr |
| Your EUI | 21 kBtu/sf-yr |
| 75th percentile | 22 kBtu/sf-yr |

**Description of Comparison Buildings**

| For this field: | You entered: | Comparison Buildings |
|---|---|---|
| Building Type | Office | Offices |
| Zip Code | Not entered | All climate zones are shown |
| Floor Area | 100,225 | |
| Filter? | Checked | Buildings with one half to twice the floor area entered are shown. |
| Site/Source | Site | Results are displayed as site energy use |

Number of buildings on graphs: Electric: 98 Gas: 73

Data Sources Click for more info

**Figure 3.** Sample Cal-Arch results page: office building energy use comparison.

**Figure 3** gives an example of output from Arch 2.0. The histograms for gas and electric EUIs provide a quick visual method of determining whether a given building has a high, low, or typical energy-use intensity relative to others. The distribution of site EUIs are on the x-axis and frequencies (% of total sample) and cumulative percent frequencies are on the y-axis. A number of statistics may be considered useful in comparing building EUIs. The key statistics chosen for display here are the inner quartiles and percent of buildings with lower EUIs

**Interpretation.** A question that frequently arises in benchmarking studies is whether a benchmark is an effective indicator of efficiency. Efficiency can only be defined in relative terms, and there is a danger that the comparison buildings themselves are inefficient. There are a number of differences that are not accounted for that may affect whether or not a building should be considered "efficient" or "inefficient." For example, a building with unusually long operating hours may have a high EUI but still be considered "efficient." Thus no attempt is made to define "more efficient" and "less efficient" in the Cal-Arch output though clearly the intention is to compare EUIs. It is important in interpreting benchmarking results to recall that benchmarking is a first step in the process of evaluating energy efficiency.

## Conclusions and Future Directions

This paper has provided an overview of techniques, tools, and issues regarding commercial building energy benchmarking. In particular, we describe the development of a California-based benchmarking tool. We have found there to be significant, interests in regional benchmarking tools that allow building owners and others to understand how a building's energy use compares to others in its local context. Previous tools, such as the EPA/DOE Energy Star tool, provide a good framework for national benchmarking. Further research is needed to understand how to improve benchmarking tools to account for the diversity of factors that influence energy use in order to make the comparisons more robust and reliable. Another challenge is to define data collection needs. Cal-Arch's development will be completed by Summer 2003. The following items are underway or under consideration.

**Extended data sets.** The feasibility of adding additional data sets is being evaluated. These include additional CEUS data, municipal utility data, statewide averages, private-sector data sets, and user data archived by Cal-Arch.

**Peak demand.** Depending on data availability, methods of incorporating peak demand will be implemented.

**Advanced benchmarking techniques.** Additional benchmarking comparison methods will be evaluated including normalization techniques, simulations, regression-based statistical data sets, hybrid approaches, and simulation benchmarks. Normalization parameters include weather, hours of use, number of people, building characteristics (are efficient equipment present), vintage, building type, occupancy, building uses.

**Economic analysis capabilities.** Economic comparisons in benchmarking tools include: rate schedules (TOU, peak demand), and energy type (electricity, gas, steam, etc.).

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