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EXECUTIVE SUMMARY

This report describes the development and testing of a new method of benchmarking whole-building energy use in laboratory buildings. The energy intensity of laboratory buildings is four to five times higher than that of other kinds of commercial buildings such as office buildings. This fact coupled with the importance of high-tech industries in California makes energy-efficiency of laboratory buildings an important issue in California.

The most common method of benchmarking energy use in buildings is to compare the energy use of the building under consideration with the energy use of a population of like buildings. Usually there is some empirical compensation for features and factors that affect energy use such as the size of the building and the weather conditions. Two fundamental limitations of this approach are: 1) only similar kinds of buildings can be compared, and 2) the entire population may be inefficient, which would cause many inefficient buildings to be rated as efficient. The first limitation is important when benchmarking laboratory buildings because there is no public database of energy use and building features that can be used to construct empirical benchmarks for laboratories. The second limitation is also important because there is evidence that energy-consuming processes in laboratory buildings, especially HVAC systems, are inefficient because of highly conservative design practices and the need for risk avoidance.

The benchmarking method described in this report is fundamentally different than the method described above. The principle is to construct a benchmark that represents the minimum amount of energy required to meet a set of basic functional requirements of the building. These requirements include code-compliant environmental controls, adequate lighting, etc. The benchmark is computed based on idealized models of equipment and system performance. Using idealized models produces a benchmark that is independent of design and easy to compute.

Once the benchmark has been computed for a single building, an effectiveness metric is computed by dividing the model-based benchmark by the actual consumption. This metric, or its inverse, can be compared with the metrics of other buildings. Since functional requirements have been incorporated into the benchmark, it is possible to compare the performance of dissimilar buildings, or buildings that have rare or unique functional requirements.

A benchmarking tool was developed that implements the benchmarking method described above. The tool is an MS Access database with calculation methods for implementing the model-based calculations. The database produces reports that allow a user to view historical performance trends as well as relative performance compared to other buildings in the database.

The performance of the model-based benchmarking method was compared with two alternative methods based on the ability to predict actual energy use. Using building energy data from the UC Berkeley campus, it was shown that the model-based benchmarking method was more accurate when a combination of laboratory and non-laboratory buildings were analyzed.

In addition to demonstrating the efficacy of model-based benchmarking, several other lessons were learned about building energy analysis. By constructing a model that represents the best possible performance, errors in the input data regarding schedule of operation and recorded energy use were detected because of effectiveness metrics that were significantly greater than unity. This demonstrates that recorded energy-related data may be unreliable and that the model-based benchmarking method may be able to detect errors of this kind in addition to detecting unsatisfactory energy-use performance. From analyzing building data that included a class 100 cleanroom it was clear that improvements in the fan power model could yield further improvements in the benchmarking accuracy.

INTRODUCTION

This report describes the results of work by the Center for Environmental Design Research at the University of California at Berkeley on laboratory field studies and performance feedback, which was part of the year-four phase of CIEE's laboratory efficiency improvement program.

Background on Energy Use in Laboratory Buildings

Laboratory buildings consume considerably more energy per square foot than other kinds of commercial buildings, and they are becoming increasingly energy intensive. Mills et al. (1996) estimate that energy use intensities (e.g., kWh/ft^2/year) in laboratory buildings are four to five times higher than those found in non-laboratory buildings, such as offices, and that energy consumption in laboratory buildings in California is growing exponentially at a rate of 3.9% per year. Huizenga et al. (1998) showed that the energy intensity of laboratory buildings on the UC Berkeley campus is three times greater than that of non-laboratory buildings. For laboratory buildings constructed after 1980 it is six times that of non-laboratory buildings.

One of the reasons that the energy intensity of laboratories is so high is because of the HVAC requirements that are specific to laboratories. Due to the nature of work in laboratories, the air change rate must be higher than in other kinds of commercial buildings, and they are usually supplied with 100% outside air. Large quantities of air are exhausted from the laboratory either through the exhaust from the occupied space or from fume hoods or other local exhaust devices. The movement of large quantities of air causes the fan power used by laboratory buildings to be high. Conditioning large quantities of air causes the chiller power to be high.

Concerns for occupant safety and reliable process operation combined with considerable uncertainty about the magnitude and variation of heating and cooling loads often leads to decisions which result in the inefficient operation of laboratory buildings. This problem is amplified by the fact that the energy intensity of laboratory buildings is high and the energy consumption is growing exponentially. Consequently, there is a need for tools that will allow operations staff to determine how well laboratory buildings are operating so that design and operational problems can be addressed.

Objectives of this Project

In an earlier phase of this project, protocols for assessing the performance of building subsystems such as chiller, boilers, lighting, and plug and process loads were developed and documented (Huizenga et al., 1996). One motivation for that work was the desire to document actual loads in laboratory buildings so that designers could make more accurate decisions about the necessary capacity of mechanical equipment such as chillers. Huizenga et al. (1998) used the protocols to show that cooling loads and plug and process loads in a building on the UC Berkeley campus were significantly lower than that indicated by the design documentation.

This phase of the project has been focused on benchmarking whole-building energy use of laboratory buildings. The objectives of this phase of the project were as follows:

1. to develop a second-generation database,
2. to add buildings to the second-generation database,
3. to improve the benchmarking calculation methods,
4. to improve the reports and make them compatible with the design intent tool,
5. to study the opportunity to establish a web interface for the database.

Previous Work on Benchmarking

Benchmarking is one of the first activities in the process of deciding whether or not to invest in energy-conservation measures in buildings. Consequently, improvements in benchmarking methods could have a large impact on energy use and the profitability of companies that use energy or provide energy services.

Most energy service companies (ESCOs) and other organizations responsible for energy-efficiency of buildings use the mean or median value of the energy use intensity (EUI) for the kind of building being investigated as a benchmark for determining whether or not the building is a good candidate for energy conservation measures. The EUI is the average power normalized by gross square footage, typically expressed in kW-h/ft^2/year or MBtu/ft^2/year.

The EUI accounts for only one building feature that affects energy consumption: plan area. To account for the effect of other features that affect energy consumption, benchmarks have been constructed by using statistical methods to correlate other features with energy use (Sharp, 1996; Birtles, 1997). Sharp's method is based on an analysis of the 1992 Commercial Buildings Energy Consumption Survey (CBECS). Linear regression models were used to correlate building characteristics with energy consumption. Seven of the 75 characteristics investigated were found to be statistically significant indicators of energy consumption.

This approach has been modified slightly and used as the basis of the Energy Star® benchmark (Hicks and Clough, 1998). Rather than using census location as a proxy for weather, the Energy Star® benchmark explicitly compensates for weather. The Energy Star® benchmark is the 25th percentile of the EUI distribution because this level is expected to be the level required for compliance with energy codes.

An energy analysis activity that is related to benchmarking is baselining. The key difference between benchmarking and baselining is that benchmarking generally involves a comparison of energy performance with other buildings while baselining generally involves a comparison of past energy performance of a single building with current energy performance. The most common methods of baselining are similar to the methods described above for benchmarking. Statistical methods are typically used to correlate weather data and other important variables of a single building with measured

energy use. Examples of this kind of baselining are described by Reddy et al. (1997) and Sonderegger (1998).

One problem with existing benchmarking methods is that they do not sufficiently account for differing functional requirements of buildings. This fact limits the accuracy of existing methods and makes them difficult to apply existing methods to dissimilar buildings. For example it is not possible using existing benchmarking methods to compare the performance of laboratory buildings with office buildings. The ability to do so is important because nearly all laboratory buildings contain non-laboratory space. Although Sharp's method does account for some functional requirements, many of the functional requirements that have a significant impact on energy use are not included. For example, temperature control, humidity control, ventilation rate, filtration efficiency, and plug and process loads are not explicitly treated as functional requirements.

Another problem with existing benchmarking methods is that all current benchmarks are based on the performance of other buildings. They do not reflect the extent to which the energy efficiency could be improved because the entire population could be making ineffective use of energy. Therefore, existing benchmarking methods cannot be used by an energy engineer to determine the energy-saving potential that exists even in buildings that are considered to be energy-efficient.

Method

The scientific approach to benchmarking whole-building energy use proposed here involves a two-part process. The first part involves the use of a simplified building energy model that is used to convert functional requirements into minimum energy use requirements. Geographical location, indoor air quality requirements, code compliance, lighting requirements, temperature and humidity requirements, schedule, staffing requirements, and requirements for process equipment are some examples of the functional requirements of the building that affect energy consumption. The energy calculations are not typical load calculations, as used to predict actual use. Instead they are calculations based on ideal performance of components such as fans, chillers, lighting systems, etc. This makes the calculations independent of the kind of components used in the actual building or how they are actually operated, and significantly simplifies the calculations.

Report Organization

The next section contains a description of the benchmarking method. The description is mainly conceptual. Details regarding calculation methods are included in Appendix A and B.

The subsequent section contains a description of the benchmarking database. Data entry, operation of the functions, and the reporting features are described. An example illustrating the use of the database is included.

The section on results illustrates how well the model-based benchmarking method compares with conventional methods of benchmarking.

MODEL-BASED BENCHMARKING FOR LABORATORY BUILDINGS

There are numerous performance metrics in existence for engineered systems. Two important kinds are efficiency metrics and effectiveness metrics. Efficiency metrics are used to compare output with input. Metrics of this type include the thermodynamic efficiency of a heat engine, which is shaft power divided by fuel power, and the mechanical efficiency of a fan, which is aerodynamic power divided by shaft power. Efficiency metrics are not applicable to the development of a whole-building energy consumption benchmark because it is difficult to define the output of a building and because it is difficult to quantify the output even if it can be defined. The output is not the energy consumption. It might be the comfort provided to the occupants, or it might be the work output of the occupants.

Effectiveness metrics involve a comparison with a benchmark, and are therefore relevant to the development of a whole-building energy consumption benchmark. An example of an effectiveness metric is heat exchanger effectiveness, which is defined as the actual heat transfer divided by the maximum possible heat transfer. Engineering effectiveness metrics do not always use the theoretically best performance as a benchmark. For example, ventilation effectiveness is often defined as the measured age accumulation of air in a building divided by the age accumulation for a perfect-mixing system, which has twice the age accumulation of the most effective system (a plug-flow system). The key difference between efficiency and effectiveness is that efficiency is a comparison of input and output while effectiveness is a comparison of a key system variable (not necessarily the output) with a well-defined, calculable, and often theoretically ideal benchmark.

The most common performance metric for whole-building energy consumption is EUI. This metric is not particularly useful by itself because many other factors besides plan area affect energy consumption. This fact is evident from the range of values in Table 1 of Huizenga et al. (1996). In this set of buildings, which are all laboratory buildings located on the UC Berkeley campus (and therefore exposed to the same weather), the standard deviation is 70% of the mean. This illustrates that EUI is not a discriminating metric. Part of the reason that there is a large variation in this metric for this set of buildings is because some of the buildings are not air-conditioned, because lighting efficiency varies, because plug and process loads vary, and because the design of the air distribution systems vary.

In this section, a benchmark that compensates for weather differences, design differences, and usage differences is described. The objective is for the benchmark to be the energy consumption of an "ideal" building that consumes the minimum amount of energy required to achieve the same indoor temperature, humidity, lighting, and ventilation conditions as the actual building. Complications that arise from defining and computing the theoretical minimum are addressed by using simplifying assumptions. The result is a benchmark that represents a highly effective use of energy.

The benchmarking protocol has two parts. First, the actual energy consumption is compared with the consumption benchmark. The ratio of the benchmark to the actual consumption is an effectiveness metric analogous with other engineering effectiveness metrics such as heat exchanger effectiveness. The second part of the benchmarking protocol involves a comparison of the effectiveness of a particular

building with that of a set of buildings, and with the past performance of that same building. This part of the protocol involves statistical comparisons.

The Benchmark

The performance of the ideal building is more difficult to quantify than the performance of the ideal heat exchanger. Therefore, the benchmark building is selected with features that make the calculation of the minimum energy consumption a tractable problem with some simplifying assumptions.

The following is a list of the important features and assumptions:

No energy storage.

This definition also implies that the structure of the building is not used for thermal storage. Defining the benchmark building as having no energy storage significantly simplifies the calculations. Most laboratory facilities have little or no energy storage. Since the benchmark is defined as having no storage, laboratory buildings with energy storage may, in theory, use less energy than the benchmark.

No conduction or transmission.

The benchmark building has perfect insulation and allows no transmission of solar energy into the building. This assumption also significantly reduces the complexity of computing the benchmark. Laboratory energy consumption is dominated by ventilation rather than by heat transfer through the shell, so there would be little benefit to including conduction and transmission in the calculations. If this benchmark were used to analyze the energy consumption of non-laboratory buildings, the results would indicate that the non-laboratory buildings were less effective at using energy because heat transfer through the shell is a larger component of the load in non-laboratory buildings.

Maximum use of daylight.

The lighting power benchmark is zero between sunrise and sunset. When the building is in use between sunset and sunrise, the benchmark is the average specific lighting power measured by Huizenga et al. (1996), which is 0.54 W/ft^2.

Empirical benchmark for plug and process loads.

For the laboratory space, the default specific plug and process power is the average value measured by Huizenga et al. (1996), which is 1.2 W/ft^2. For the non-laboratory space, the default specific plug and process power is 140 W/person, which is derived from power requirements of office computers.

Fan power

In theory, the minimum fan power required to move air is zero because it could be moved at an arbitrarily low static pressure (i.e., with arbitrarily low resistance). This is not a reasonable benchmark because ducts must have a finite size. Therefore, the specific fan power specified by Title 24 for constant volume systems (0.8 W/cfm) is used as the benchmark for fan power.

Transportation systems

Efficient elevator systems use counterweights and energy recovery so that they do not contribute substantially to the total energy consumption of a building. This benchmark will penalize buildings with hydraulic elevators more than buildings with counterweighted elevators.

Efficient air distribution

VAV laboratories will use considerably less energy than constant volume laboratories as long as the design air change rate is sufficiently low and as long as fume hoods are closed when not in use. According to Black (1998), sashes of fume hoods on the UC Berkeley campus are generally found to be in the closed position. This indicates that the need for occupants to be working at the hoods is intermittent, and that selecting the benchmark as constantly closed would only penalize facilities where fume hoods were left open unnecessarily and persistently. With sashes in the closed position, the ventilation rate will usually be dependent on the air-change requirement and not on the fume hood exhaust flow rate.

Optimal heat recovery.

For the laboratory space, the benchmark is based on 100% heat recovery from lighting and plug and process loads. For the non-laboratory space, the benchmark is based on 100% heat recovery from lighting. The term heat recovery, as used here, does not refer to transferring heat from an exhaust stream to a supply stream. Instead it refers to control of waste heat at the source. For equipment, this could be achieved by locating the equipment in a ventilated cabinet which was exhausted when heat was not needed, but which was recycled when heating was required.

Computing the Benchmark

It is possible to compute the energy consumption of the benchmark from first principles with relatively little information about the building.

Inputs

The following seven inputs are required to compute the benchmark energy usage, and they have no defaults.

1. Plan area (e.g., square feet) of the lab space
2. Plan area (e.g., square feet) of the non-lab space
3. Total linear feet of fume hoods
4. Fraction of lab space that is air-conditioned

5. Fraction of non-lab space that is air-conditioned
6. Location
7. Month

The next eight inputs are used in the benchmark calculations, but defaults are provided in case the specific values are not known. The defaults are shown in brackets.

8. Design air change rate [6 air changes per hour]
9. Schedule of operation [24 hours, 7 days for lab space; 7am - 9pm, 7 days for non-lab space]
10. Number of lab occupants [1 occupant per 766 square feet]
11. Number of non-lab occupants [1 occupant per 766 square feet]
12. Altitude above sea level [determined by weather data location]
13. Specific fan power [0.8 W/cfm]
14. Specific pump flow rate [1.6 gpm/ton]
15. Specific pump power [6.3 W/gpm]
16. Average plug and process load power for the lab [1.2 watts per square foot of lab space]
17. Average plug and process load power for non-lab space [140 watts per person]
18. Office design ventilation rate [20 cfm/person]
19. Conditioned space temperature [72 $^{\circ}$F]
20. Conditioned space relative humidity [50%]

The default for the design air change rate is derived from Bell et al. (1998). The default for the schedule is derived from the operation of labs on the UC Berkeley campus. The defaults for specific pump flow rate, specific pump power, and average plug and process load power for the lab are derived from measurements made by Huizenga et al. (1998). The default for the number of occupants is derived from the CBECS database (U.S. Department of Energy, 1995). The default for the average plug and process load power for non-lab space is derived from Brown (1996).

The following inputs are used to compute the electrical consumption effectiveness and the fuel consumption effectiveness.

21. Electrical consumption
22. Fuel consumption

The default for input number 8 is derived from Bell et al. (1998). The defaults for inputs 10 and 11 are derived from the U. S. Department of Energy (1995). The default for input 13 is derived from the value measured by Huizenga et al. (1996). The default for office plug loads is based on one computer per person. According to Brown (1996), the power consumption of a computer, monitor, and laser printer operating in idle mode is 56 W, 60 W, and 24 W, respectively. Therefore, the default for office plug loads is 140 W/person.

Pre-Calculations

The following quantities are computed prior to making hourly energy consumption calculations. Details regarding the calculations can be found in Appendix B.

1. Space pressure
2. Conditioned air saturated vapor pressure
3. Conditioned air vapor pressure
4. Conditioned air humidity mass ratio
5. Conditioned air gas constant
6. Conditioned air enthalpy
7. Conditioned air density
8. Fume hood mass flow rate
9. Total exhaust mass flow rate of lab
10. Mass flow rate of supply air to laboratory
11. Lab occupant load
12. Office occupant load
13. Lab lighting load
14. Office lighting load

Conditioned air refers to the air in the occupied space, not to the air supplied to the space.

Hourly Calculations

After the pre-calculations are completed, hourly calculations that correspond to hourly weather data are made. Details regarding these calculations are included in Appendix B. These calculations can be broken down in to three categories: properties, office calculations, and laboratory calculations.

Calculate Properties

1. Saturated vapor pressure of outdoor air
2. Vapor pressure of outdoor air
3. Humidity mass ratio of outdoor air
4. Gas constant of outdoor air
5. Specific enthalpy of outdoor air
6. Density of outdoor air
7. System on?

Office Calculations

1. Minimum outdoor air mass flow rate of office
2. Maximum outdoor air mass flow rate of office
3. Office load

Electrical calculations:

4. Office cooling load
5. Office fan power
6. Office pump power

7. Office electrical power

Fuel calculations:

8. Office heating load

Lab Calculations

1. Office enthalpy if not air-conditioned
2. Lab load

Electrical calculations:

3. Lab cooling load
4. Lab fan power
5. Lab pump power
6. Lab electrical power

Fuel calculations:

7. Lab heating load

Outputs

After the hourly power calculations are completed, the results are accumulated for the time period of interest. Two performance metrics are computed. They are the electrical consumption effectiveness and the fuel consumption effectiveness. The electrical consumption effectiveness, denoted as e_e, is defined as the electrical consumption of the benchmark divided by the actual electrical consumption for the same time period. Similarly, the fuel consumption effectiveness, denoted as e_f, is defined as the fuel consumption of the benchmark divided by the actual fuel consumption for the same time period. Consequently, higher values are better than lower values, and the values should range between zero and one.

Statistical Comparison

After the electrical energy and fuel consumption effectiveness metrics have been computed for a particular building they are compared with the metrics for a set of buildings. The mean and variance of each metric in the comparison set is computed so that the user can determine if the performance of the test building is above or below the norm, and by how much. If the performance is significantly poorer than average, then the protocols described by Huizenga et al. (1998) could be used to investigate the cause.

LABORATORY PERFORMANCE DATABASE

Description

In order to compare the energy consumption of one or more laboratory buildings with that of others, a database has been created using Microsoft Access. The database contains tables for the building statistics provided by the users as well as tables for weather data. Forms for entering data, initiating calculations, and displaying the results have been created so that the database is easy to use.

The building statistics include the data necessary for calculating the benchmarks as well as data that will be useful for filtering. These additional inputs include performance metrics that may have been determined from a more detailed audit of the building using the protocols described by Huizenga et al. (1998), as well as design information that is relevant to energy consumption analysis (e.g., VAV or constant volume air distribution).

Example of use

Figure 1 shows the first form in the tool for entering data. This form is used for inputting basic input data about a building.

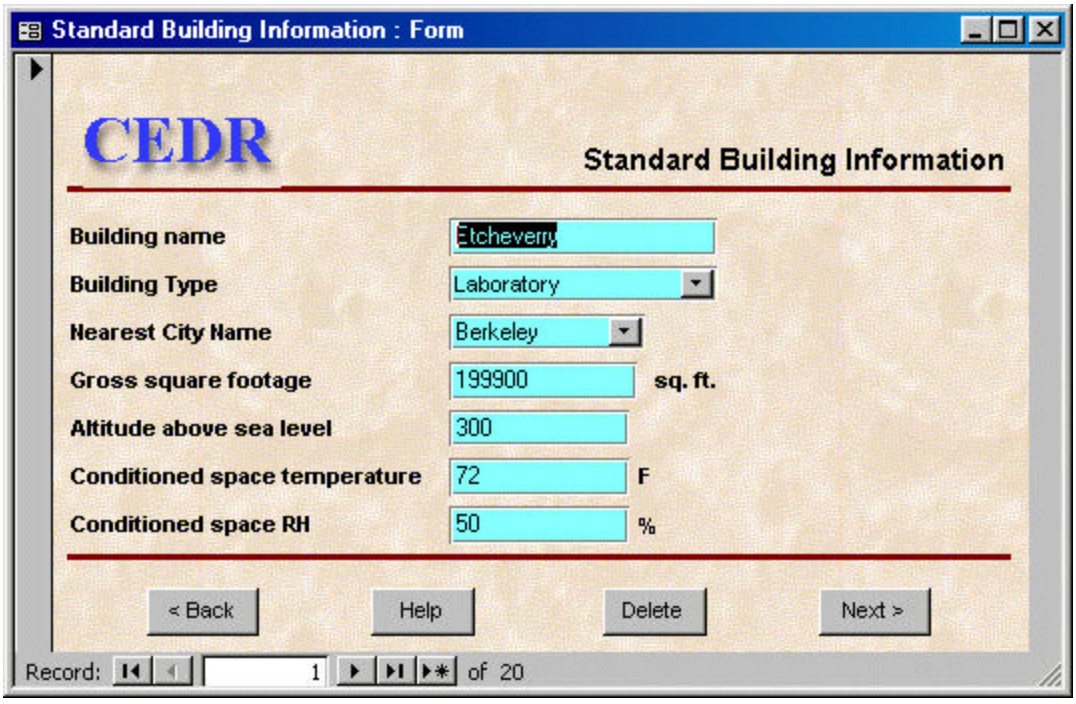

Figure 1: Input data that has defaults.

Pressing the "Help" button shown in Figure 1 brings up the form shown in Figure 2. This form provides the user with information about how to use the form.

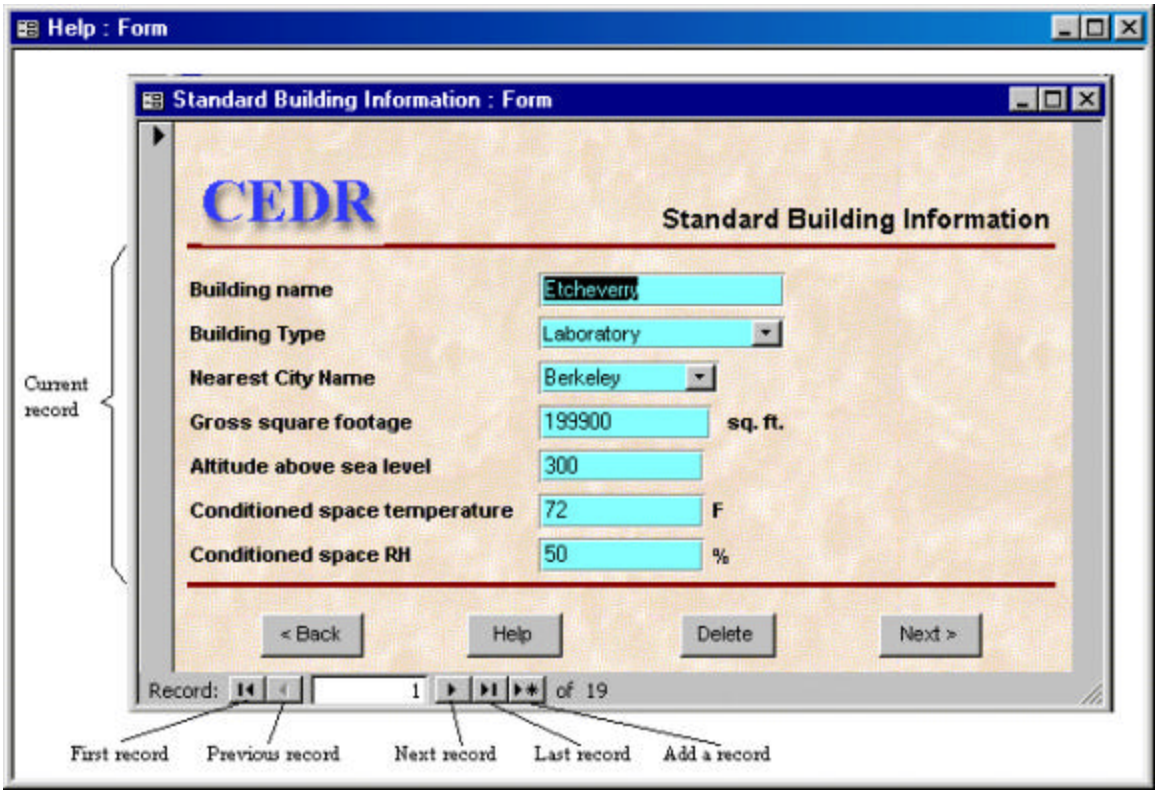

Figure 2: Help form.

Clicking on the button labeled "Next" in Figure 1 brings up the form shown in Figure 3. This form is used to acquire necessary information about the laboratory space.

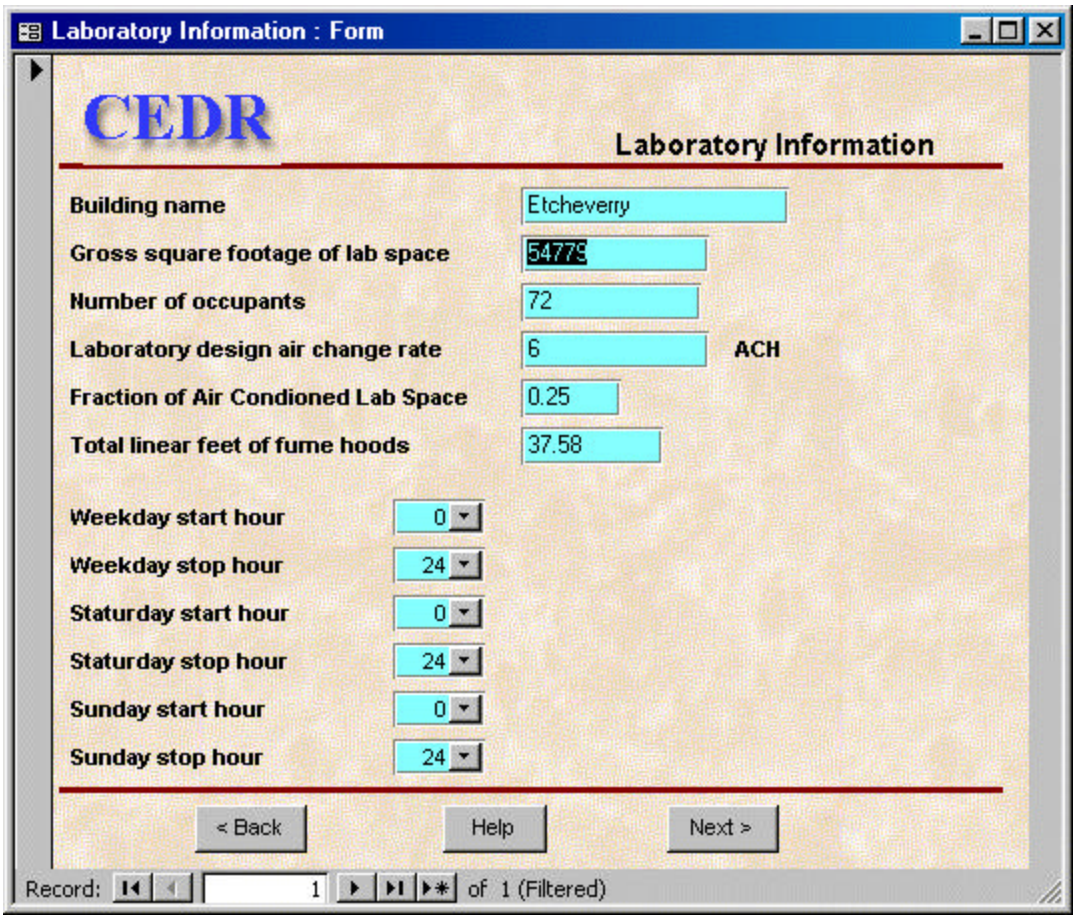

Figure 3: Form for entering data about the laboratory space.

Clicking on the "Next" button shown in Figure 3 brings up the form shown in Figure 4. This form is used to acquire necessary information about the non-laboratory (office) space.

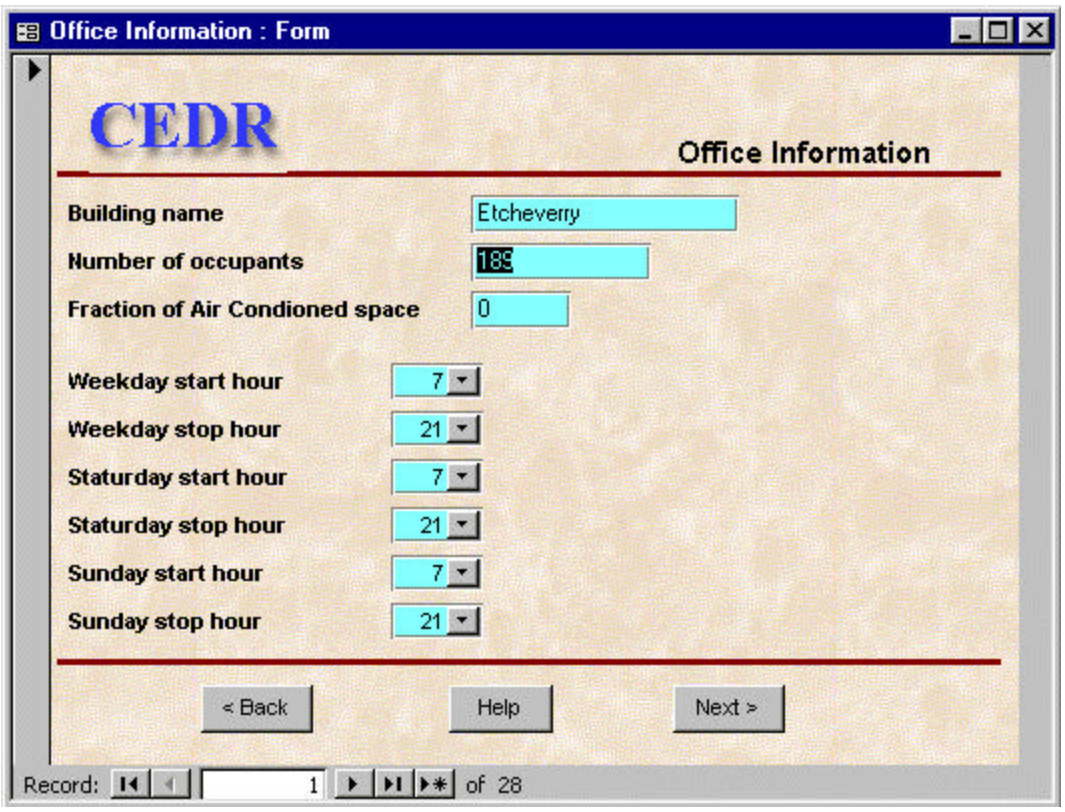

Figure 4: Form for entering data about the non-laboratory space.

Clicking on the button labeled "Next" in Figure 4 brings up the form shown in Figure 5. This form enables the user to input energy consumption data for a set of time intervals. The form, database, and calculations are designed to handle time intervals of arbitrary duration. The start date for all intervals but the first is the end date for the previous interval. The form, database, and calculations are also designed to handle multiple meters so that data from electrical bills can be entered directly into the database.

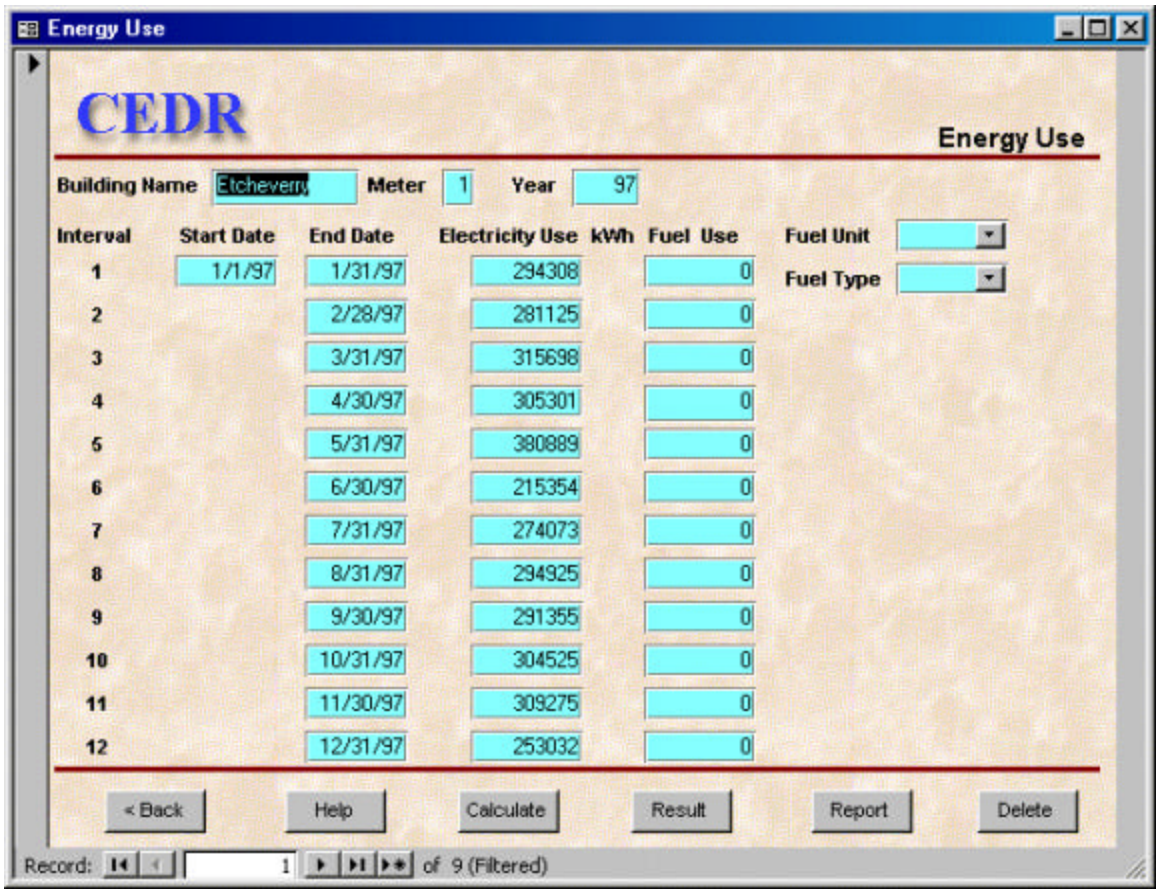

Figure 5: Form for inputting energy data.

Clicking on the button labeled “Calculate” in Figure 5 brings up the form labeled “constants” in Figure 6. This form enables the user to modify certain parameters of the energy model, if appropriate.

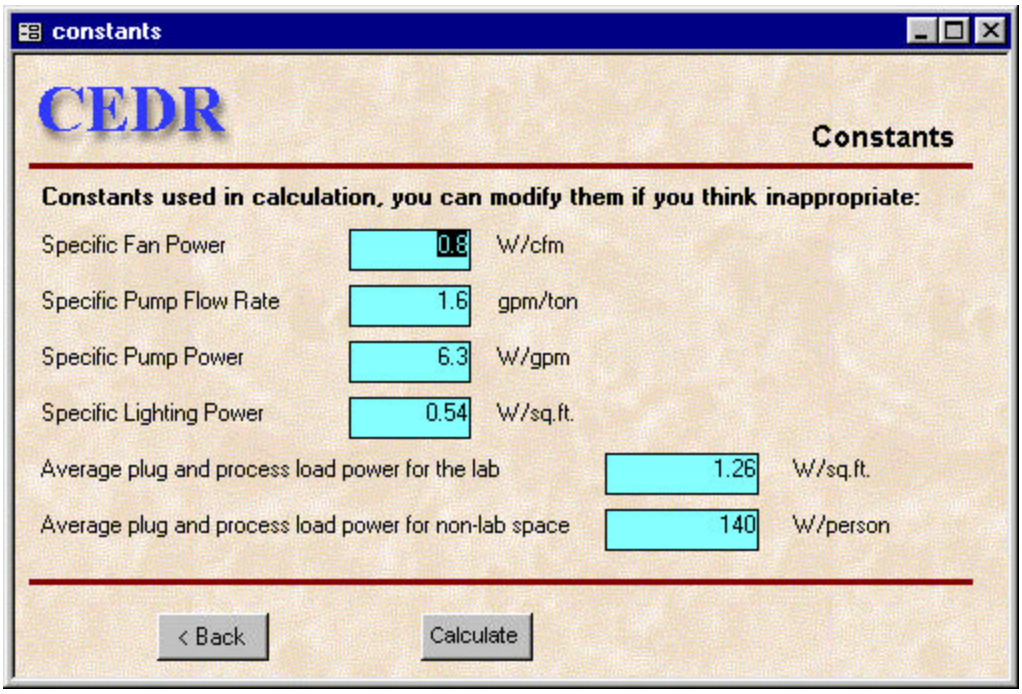

Figure 6: Constants used by the energy model.

Clicking on the button labeled "Calculate" in Figure 6 initiates the calculation of the energy performance metrics. To display the result, the user clicks on the button labeled "Result." Doing so brings up the form shown in Figure 7. The graphs in the top of the form show how a single building compares with a population of buildings. The upper left graph is electrical performance and the upper right graph is fuel performance. The smooth distributions are computed assuming normal distributions using the sample mean and standard deviation of the population from the database. The lower left figure shows a scatter plot of the actual data. In this case many buildings have a fuel consumption effectiveness of zero because no fuel consumption (i.e., steam consumption) data were available for those buildings. The lower right graph shows a trend log of the monthly electrical performance. This feature can be used to establish a baseline for the building and to detect unusual performance.

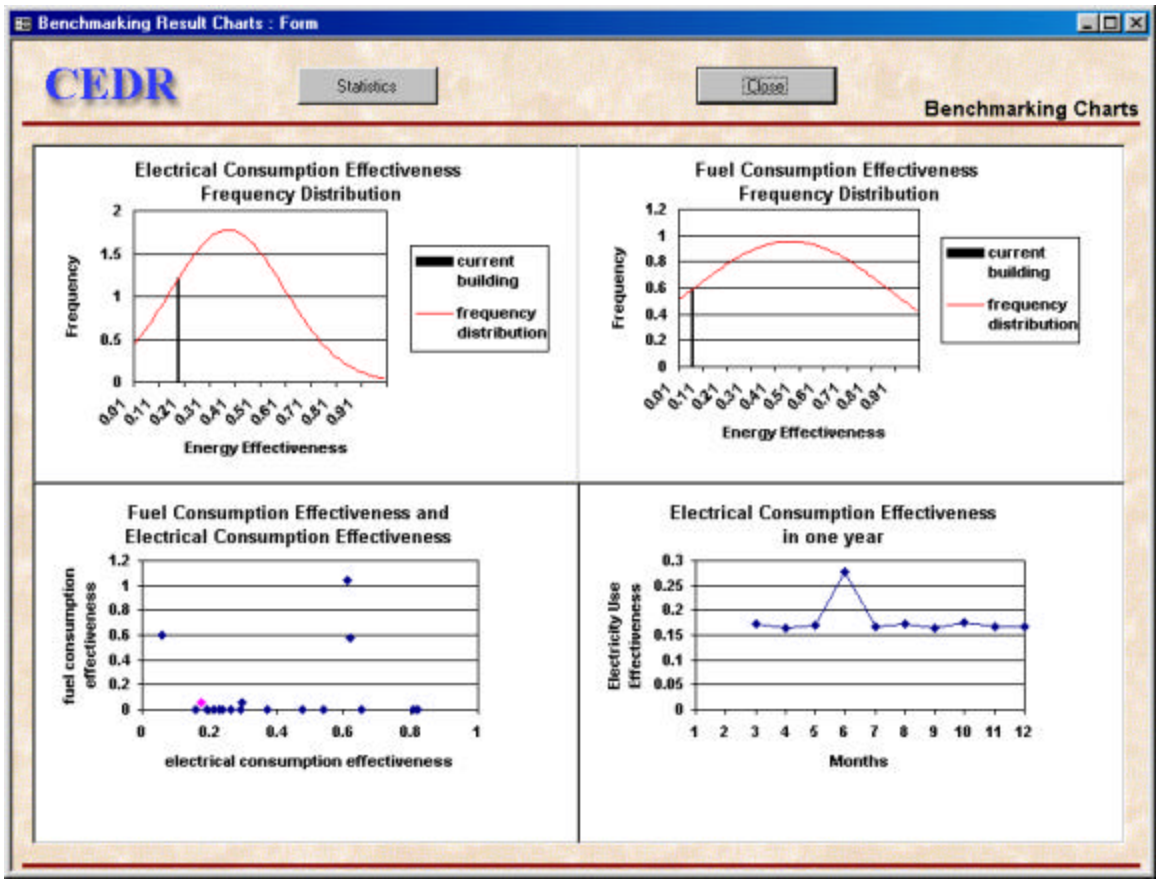

Figure 7: Display of performance metrics.

Clicking on the button labeled "Statistics" in Figure 7 brings up the form labeled "Result statistics" shown in Figure 8. This form shows additional performance metrics that are derived from the idealized benchmarking model. These metrics could be used as design intent targets for a highly efficient lab. If a less aggressive target were desired, then the whole building energy use statistic in this figure could be divided by a target effectiveness less than one to get less aggressive design intent target for whole-building energy use. Clicking on the button labeled "Close" in the Results statistics form will close the form, reverting to the form shown in Figure 7. Clicking on the button labeled "Close" in Figure 7 will close that form, reverting to the form shown in Figure 5.

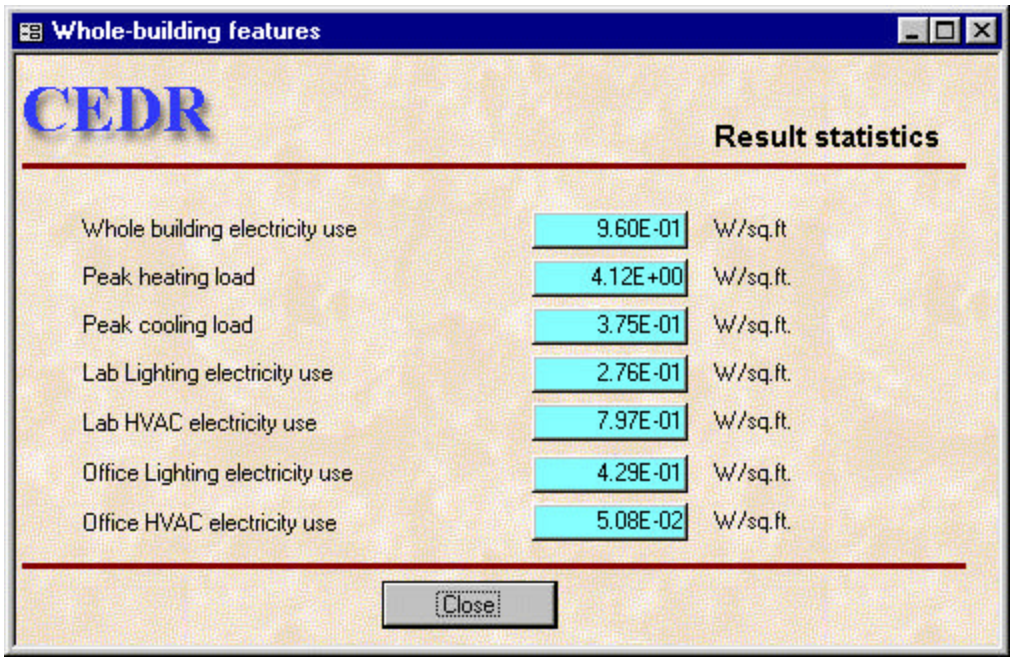

Figure 8: Alternative performance metrics.

Clicking on the button labeled "Report" in Figure 5 generates a report that is intended to be printed and used as a hard-copy document.

The opportunity to establish a web interface for the database

Web-enabled database applications allow remote access to users. This enhances the diffusion of web-enabled applications for practical use. If the laboratory energy benchmarking application were web-enabled, it would be available for use by the widest possible range and number of users. It could be used by both the private and public sector worldwide as a tool for assessing the performance of laboratory buildings.

Software tools for producing web-based applications have become readily available in the past two years, so the task of producing a web-based user interface for the laboratory energy benchmarking application is clearly feasible. Examples of closely related applications with web-enabled front ends include the UC Berkeley occupant satisfaction survey and the EPA EnergyStar benchmarking tool.

Microsoft has developed a set of tools that allow one to design web-based user interfaces for Microsoft applications. A description of how these tools could be used to develop a user interface for the laboratory energy benchmarking application is described in Appendix C.

The cost associated with a web-based application includes design, development, and maintenance. Design and development would be primarily a software development task, but the software must run on a host with sufficient throughput and memory capacity. If the hardware resources are not already available, then they must be included in the development cost. Maintenance includes maintenance of

both software and hardware. Management of a continually expanding database, regular system backups, and network management would be required for sustained operation of a web-enabled laboratory energy benchmarking application. EPA has recently developed a web-enabled database application for the EnergyStar program. The EPA application allows users to compare the performance of their building with a benchmark derived from the method proposed by Sharp (1996). Costs associated designing, developing, and maintaining a web-enabled version of the laboratory energy benchmarking application could be estimated accurately by determining the costs associated with the EPA effort.

RESULTS OF APPLICATION OF THE BENCHMARKING TOOL

Effect of Cooling Equipment on Effectiveness

Due to strict energy requirements for state buildings, some of the laboratory buildings on the UC Berkeley campus are not mechanically cooled. This fact allows us to compare the effect of air-conditioning on energy consumption effectiveness.

Of the 19 laboratory buildings studied, four had no cooling, one had negligible cooling capacity, and five were completely cooled by vapor compression. The mean and median of the electrical consumption effectiveness for the uncooled buildings were 0.66 and 0.79, respectively, The mean and median of the electrical consumption effectiveness for the cooled buildings were 0.31 and 0.29, respectively. Since the benchmark compensates for the functional requirement of cooling, the effectiveness of the cooled buildings should be equal to the effectiveness of the uncooled buildings if the cooling system were as efficient as the other systems in the building. Using the robust rank order test (Siegel and Castellan, 1988), the probability of observing this difference by chance is 9.4%. Therefore, it is likely that the mechanical cooling equipment is less efficient than other energy-consuming systems in the building based on the way that the benchmarks for those systems have been constructed.

Performance Comparison

Comparing one benchmarking method with another is complicated by the fact that the "true" energy-use effectiveness cannot be measured. However, we can measure how well different benchmarking methods compensate for features or functional requirements that affect energy use. This can be accomplished by comparing the degree of association (correlation) between the "model" associated with each method and the actual energy consumption.

In this section, the model-based benchmarking method described in this report is compared with benchmarking based on the EUI metric and Sharp's method using buildings located on the UC Berkeley campus. All of these buildings nominally have the same occupant density, computer density, and schedule, and all of them are owner-occupied. None of the laboratories have economizers; all are 100% outside air systems. Therefore, Sharp's method differs from the EUI method only by compensating for whether or not the building has a chiller.

For each method, two different correlation coefficients were computed. They were the Pearson product-moment correlation coefficient and the Spearman rank-order correlation coefficient. If the residuals (difference between the actual consumption and the consumption predicted by the model) are normally distributed , then the square of the Pearson coefficient is the percentage of the variance explained by the model. As noted by Sharp and others, the residuals for building energy-use data are frequently not normally distributed. The Spearman coefficient is a non-parametric measure of association that has a similar interpretation as the Pearson coefficient. It can be used to measure association when underlying distribution is not known.

Table 1 shows the square of the two coefficients for each of the three methods when applied to 19 laboratory buildings on the UC Berkeley campus. The Siegel-Tukey test was used to test whether or not the size of the residuals was significantly different from one method to another. This test indicates that the difference between Sharp's method and the model-based method is not statistically significant. The test statistic indicated that the model-based method was slightly better even though the correlation coefficient was lower. However, the single-sided probability of observing a larger difference by chance was 45%.

Table 1: Comparison of methods.

	Pearson, R^2	Spearman, R_s^2
Model-based method	41%	55%
Sharp's method	46%	63%
EUI method	40%	52%

Inspection of the residuals shows that one of the 19 buildings is an outlier. This laboratory contains a class 100 cleanroom, so the predicted energy use is much lower than the actual energy use. If this building is eliminated from the data set, then the correlation coefficients are as shown in Table 2. Again, the Siegel-Tukey test indicates that the differences are not significant. The single-sided probability of observing a larger difference by chance is 32%.

Table 2: Comparison with outlier removed.

	Pearson, R^2	Spearman, R_s^2
Model-based method	73%	53%
Sharp's method	54%	58%
EUI method	51%	45%

Table 3 shows the two coefficients for each of the three methods when applied to 19 laboratory buildings and 7 non-laboratory buildings on the UC Berkeley campus. This table illustrates that model-based benchmarking is better at comparing the performance of dissimilar building types than are empirical methods of benchmarking. In this case the difference between the model-based method and Sharp's method is statistically significant. The single-sided probability of observing a larger difference by chance is just 3.2%. However, the difference between the model-based method and the EUI method is still not statistically significant at the 95% level of confidence. The single-sided probability of observing a larger difference by chance is 6.4%.

Table 3: Comparison with dissimilar building types.

	Pearson, R^2	Spearman, R_s^2

Model-based method	43%	41%
Sharp's method	16%	19%
EUI method	22%	18%

DISCUSSION AND CONCLUSIONS

The benchmarking method described in this report will penalize buildings that use inefficient systems to supply energy-consuming functional requirements. For example, buildings with the following design subsystems or features will be penalized:

1. Oversized systems if part-load efficiencies are poor
2. Constant volume systems
3. Any systems that use reheat
4. Hydraulic elevators
5. Inefficient lighting systems
6. Inefficient fans and air distribution systems

Additionally, the following operational factors will be penalized:

7. Fume hoods left open
8. Poor controller tuning, if it induces sequential heating and cooling
9. Faulty control logic, if it induces simultaneous heating and cooling

The benchmarking method will also penalize buildings in which fume hoods must be used (i.e., opened) continually. Based on the experience of UC Berkeley facilities staff, it is expected that this will be a rare requirement. Open fume hoods are a safety hazard. The benchmarking method will also penalize buildings that do not have laboratory space or that have very little laboratory space because conduction and transmission heat transfer is a larger fraction of the heating and cooling load in those buildings. This will only be a problem for the case where a small laboratory is connected to a large non-laboratory building. The magnitude of these "unfair" penalties is difficult to quantify and it will be different for each case.

The analysis described in the results section indicates that air-conditioned buildings use energy less effectively than non-air-conditioned buildings even after the functional requirement of cooling has been considered. This result could be because typical mechanical cooling designs are inefficient relative to the efficiency of other systems such as lighting systems, or that the benchmarking method unfairly penalizes mechanical cooling. More research is need to determine the cause of the finding, but it is consistent with the perception that HVAC systems in modern laboratories are significantly oversized, which causes gross inefficiency.

When applying the model-based benchmarking method to 19 laboratory buildings on the UC Berkeley campus, the model-based method was not a better predictor of energy use than one of the alternatives (Sharp's method). But when a single outlier was removed from the set of 19 lab buildings, it was as good as or better than both alternates. This outlier contains a class 100 cleanroom. This finding suggests that the fan power calculations of the benchmark could be improved so that they more accurately reflect

filtration requirements. Doing so would yield a significant improvement in accuracy, and should be the subject of future research.

When applying the model-based benchmarking method to non-lab buildings in addition to lab buildings, the model-based approach was clearly better than the two alternatives. This fact demonstrates one of the advantages of model-based benchmarking over empirical methods. A single model can be used to benchmark and compare a wide variety of buildings. It should be noted, however, that although the correlation between energy use and predicted energy use was much higher using the model-based method than either of the two empirical methods, it was much lower than when applied to just laboratory buildings. This could be due to a large variation in efficiency when considering a larger, more diverse population of buildings, or it could be that the models are less accurate when applied to non-lab buildings. Future research is needed to determine the efficacy of using the existing model-based benchmarking method for analyzing the energy performance of non-lab buildings.

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APPENDIX A: NOMENCLATURE AND DEFINITIONS

Figure 9 shows the flow rates used in the calculations. The first letter of the subscripts refers to the space that the air is coming from. The second letter refers to the space that the air is going to.

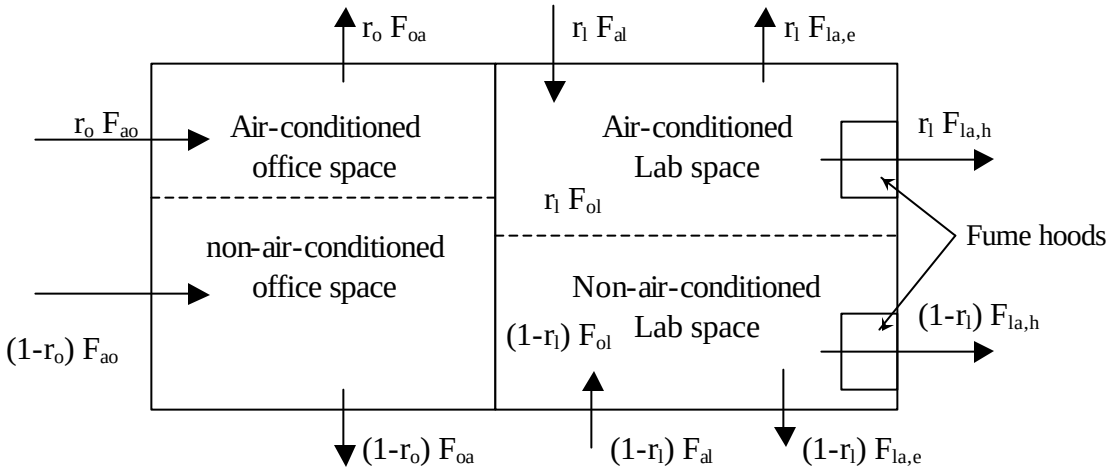

Figure 9: Schematic diagram of the laboratory building.

Constants

l : specific lighting power (0.54 W/ft^2)
$p_{pp,l}$: specific plug and process power for lab (default = 1.2 W/ ft^2)
$p_{pp,o}$: specific equipment power for office (default = 140 W/person)
p_f : specific fan power, (0.8 W/cfm)
p_p : specific pump power, (6.3 W/gpm)
a : standard temperature lapse rate (0.0065 $^\circ$K/m)
c : ceiling height (10 ft)
C_1 : saturated vapor pressure constant (-5674.5359)
C_2 : saturated vapor pressure constant (6.3925247)
C_3 : saturated vapor pressure constant (-0.009677843)
C_4 : saturated vapor pressure constant (0.000000622115701)
C_5 : saturated vapor pressure constant (0.0000000020747825)
C_6 : saturated vapor pressure constant (-0.0000000000009484024)
C_7 : saturated vapor pressure constant (4.1635019)
C_8 : saturated vapor pressure constant (-5800.2206)
C_9 : saturated vapor pressure constant (1.3914993)
C_{10} : saturated vapor pressure constant (-0.048640239)
C_{11} : saturated vapor pressure constant (0.000041764768)
C_{12} : saturated vapor pressure constant (-0.000000014452093)

C_{13} : saturated vapor pressure constant (6.5459673)
COP : coefficient of performance of chiller used for benchmark calculations (5)
d : height of the opening below the sash of a closed fume hood (3 in)
f_p : specific pump flow rate (1.6 gpm/ton)
g : gravitational constant (9.80665 m/s^2)
h_{occ} : heat generation per person (100 W/person)
m_a : molecular weight of dry air (28.9645 kg/mole)
m_w : molecular weight of water (18.01528 kg/mole)
P_0 : standard atmospheric pressure at sea level (101.3 kPa)
R_a : gas constant of dry air (287.055 J/(kg $^\circ$K)
R_w : gas constant of water vapor (461.520 J/(kg $^\circ$K)
T_c : conditioned space temperature (default = 72 $^\circ$F)
T_0 : standard absolute temperature at sea level (288 $^\circ$K)
V : fume hood face velocity (100 fpm)

Variables

e_e : electrical consumption effectiveness
e_f : fuel consumption effectiveness
f : relative humidity
f_c : relative humidity of conditioned air
r : density of air
r_a : density of outdoor (ambient) air
r_c : density of conditioned air
Ω : air change rate
d : solar declination, degree of arc
A_{Lab} : Calculated laboratory space area, (ft^2)
A'_{Lab} : Reported laboratory space area, (ft^2)
A_l : gross plan area (e.g., square footage) of the lab
A_o : gross plan area of the non-lab space
ET : equation of time, minutes of time
F_{al} : flow from the outdoors to the lab
F_{ao} : flow from the outdoors to the office
$\underline{F}_{ao}$: maximum flow from the outdoors to the office
$\overline{F}_{ao}$: minimum flow from the outdoors to the office
F_{oa} : flow from the office to the outdoors

$F_{la,e}$: flow from the lab to the outdoors through the general space exhaust

$F_{la,h}$: flow from the lab to the outdoors through the fume hoods

h : specific enthalpy of air

h_c : specific enthalpy of conditioned air

$H_{c,o}$: cooling load of office space

h_o : specific enthalpy of transfer air from office to lab

$h_{o,u}$: specific enthalpy of non-air-conditioned office air

$H_{o,c}$: load (heating or cooling) of air-conditioned office space

$H_{occ,l}$: heat generated by occupants in the lab area

$H_{occ,o}$: heat generated by occupants in the non-lab (office) area

H_{sunset} : sunset hour

$H_{sunrise}$: sunrise hour

L : linear quantity of fume hoods

LAT : local latitude, degree of arc

LON : local longitude, degree of arc

LSM : local standard time meridian, degree of arc

M : total mass of laboratory air

N_l : number of laboratory occupants

N_o : number of office occupants

p_w : vapor pressure of water in air

$p_{w,c}$: vapor pressure of water in conditioned air

p_{ws} : saturated vapor pressure of water in air

$p_{ws,c}$: saturated vapor pressure of water in conditioned air

P : atmospheric pressure

$P_{l,l}$: lighting power in the lab space

$P_{l,o}$: lighting power in the non-lab (office) space

$P_{pp,l}$: plug and process power in the lab space

$P_{pp,o}$: plug and process power in the non-lab (office) space

$\underline{q}_{ao}$: minimum outdoor air volume flow per person for the office

$\overline{q}_{ao}$: maximum outdoor air volume flow per unit of plan area for the office

r_l : fraction of lab space that is air-conditioned

r_o : fraction of office space that is air-conditioned

R : gas constant of air

R_c : gas constant of conditioned air

W : humidity mass ratio

W_c : humidity mass ratio of conditioned air

APPENDIX B: ENERGY CONSUMPTION CALCULATIONS

This Appendix contains a list of the calculation procedures for computing the benchmarks. Unit conversions are not shown here.

Precalculations

Lab Area:

$$A_{Lab} = (A'_{Lab} + 16030 + 164.1 * L) / 2 \quad \text{(A-1)}$$

Space Pressure:

Space pressure is computed based on the NACA standard atmosphere. Below an altitude of 10769 meters (35332 feet) above sea level, the pressure of the standard atmosphere is given by the following equation (List, 1971):

$$P = P_0 \left(1 - \frac{a}{T_0} Z \right)^{\frac{g}{aR_a}} \quad \text{(A-2)}$$

Minimum outdoor air volume flow rate for office

$$\underline{Q}_{ao} = \underline{q}_{ao} N_o \quad \text{(A-3)}$$

Maximum outdoor air volume office

$$\overline{Q}_{ao} = \overline{q}_{ao} A_o \quad \text{(A-4)}$$

Saturated vapor pressure of conditioned air:

According to ASHRAE (1997), the saturated vapor pressure is given by the following empirical relation when the air temperature is less than 0 °C:

$$p_{ws,c} = \exp\left(\frac{C_1}{T_c} + C_2 + C_3 T_c + C_4 T_c^2 + C_5 T_c^3 + C_6 T_c^4 + C_7 \ln(T_c) \right) \quad \text{(A-5)}$$

When the temperature is greater than 0 °C, the saturated vapor pressure is given by the following empirical relation:

$$p_{ws,c} = \exp\left(\frac{C_8}{T_c} + C_9 + C_{10} T_c + C_{11} T_c^2 + C_{12} T_c^3 + C_{13} \ln(T_c) \right) \quad \text{(A-6)}$$

The values for the constants are given in Appendix A. Using the constants in Appendix A requires that the temperature in Equations A-5 and A-6 is in °K, and results in Pascal pressure units.

Vapor pressure of conditioned air:

The vapor pressure is equal to the product of the relative humidity and the saturated vapor pressure.

$$p_{w,c} = p_{ws,c} f_c \tag{A-7}$$

Humidity mass ratio of conditioned air:

The humidity mass ratio is the ratio of the mass of water vapor in the air to the mass of dry air in the air. It is computed based on the molecular masses of dry air and water, the pressure, and the vapor pressure as follows:

$$W_c = \frac{m_w}{m_a} \frac{p_{w,c}}{P - p_{w,c}} \tag{A-8}$$

Gas constant of conditioned air:

The gas constant of the air is the mass-weighted average of the gas constants of dry air and water vapor. It is computed as follows:

$$R_c = \frac{R_a + R_w W_c}{1 + W_c} \tag{A-9}$$

Specific enthalpy of conditioned air:

The specific enthalpy of air is computed as follows:

$$h_c = \frac{T_c + W_c (2501 + 1.805 T_c)}{1 + W_c} \tag{A-10}$$

Note that Equation A-10 is different than that published in ASHRAE (1997) because Equation A-10 is the energy per unit mass of moist air rather than per unit mass of dry air.

Density of conditioned air:

The density is calculated as follows:

$$r_c = \frac{P}{R_c T_c} \tag{A-11}$$

Fume hood mass flow rate

The total mass flow rate through the fume hoods is computed as follows:

$$F_{la,h} = r_c LVd \tag{A-12}$$

Total laboratory exhaust air mass flow rate

The total mass flow rate of air exhausted from the laboratory through fume hoods and space exhaust is computed as follows:

$$M = r_c A_l c \tag{A-13}$$

$$F_{la} = \max\left(F_{la,h}, M\Omega\right) \tag{A-14}$$

Equation A-13 indicates that the total exhaust flow rate may either be determined by the design air change rate or by the number of fume hoods.

Laboratory supply air mass flow rate

The supply air mass flow rate to the laboratory is computed as follows:

$$F_{al} = F_{la} \tag{A-15}$$

Laboratory occupant load

The laboratory occupant load is computed as follows:

$$H_{occ,l} = h_{occ} N_l \tag{A-16}$$

Office occupant load

The office occupant load is computed by substituting the number of office occupants for the number of laboratory occupants in Equation A-15.

Lab lighting load

The lab lighting load is computed as follows:

$$P_{l,l} = l A_l \quad \text{(A-17)}$$

Office lighting load

The office lighting load is computed by substituting the gross plan area of the office for the gross plan area of the lab in Equation A-16.

Hourly Calculations

Saturated vapor pressure of outdoor air:

The saturated vapor pressure of outdoor air is computed using Equation A-5 or A-6 with the outdoor air temperature substituted for the conditioned air temperature.

Vapor pressure of outdoor air:

The vapor pressure of outdoor air is computed using Equation A-7 with the outdoor air temperature substituted for the conditioned air temperature, and the relative humidity of the outdoor air substituted for the relative humidity of the conditioned air.

Humidity mass ratio of outdoor air:

The humidity mass ratio of outdoor air is computed using Equation A-8 with the outdoor air vapor pressure substituted for the conditioned air vapor pressure.

Gas constant of outdoor air:

The gas constant of outdoor air is computed using Equation A-9 with the outdoor air humidity mass ratio substituted for the conditioned air humidity mass ratio.

Specific enthalpy of outdoor air:

The specific enthalpy of outdoor air is computed using Equation A-10 with the outdoor air temperature substituted for the conditioned air temperature, and the humidity mass ratio of the outdoor air substituted for the humidity mass ratio of the conditioned air.

Density of outdoor air:

The density of outdoor air is computed using Equation A-11 with the outdoor air temperature substituted for the conditioned air temperature, and the gas constant of the outdoor air substituted for the gas constant of the conditioned air.

Is system on?

If the schedule indicates that the system is on, then $O = 1$. Otherwise, $O = 0$.

Minimum outdoor air mass flow rate for the office:

The minimum outdoor air mass flow rate for the office is the maximum of the flow rate required for ventilation and the makeup air flow rate for the lab.

$$\underline{F}_{ao} = r_a \underline{Q}_{ao} \tag{A-18}$$

Maximum outdoor air mass flow rate for the office:

The maximum outdoor air mass flow rate for the office is computed as follows:

$$\overline{F}_{ao} = r_a \overline{Q}_{ao} \tag{A-19}$$

Lighting Energy Use:

Following equations could calculate sunrise and sunset hour for each month. Because we assume that there is no much difference in sunset or sunrise time among days in one month, we only calculate twelve sunset and twelve sunrise time in one year.

$$H_{sunrise} = [720 - 4 \cdot \arccos(-\tan LAT \cdot \tan d) - ET - 4 \cdot (LSM - LON)] / 60 \tag{A-20}$$

$$H_{sunset} = [720 + 4 \cdot \arccos(-\tan LAT \cdot \tan d) - ET - 4 \cdot (LSM - LON)] / 60 \tag{A-21}$$

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Equation of Time, min.	-11.2	-13.9	-7.5	1.1	3.3	-1.4	-6.2	-2.4	7.5	15.4	13.8	1.6
Declination, degrees	-20.0	-10.8	0.0	11.6	20.0	23.45	20.6	12.3	0.0	-10.5	-19.8	-23.45

Compute the thermal load on the office space

The following calculations are made assuming that the entire office space is air-conditioned. Compensation for partially air-conditioned office spaces is made later.

The office load calculation is based on the assumption that fan power does not contribute to the load. The logic for computing the load when there is an economizer and control of waste heat from lights is as follows.

If $h_c - h_a \le 0$, then

$$F_{ao} = \underline{F}_{ao} \quad \text{(A-22)}$$

$$H_o = F_{ao}(h_c - h_a) - H_{occ,o} - P_{pp,o} \quad \text{(A-23)}$$

Otherwise, compute the load with the maximum flow rate and no lighting load as follows:

$$H_{o,1} = \overline{F}_{ao}(h_c - h_a) - H_{occ,o} - P_{pp,o} \quad \text{(A-24)}$$

If $H_{o,1} \le 0$, then

$$F_{ao} = \overline{F}_{ao} \quad \text{(A-25)}$$

$$H_o = H_{o,1} \quad \text{(A-26)}$$

Otherwise, compute the load with the minimum outdoor air flow rate and the maximum lighting load as follows:

$$H_{o,2} = \underline{F}_{ao}(h_c - h_a) - H_{occ,o} - P_{pp,o} - P_{l,o} \quad \text{(A-27)}$$

If $H_{o,2} \le 0$, then $H_o = 0$. The outdoor air flow rate under this condition is computed as follows. Compute the load assuming a minimum flow rate and no lighting load as follows:

$$H_{o,3} = \underline{F}_{ao}(h_c - h_a) - H_{occ,o} - P_{pp,o} \quad \text{(A-28)}$$

If $H_{o,3} \ge 0$, then

$$F_{ao} = \underline{F}_{ao} \quad \text{(A-29)}$$

Otherwise,

$$F_{ao} = \frac{H_{occ,o} + P_{pp,o}}{h_c - h_a} \quad \text{(A-30)}$$

If $H_{o,2} > 0$, then $F_{ao} = \underline{F}_{ao}$ and $H_o = H_{o,2}$.

If the system is off, then the office load is zero.

Compute office cooling load:

If the office load is negative, then the cooling load equals the magnitude of the office load. Otherwise it equals zero. This is computed as follows:

$$H_{c,o} = \left|\min(0, r_o H_o)\right| \quad \text{(A-31)}$$

Compute the office heating load:

The office heating load is computed as follows:

$$H_{h,o} = \max(0, H_o) \quad \text{(A-32)}$$

Compute office fan power:

The office fan power is computed as follows:

$$P_{f,o} = \frac{F_{ao} p_f}{r_a} \quad \text{(A-33)}$$

Compute office pump power:

The office pump power is computed as follows:

$$P_{p,o} = \max\left(H_{c,o}, H_{h,o}\right) f_{pl} p_p \quad \text{(A-34)}$$

Compute office electrical power:

The electrical power is computed as follows:

$$P_o = \frac{H_{c,o}}{COP} + P_{pp,o} + P_{l,o} + P_{f,o} + P_{p,o} \quad \text{(A-35)}$$

Compute thermal load of the lab space

The following calculations are made assuming that the entire lab space is air-conditioned. Compensation for partially air-conditioned lab spaces is made later.

The lab load calculation is based on the assumptions that fan power does not contribute to the load, and that waste heat from lights, and plug and process loads is used for heating but rejected when cooling. The thermal load with waste heat from lights and plug and process power is as follows:

$$H_{l,h} = F_{la}\left(h_c - h_a\right) - H_{occ,l} - P_{l,l} - P_{pp,l} \quad \text{(A-36)}$$

The logic for computing the lab load to effectively use waste heat is as follows. First, compute the load according to Equation A-38. Then compute the load assuming that the heat from lights and equipment is exhausted.

$$H_{l,e} = F_{la}\left(h_c - h_a\right) - H_{occ,l} \tag{A-37}$$

The lab load with effective use of waste heat is the following:

If the sign of $H_{l,h}$ is not the same as the sign of $H_{l,e}$, then the load is zero. Otherwise, the load is equal to the value of $H_{l,h}$ or $H_{l,e}$ with the smallest magnitude.

Compute the lab cooling load

This calculation is similar to the cooling load calculation for the office.

$$H_{c,l} = \left|\min(0, r_l H_l)\right| \tag{A-38}$$

Compute the heating load for the lab

This calculation is similar to the heating load calculation for the office.

$$H_{h,l} = \max(0, H_l) \tag{A-39}$$

Compute the lab fan power

This calculation is similar to the fan power calculation for the office.

$$P_{f,l} = \frac{F_{la} p_f}{r_a} \tag{A-40}$$

Compute the lab pump power

This calculation is similar to the pump power calculation for the office.

$$P_{p,l} = \max\left(H_{c,l}, H_{h,l}\right) f_{pl} p_p \tag{A-41}$$

Compute the total electrical power for the lab

This calculation is similar to the electrical load calculation for the office.

$$P_l = \frac{H_{c,l}}{COP} + P_{pp,l} + P_{l,l} + P_{f,l} + P_{p,l} \quad \text{(A-42)}$$

Compute the electrical consumption benchmark

The electrical consumption benchmark is the sum of the electrical loads times the time interval corresponding to each load (one hour).

Compute the fuel consumption benchmark

The fuel consumption is the sum of the heating loads times the time interval corresponding to each load (one hour).

Compute the electrical consumption effectiveness

The electrical consumption effectiveness is the electrical consumption benchmark divided by the actual electrical consumption.

Compute the fuel consumption effectiveness

The fuel consumption effectiveness is the fuel consumption benchmark divided by the actual fuel consumption.

APPENDIX C: STEPS FOR DEVELOPING A WEB-BASED USER INTERFACE

Brief Introduction to ASP:

An Active Server Page (ASP) is an HTML page that includes one or more scripts (small embedded programs) that are processed on a Microsoft Web server before the page is sent to the user. An ASP is somewhat similar to a server-side include or a common gateway interface (CGI) application in that all involve programs that run on the server, usually tailoring a page for the user. Typically, the script in the Web page at the server uses input received as the result of the user's request for the page to access data from a database and then builds or customizes the page on the fly before sending it to the requestor.

ASP is a feature of the Microsoft Internet Information Server (IIS), but, since the server-side script is just building a regular HTML page, it can be delivered to almost any browser. You can create an ASP file by including a script written in VBScript or JScript in an HTML file and then renaming it with the ".asp" file suffix. Microsoft recommends the use of the server-side ASP rather than a client-side script, where there is actually a choice, because the server-side script will result in an easily displayable HTML page. Client-side scripts (for example, with JavaScript) may not work as intended on older browsers.

How ASP works:

1. First the server receives the user's request for an ASP file. Instead of transmitting the file immediately back to the user as HTML, the server will treat the file as a BASIC program. First it will parse the file into executable code, then execute it. During this process, data can be fetched from a database or a database on the server can be updated, depending on different SQL calls.
2. Next, the server will try to form an HTML page using the output data of the Visual BASIC (VB) program. Instead of outputting data onto the screen, the output of the VB code is put in a web page. That's why you can manage to output two totally different web pages using the same ASP file, by including a "IF..ELSE…END IF" structure in your program.
3. After the user receives the HTML page, they may find a form in that page. They can fill up the form and send it back to server. All the data that the user has input in the forms are parameters sent to the ASP program by using the HTTP POST method. This is transparent to the users.
4. In ASP file, we can use the "Request" object to get parameters that we can call user input. These data can be inserted into SQL calls to get different kinds of data from a database. Once the server finishes execution of the program, it will send the result back to the user. The process then returns to step 2.

Instructions:

Instructions below provide basic steps to follow to publish the laboratory energy benchmarking database on a Windows NT server using ASP:

1. Create a website on a server or build a new branch in an existing website.

Creating a new website requires more work than simply creating a bunch of webpages and putting them in an existing website. Since there are many web servers at LBNL and also at UC Berkeley, we may be able to use an existing host. We can use Microsoft Frontpage, Macromedia Dreamweaver or any web page design tool. But if you want to use Frontpage, you should tell the server administrator that you want to create a Frontpage website so that they can set it up for you. If you don't want to use Frontpage, you simply ask for FTP access to the server, and then start building your HTML or ASP pages. Some servers allow you put ASP in arbitrary directory, but some servers don't, so you should ask for a special ASP directory.

2. Register a DSN for the database.

You should ask the server administrator to register the database that you have already put on the server with a new Data Source Name, which is just a link to the database. If server the administrator tells you he/she don't know how to do that, tell him visit this website: http://www.activeserverpages.com/learn/dsn1.asp/.

3. Writing ASP code:

3.1. Data input interface in web page.
Microsoft Access allows you save a form in a database as an ASP file. But usually, the file generated by Access will not fit your requirements exactly. So you have to understand the format of that file first, then modify it. You can build forms yourself using any HTML editor. Most editors will let you put text fields, drop-down lists, radio buttons, etc. in your web page.

3.2. Fetch, add new or update data in database.
This could be divided into two steps. First, you should write code to receive data sent by the user. As mentioned earlier, this could be done using the "Request" object defined by ASP. Next, you can write SQL calls and manipulate data in the database.

3.3. Trigger calculation module in database.
Simply outputting and inputting data is not the aim of this database. The primary activity of the database is to perform energy use calculations. So we have to find a way to trigger this calculation once the user has finished the data input. In Access, you can define a certain kind of macro to run a VB module, and one type of SQL command could run the selected macro. So this task could be accomplished by using a SQL call macro and the macro could run the VB module which is the energy use calculation module. One important issue that should be considered here is multiple users. Once a user triggers the calculations, we must prohibit another user from triggering the calculations again until the first calculations have finished.

3.4. Output charts.
Many Java applets and ASP components are available for displaying charts on a webpage. These components must be purchased, so they would add to the development cost. Excel could be used to generate charts for use on a webpage, but this would cause some burden on the server side. First, we have to let the server administrator open the Excel file and let it run all the time. The macro in this Excel file could do a web/local database query every five to ten seconds, depending on the settings. This query is fairly simple, just for knowing if the database got updated or not. If yes, the macro will do another web/local database query to get all the

data from certain tables in the database. After this, Excel could update the charts automatically. Then the macro should generate GIF files for all the charts. With links to these GIF files in the HTML pages, the charts will be updated once the database gets updated, which would be at most after ten seconds.

4. Debugging and testing

Debugging an ASP program is not as easy as debugging a C++ program because it runs on a server in real time. There is no real-time running and debugging tool equivalent to the development environments available for C++. However, you can use some basic debugging methods such as printing values of important variables.

After conducting the basic debugging, the application should be beta tested. Beta testing will help determine whether or not bugs that are difficult to detect during basic debugging are present. One problem with Microsoft Access is that it can handle only 50 users simultaneously.